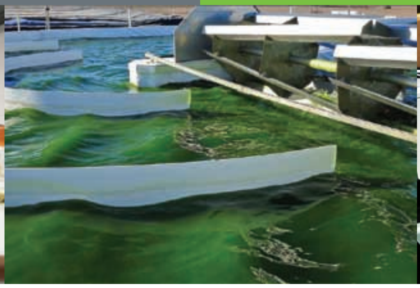
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOENERGY TECHNOLOGIES OFFICE

2015 PEER REVIEW REPORT

REVIEW PANEL SUMMARY REPORT AND PROJECT RESULTS

March 2016

2015 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

March 23-27, 2015, Alexandria, VA

2015 PROGRAM MANAGEMENT REVIEW

U.S. DEPARTMENT OF ENERGY • BIOENERGY TECHNOLOGIES OFFICE

June 25, 2015, Washington, DC

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Dear Colleagues,

In the spring and summer of 2015, the Office of Energy Efficiency and Renewable Energy's (EERE's) Bioenergy Technologies Office (BETO or the Office) implemented a comprehensive external review of its research, development, and demonstration portfolio. The BETO 2015 Project Peer Review was held March 23-27, 2015, in Alexandria, Virginia, and was followed by a high-level Program Management Review on June 25th in Washington, D.C. The review was conducted in accordance with EERE peer review guidelines, and it was designed to provide an external assessment of the projects in BETO's portfolio and collect external stakeholder recommendations on the overall scope, focus and strategic direction of the Office. Results from the peer review process are used to inform programmatic decision-making; enhance active project management; and modify, expand, or discontinue existing projects.

This review process is critical to the success of our core mission: to invest in the research, development, and demonstration of new technologies that will help accelerate the commercialization of an advanced and sustainable bioenergy industry. Our nation's abundant biomass resources present a tremendous opportunity to sustainably produce high performance bio-based fuels, bioproducts, and renewable chemicals and help realize national goals for the future bioeconomy. The peer review process enables external stakeholders to provide feedback on the responsible use of taxpayer funding and develop recommendations for the most efficient and effective ways to accelerate the development of an advanced bioenergy industry.

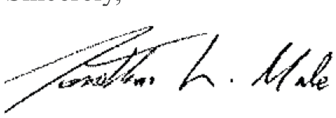
The 2015 review cycle featured 190 projects across 7 key technology areas, representing a combined value of approximately $403 million from Fiscal Years 2013-2014. The seven technology areas reviewed during the 2015 Project Peer Review were as follows:

- Algal Feedstocks
- Biochemical Conversion
- Cookstoves
- Demonstration and Market Transformation
- Sustainability and Strategic Analysis
- Terrestrial Feedstocks
- Thermochemical Conversion

The 2015 Peer Review comprised three levels of review: (1) individual projects were scored on the basis of accomplishment, relevance, approach, future plans, and critical success factors; (2) each technology area portfolio was evaluated for overall potential impact, synergies, and effective project management; and (3) the structure and overall strategic direction of the Office was reviewed by an external Steering Committee. This report contains the results of each level of review and the inputs of approximately 300 participants in the peer review process, including principal investigators, reviewers, Steering Committee members, BETO staff, and contractors from BCS, Incorporated.

The Office would like to thank all of the reviewers and members of the Steering Committee who participated in this review. BETO is appreciative of the valuable insights and contributions that have been provided throughout the peer review process. Achieving the objectives of the Office is dependent on the effective management of all the projects in BETO's existing portfolio and on the appropriate focus and structure of future initiatives. BETO values the input of all the stakeholders in the bioenergy sector and looks forward to working with them in the years ahead to continue progress on the path toward building a successful advanced bioenergy industry and a sustainable bioeconomy.

Sincerely,



Dr. Jonathan Male

Director, Bioenergy Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

EXECUTIVE SUMMARY

The 2015 peer review process, which took place from March 23-27, 2015, yielded a number of important results for the Bioenergy Technologies Office (BETO or the Office). External reviewers and Steering Committee members delivered a positive overall assessment of the Office and validated much of the current research approach and technical strategy. The Steering Committee recognized the progress made since 2013 and acknowledged that: (1) BETO has been responsive to feedback provided during the 2013 Peer Review Process (e.g., pathways, refinery integration, products); (2) many projects are much better positioned for significant breakthroughs than in 2013; (3) the Principal Investigators (PIs) are much more informed about the relationship of their work to BETO goals and their role within the supply chain; (4) BETO's project management is yielding dividends; (5) sustainability and techno-economic analysis efforts have shown significant progress and are moving toward implementation; (6) consortiums have proved to be an excellent model for coordinating research efforts, and should continue to be utilized; and (7) excellent resources and capabilities of the National Laboratories continue to be great assets for the program.

The Steering Committee has also recognized several attributes of BETO's program, including the following: (1) strong support for high tonnage projects, feedstock regional partnerships, resource availability analysis, fundamental genetics projects, and the Idaho National Laboratory (INL) user facility; (2) strong program support for the Algae Testbed Public-Private Partnership (ATP3), Sapphire/University of California San Diego outdoor genetically modified algae trials, Pacific Northwest National Laboratory's techno-economic analysis (TEA) modeling, algae wastewater treatment systems, and tools of genetic evolution and manipulation; (3) excellent coordination among biochemical conversion projects to meet 2017/2022 goals; (4) evidence of strong project management, with key efforts including the National Renewable Energy Laboratory (NREL) analytical work, the Biochemical Feedstocks Interface work with INL/NREL, and multiple lignin conversion projects; (5) continued expansion of thermochemical conversion work on refinery integration; and advocating the national laboratories as an excellent focal point for industry efforts, with highly rated projects, such as the Computational Pyrolysis Consortium and the Oak Ridge National Laboratory (ORNL) Corrosion Studies; (6) Demonstration and Market Transformation (DMT) program's shift away from ethanol, focus on the products component, as well addressing storage issues, and development of commercial feedstock supply chains; (7) strong support for ORNL Defining Sustainability, Biomass Scenario Modeling, TEA and life-cycle analysis (LCA) activities, and international engagements; and (8) strong support and continued investment in the development of national laboratory resources and expertise in sustainability that have resulted in the program now "reaping the benefits of that commitment."

The Steering Committee's overall recommendations included the following: (1) improve and expand collaboration with the U.S. Department of Agriculture (USDA) at higher agency levels; (2) explore synergies and hybrid approaches in thermochemical and biochemical pathways; (3) provide consistent TEA template at start of a project and/or as part of Funding Opportunity Announcement (FOA) applications; (4) expand outreach efforts to communicate success stories; (5) focus on new influence networks and new lexicons of communication; (6) more cross-fertilization of ideas and understanding is needed between high and low Technology Readiness Levels (TRLs), and between conversion research and development (R&D) and DMT; (7) continue to focus on technologies that have separate fueling infrastructures to get fuels to market, i.e., marine and aviation fuels; and (8) complete financial lessons learned for all demonstration projects.

The Steering Committee also provided program-specific key recommendations to further strengthen the program's effectiveness. For example, these include the following: (1) focus on kinetic improvements, build robust upstream models, and standardize reported metrics (Algal Feedstocks); (2) invest in demonstration-scale depot projects, develop better linked models from subfield to national scale, and recognize that increased investments are needed now outside the gates of the biorefinery (Terrestrial Feedstocks); (3) more focus on acid-pretreatment for lignin, ethanol as a platform chemical, and synergies between reactor design and enzyme research; and TEA templates should be provided at project outset or as part of the FOA process (Biochemical Conversion); (4) continue to expand work on refinery integration and consider funding a consortia focused on catalysis; and the focus on design cases can sometimes overshadow individual performance metrics and "big picture" goals (Thermochemical Conversion); (5) provide funds to successful pilot projects, for projects that produce high-value products, and projects with existing feedstock sources, such as pulp/paper, municipal solid waste (Demonstration and Market Transformation); and (6) expand avenues to connect with decision-makers, continue efforts to engage with international forums, and explore ways to incorporate policy ideas into complex system models (Sustainability and Strategic Analysis).

As a result of the 2015 Peer Review, BETO is moving forward with many of the recommendations provided by the Steering Committee and individual review panels. At the portfolio level, the peer review provided a number of invaluable insights and specific recommendations that will continue to be utilized in managing specific projects and ongoing improvements in portfolio planning and oversight. The Office is currently going through the Strategic Planning process and the recommendations received will be considered in shaping the program direction and accomplishing the defined vision.

ACRONYM GUIDE

$/MT	Dollars per Metric Ton
ABPDU	Advanced Biofuels Process Demonstration Unit
ABY	Algal Biomass Yield
AD	Anaerobic Digestion
ADM	Archer Daniels Midland
AFDW	Ash-Free Dry Weight
AFEX	Ammonia Fiber Expansion
AFRI	Agriculture and Food Research Initiative
AGM	Algae Growth Model
AHTL	Algae Hydrothermal Liquid
ALD	Atomic-Layer Deposition
ALM	Algae Logistics Model
ALU	Algal Lipid Upgrading
ANL	Argonne National Laboratory
AOP	Annual Operating Plan
ARRA	American Recovery and Reinvestment Act of 2009
ARPA-E	Advanced Research Projects Agency-Energy
ASAP	Adaptive Sampling and Prediction
ASCENT	Aviation Sustainability Center of Excellence
ASTM	American Society for Testing and Materials
ATP3	Algae Testbed Public–Private Partnership
ATS	Algal Turf Scrubber
AVDC	Advanced Vehicles Data Center (DOE)
BAT	Biomass Assessment Tool
BDO	Butanediol
BDT	Bone Dry Ton
BER	Biological and Environmental Research (DOE Office of Science)
BES	Basic Energy Sciences (DOE Office of Science)
BETO	Bioenergy Technologies Office
BFNUF	Biomass Feedstock National User Facility
BIC	Biofuels Information Center
BIPCS	Biomass Industry Panel on Codes and Standards
BMP	Best Management Practices
BOAP	Bio-Oil Aqueous Phase
BPT	Bale-Picking Truck
BRDI	Biomass R&D Initiative
BSI	Bench Scale Integration

BSM	Biomass Scenario Model
BT16	Billion Ton Report Update in 2016
C	Carbon
Ca	Calcium
c.a.	Controlled Atmosphere
CABComm	Consortium for Algal Biofuels Commercialization
CAFE	Corporate Average Fuel Economy
CAP	Coordinated Agriculture Projects
CAPEX	Capital Expenditure
CBH	Cellobiohydrolase
CBM	Cellulose-Binding Module
CBP	Consolidated Bioprocessing
cc	Cubic Centimeter
CDP	Congressionally Directed Projects
CEH	Continuous Enzymatic Hydrolysis
CFD	Computational Fluid Dynamics
CGE	Computational General Equilibrium
CH_4	Methane
CHASE	Carbon, Hydrogen, and Separation Efficiencies in Bio-Oil Conversion Pathways
CHG	Catalytic Hydrothermal Gasification
CIP	Clean-In-Place
CLP	Consolidated Lignin Processing
cm	Centimeter
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPBR	Consortium for Plant Biotechnology Research
CPC	Computational Pyrolysis Consortium
cpm	Cells per Milliliter
CRADA	Cooperative Research and Development Agreement
CRP	Conservation Reserve Program
CS	Corn Stover
CSU	Colorado State University
CTG	Coarse Tub Grind
CTV	Chevron Technology Ventures
DARPA	Defense Advanced Research Projects Agency
DCR	Davison Circulating Riser
DMC	Direct Microbial Conversion
DMR	Deacetylation/Mechanical Refining

DMR-EH	Deacetylated/Mechanical-Refined, Enzymatically Hydrolyzed
DMT	Demonstration and Market Transformation
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DPA	Defense Production Act
DS	Dielectric Spectroscopy
DT	Dry Ton
EERE	Office of Energy Efficiency and Renewable Energy
EH	Enzymatic Hydrolysis
EISA	Energy Independence and Security Act of 2007
EMWD	Eastern Municipal Water District
EPA	Environmental Protection Agency
ePBR	Electronic Photobioreactor
EPC	Engineer-Procure-Construct
EPSA	Office of Energy Policy and Systems Analysis (DOE)
EtOH	Ethanol
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
FCC	Fluid Catalytic Cracking
FFA	Free Fatty Acid
FLS	Feedstock Logistics Systems
FOA	Funding Opportunity Announcement
FC	Field Chopped
FE	Office of Fossil Energy (DOE)
FFV	Flexible Fuel Vehicle
FSPP	Feedstock Supply and Project Initiative
FT-ICR-MS	Fourier Transform Ion Cyclotron Resonance Mass Spectrometry
FT	Fischer-Tropsch
FY	Fiscal Year
GTI	Gas Technology Institute
GACC	Global Alliance for Clean Cookstoves
gal	Gallon
gal/acre/yr	Gallon per Acre per Year
GBEP	Global Bioenergy Partnership
GC	Gas Chromatography
GCAM	Global Change Assessment Model
g/g	Grams per Gram
gge	Gallon of Gasoline Equivalent

GHG	Greenhouse Gas
GIS	Geographic Information System
g/l	Grams per Liter
GM	Genetically Modified
g/m^2	Grams per Square Meter
GMO	Genetically Modified Organism
GPS	Global Positioning System
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GTAP	Global Trade Analysis Project
GTI	Gas Technology Institute
H_2	Hydrogen
HCK	Hydrocracking
HDO	Hydrodeoxygenation
HiPAS	High Performance Architectured Surface
HOF	High Octane Fuels
HPLC	High Performance Liquid Chromatography
HtC	High Throughput Characterization
HTL	Hydrothermal Liquefaction
IABR	Integrated Algal Biorefinery
IAF	Integrated Assessment Framework
IBR	Integrated Biorefinery
IBSAL	Integrated Biomass Supply Analysis and Logistics
IEA	International Energy Agency
IES	Institute of Environmental Stewardship
IH2	Integrated Hydropyrolysis Plus Hydroconversion Technology
INL	Idaho National Laboratory
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISBL	Inside Battery Limits
IspS	Isoprene Synthase
ISO	International Organization for Standardization
ISU	Iowa State University
JBEI	Joint BioEnergy Institute
JEDI	Jobs and Economic Development Impact (Model)
KDF	Knowledge Discovery Framework
kg	Kilogram
L or l	Liter
LAP	Laboratory Analytical Procedures

LBNL	Lawrence Berkeley National Laboratory
LC	Liquid Chromatography
LCA	Life-Cycle Assessment
LCI	Life Cycle Inventory
LDRD	Laboratory Directed Research and Development
LEA	Lipid-Extracted Algae
LEAF	Landscape Environmental Assessment Framework
LHSV	Liquid Hourly Space Velocity
LNG	Liquefied Natural Gas
LUC	Land-Use Change
MBfR	Membrane Biofilm Reactor
MBI	Michigan Biotechnology Institute
MEC	Microbial Electrolysis Cell
MEK	A protein
MESP	Minimum Ethanol Selling Price
MFSP	Minimum Fuel Selling Price
Mg	Magnesium
mgpy	Million Gallons per Year
MIKE-SHE	An advanced integrated hydrological modeling system to simulate surface and ground-water movement
MIS	Miscanthus
MIT	Massachusetts Institute of Technology
MJ	Mega Joule
Mo	Molybdenum
MODIS	Moderate Resolution Imaging Spectroradiometer
MoS_2	Molybdenum Disulfide
MPGGE	Miler per Gasoline Gallon Equivalent
MS	Mass Spectrometer
MSDS	Material Safety Data Sheet
MSW	Municipal Solid Waste
MTG	Methanol-to-Gasoline
MWh	Megawatt Hours per Hectare per Year
MYPP	Multi-Year Program Plan
MySAB	Myriant Succinic Acid Biorefinery
N	Nitrogen
NA	Nanostructured Adsorbents
NAABB	National Alliance for Advanced Biofuels and Bioproducts
NABC	National Advanced Biofuels Consortium

NaSICON	Sodium Super Ionic Conductors
Nb	Niobium
NCASI	National Council for Air and Stream Improvement
NC A&T	North Carolina Agricultural & Technical State University
NDA	Non-Disclosure Agreement
NGO	Nongovernmental Organization
Ni	Nickel
NIFA	National Institute of Food and Agriculture
NIR	Near Infrared
NIRS	Near-Infrared Spectroscopy
NMC	New Mexico Consortium
NMR	Nuclear Magnetic Resonance
NORA	National Oilheat Research Alliance
N_2O	Nitrous Oxide
NRCS	Natural Resources Conservation Service (USDA)
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
OD	Optical Density
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
ORNL	Oak Ridge National Laboratory
OSBL	Outside Battery Limits
P	Phosphorus
PAT	Process Analytical Technologies
PBR	Photobioreactor
PCA	Protocatechuate
PCS	Pretreated Corn Stover
PDU	Process Demonstration Unit
PETRO	Plants Engineered to Replace Oil (DOE/ARPA-E)
PFD	Process Flow Diagram
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxbutyrate
PI	Principal Investigator
PM	Particulate Matter
PNAS	Proceedings of the National Academy of Sciences
PNNL	Pacific Northwest National Laboratory
POLYSYS	Policy Analysis System model
Q&A	Question and Answer
RAFT	Regional Algal Feedstock Testbed Partnership

R&D	Research and Development
RD&D	Research, Development, and Demonstration
RDD&D	Research, Development, Demonstration, and Deployment
REAP	Resilient Energy Agricultural Practices
REFABB	Renewable Enhanced Feedstocks for Biofuels and Bioproducts
REII	Renewable Energy Institute International
REMOTE	Reducing Emissions Using Methanotrophic Organisms for Transportation Energy
RFO	Renewable Fuel Obligation
RFP	Regional Feedstock Partnership
RFS or RFS2	Renewable Fuel Standard
Rh	Rhodium
RINS or RIN	Renewable Identification Number
ROI	Return on Investment
RON	Research Octane Number
RSP	Renewable Super Premium
R&TD	Research and Technology Development
RTI	Research Technology Institute
RTP	Rapid Thermal Processing
S	Sulfur
SA	Succinic Acid
SAB	Science Advisory Board
SABC	Sustainable Algal Biofuels Consortium
SBR	Soluble Biofilm Reactor
SCADA	Supervisory Control Data Acquisition
SCSA	Supply Chain Sustainability Analysis
SDMS	Scientific Data Management System
SDSU	South Dakota State University
SEQHTL	Sequential Hydrothermal Liquefaction
SEO	State Energy Office
SLS	Solid Liquid Separation
SLT	Self-Loading Trailer
SOPO	Statement/Scope of Project Objectives
SOT	State of Technology
SPB	Self-Propelled Baler
SRWC	Short-Rotation Woody Crops
S&T	Science and Technology
SUNY	State University of New York
SWAT	Soil and Water Assessment Tool
SWG	Switchgrass

SzIBR	Solazyme Integrated Biorefinery
TABB	Targeted Algal Biofuels and Bioproducts
TAG	Triacylglycerol
TAN	Total Acid Number
Btu	Terra British Thermal Unit
TCBDU	Thermochemical Process Development Unit
TCR	Targeted Conversion Research
TEA	Techno-Economic Analyses or Assessment
TEES	Texas Engineering Experiment Station
TERA	TSCA Environmental Release Application
Tg	Teregrams
TRL	Technology Readiness Level
TRY	Titer, Rate, and Yield
TSCA	Toxic Substances Control Act
UCLA	University of California Los Angeles
UCSD	University of California San Diego
UNCP	University of North Carolina at Pembroke
USDA	U.S. Department of Agriculture
USDA-ARS	U.S. Department of Agriculture's Agricultural Research Service
VBI	Vermont BioFuels Initiative
VGO	Vacuum Gas Oil
VSJF	Vermont Sustainable Jobs Fund
VPU	Vapor Phase Upgrading
VTT	Technical Research Centre of Finland
W	Tungsten
WBS	Work Breakdown Structure
WF	Water Footprint
WFO	Work for Others
WSU	Washington State University
WTE	Waste to Energy
WTF	Well to Wheels
wt%	Weight Percent
XI	Xylose Isomerase

INTRODUCTION

In the spring and summer of 2015, the Bioenergy Technologies Office (BETO or the Office) of the U.S. Department of Energy (DOE) implemented an external peer review of the projects in its research, development and demonstration (RD&D) portfolio. The Office manages a diverse portfolio of technologies across the spectrum of applied RD&D within the dynamic context of changing budgets and Administration priorities. The Office portfolio is organized according to the biomass-to-bioenergy supply chain—from the feedstock source to the end user (see Figure 1)—with major focus on feedstock supply and biomass conversion. The 2015 Project Peer Review took place March 23-27, 2015, outside of Washington, D.C., in Alexandria, Virginia, and evaluated most of the publicly funded projects in BETO's portfolio. The subsequent Program Management Review took place on June 25, 2015, in Washington, D.C., and provided an Office-level assessment of strategic planning and programmatic initiatives. The peer review process enables external stakeholders to provide feedback on the responsible use of taxpayer funding and develop recommendations for the most efficient and effective ways to accelerate the development of an advanced bioenergy industry. The planning and execution of these reviews was completed over the course of 10 months, and this report includes the results of both events.

The seven technology areas reviewed during the 2015 Project Peer Review were as follows (in alphabetical order):

- Algal Feedstocks
- Biochemical Conversion
- Cookstoves
- Demonstration and Market Transformation
- Sustainability and Strategic Analysis
- Terrestrial Feedstocks
- Thermochemical Conversion

A total of 190 projects across seven technology areas were reviewed by a total of 48 external experts from industry, academia, other government agencies, and the non-profit sector. These projects represent a total DOE value of approximately $403 million from Fiscal Years 2013-2014. Each review panel developed overall recommendations regarding the focus, management, and impact of the projects in each technology area. In addition, an external Steering Committee developed overall recommendations for the Office based on the Program Management Review. Results of the 2015 Peer Review have been, and will be, used to help inform programmatic decision making, modify or discontinue existing projects, guide future funding opportunities, and support other budget and strategic planning objectives.

BETO Project Peer Review

The 2015 BETO Project Peer Review was implemented over the course of one full week with seven simultaneous review sessions of all 190 reviewed projects. Over the course of the Project Peer Review, participants also

Figure 1: Biomass-to-Bioenergy Supply Chain

heard overview presentations on each technology area, as well as presentations on key cross-cutting topics, including early market adopters in aviation and marine biofuels, an update on BETO's pathways analysis to hydrocarbon fuels, a preview of the 2016 assessment of biomass resources, and collaborations with the Vehicle Technologies Office. This format brought together reviewers and BETO staff, with principal investigators (PIs), and other stakeholders along the entire bioenergy supply chain, which creates synergy across technology areas and enables the cross-fertilization of ideas and expertise, while providing for a more comprehensive review process. Figure 2 depicts the breakdown of proj-

Figure 2: BETO Funding by Technology Area (FY13 - FY14)

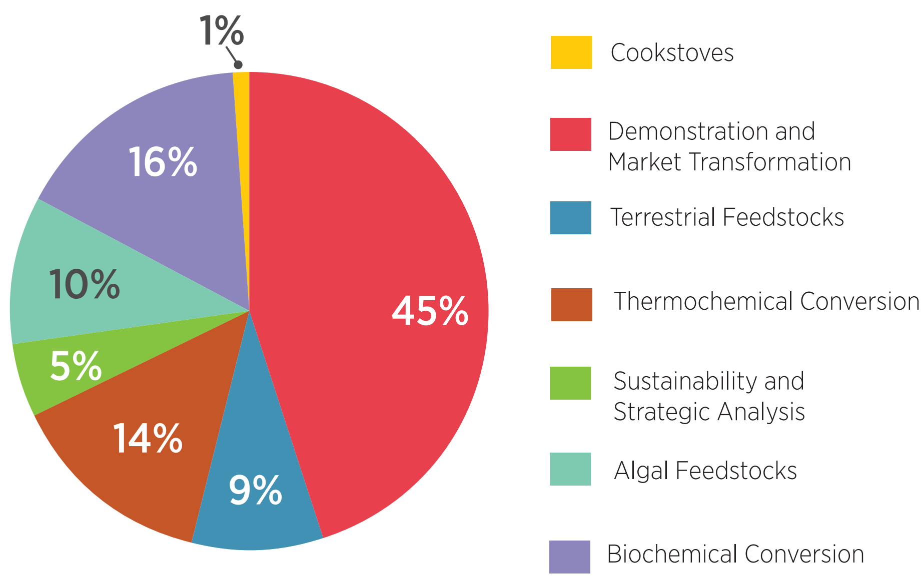
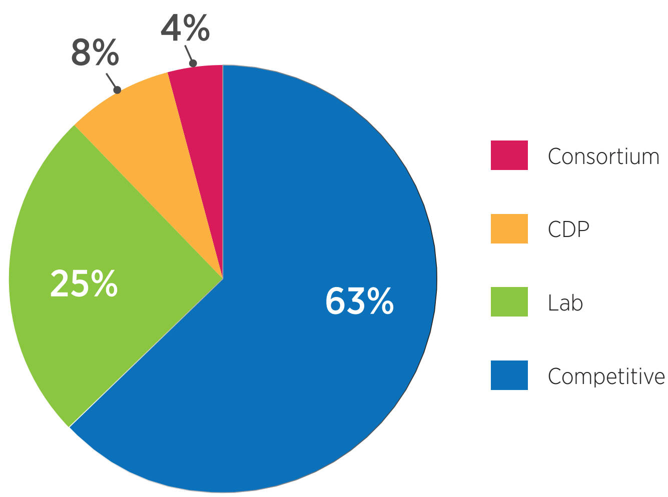


Table 1: Technology Area Teams

TECHNOLOGY AREA	DOE REVIEW LEAD	BCS SUPPORT
Algal Feedstocks	Alison Goss Eng	Colleen Ruddick
Biochemical Conversion	Kevin Craig Bryna Berendzen	Ryan Livingston
Cookstoves	Elliot Levine	Remy Biron
Demonstration and Market Transformation	Jim Spaeth	Remy Biron
Sustainability and Strategic Analysis	Alicia Lindauer Kristen Johnson	Max Broad
Terrestrial Feedstocks	Alison Goss Eng Steven Thomas	Max Broad
Thermochemical Conversion	Kevin Craig Nichole Fitzgerald	Andrea Bailey
Overall Coordination	Valerie Reed	Roy Tiley Andrew Graves Feridun Albayrak

Figure 3: Office Funding by Award Type



ects reviewed by technology area, as based on a percentage of DOE funding.

The Demonstration and Market Transformation area represented the largest category of funding as it constitutes a substantial investment in supporting the cost-shared construction of pilot and demonstration scale integrated biorefineries.

Reviewed projects included competitively awarded projects, core research and development projects performed by DOE's national laboratories, and congressionally directed projects (CDPs). Figure 3 depicts project funding by award type as percentages of overall DOE funding. Nearly 67% of projects were awarded through a competitive funding opportunity process (including consortium projects); 25% of funding was awarded to the national laboratories, with the National Renewable Energy Laboratory (NREL) in Golden, Colorado, constituting the largest portion of laboratory funding.

Review Planning

Upon initiation of the review process, an internal DOE planning committee was designated with the responsibility for coordinating all aspects of the review process, from initiation through completion. This internal group then identified and recruited an external Steering Committee to represent perspectives of academia, industry, the financial community, and end users. The Steering Committee provided independent and impartial guidance on planning activities and the selection of external reviewers; participated in the review process; and developed cross-cutting recommendations on the Office's overall focus, scope, and strategic direction. A team of support contractors from BCS, Incorporated (BCS) provided overall planning support, built the reviewer evaluation system, facilitated development of report materials, and compiled and drafted the Peer Review Final Report. Table 1 lists the members of the internal planning committee and BCS support contractors for each technology area. Table 2 identifies the members of the external Steering Committee.

Table 2: Members of the Peer Review Steering Committee

TECHNOLOGY AREA TEAMS	
Jim Dooley	Forest Concepts, LLC
Dean Draemel	ExxonMobil / University of California, Berkeley
Jim Kellis	DuPont
Mike Lakeman	Boeing and Algae Biomass Organization
Valri Lightner	DOE Loan Programs Office
Jack McDonald	Independent Consultant
Shelie Miller	University of Michigan
Carol Werner	Environmental and Energy Study Institute

Reviewers

The 2015 BETO Peer Review was completed by 48 external experts from industry, academia, other government agencies, and the non-profit sector. Reviewers were selected on the basis of technical expertise and high-level qualifications in their designated technology area. Approximately two-thirds of the reviewers held doctorates within their field, and the remainder held other advanced technical or business degrees. Efforts were made to ensure balance within the review panel by including a mix of reviewers from the public, private, and university sector, with a range of expertise in the many sub-focus areas within each technology area. Approximately one-third of the reviewers had experience participating in previous DOE peer reviews. No reviewers had served in more than two previous DOE review cycles. Reviewers were also required to sign legal agreements stipulating an absence of a conflict of interest with the projects that they reviewed. Reviewers were proposed by the BETO technology area teams, and submitted to the external Steering Committee for comment and recommendation. Final decisions on reviewer selection were made by the internal planning committee and BETO's Director.

Individual review panels are listed within each of the technology area chapter reports. The breakdown of reviewer affiliation by sector can be seen in Figure 4.

Figure 4: Reviewers by Affiliation Sector

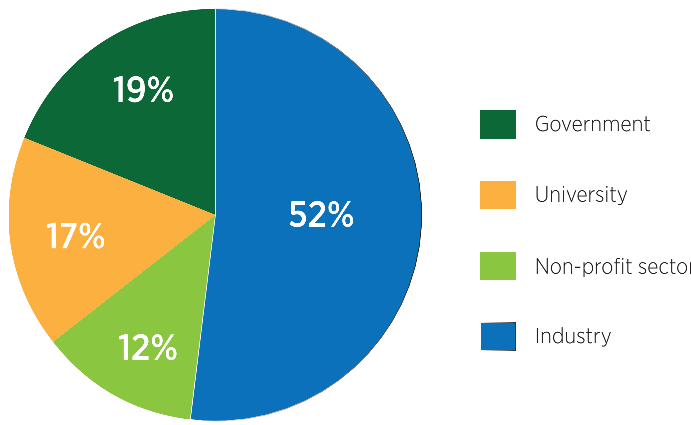


Table 3: Project Evaluation Criteria

EVALUATION CRITERIA: WEIGHTING BY PROJECT TYPE			
Scored Criteria	Sun-Setting Projects (Completed by March 2015)	New Projects (Since April 2014)	Existing Projects (Every Remaining)
Overview	5%	5%	5%
Approach	15%	25%	20%
Accomplishments/ Progress	50%	10%	30%
Relevance	30%	25%	25%
Future Work	0%	35%	20%

Evaluation Criteria

Reviewers were asked to evaluate projects based on specific criteria. The evaluation criteria (see Table 3) and descriptions below served as the standard template for the evaluation of each project. Projects received scores and comments on the five criteria described below.

Reviewers' comments contained in this report represent only those comments provided for the Overall Impressions criterion. Each comment represents the views of one reviewer. Comments were taken near-verbatim as inputted by the reviewer and were edited only for grammar and context. Each criterion received a different weight as determined by the internal planning committee, which was used to calculate the overall average score for each project.

Weighting for each criteria was also adjusted as a function of the stage of the project (New, Existing, and Completed/Sun-Setting Projects), as indicated below.

1. Project Overview

Projects were evaluated on the degree to which:

- The project performers have communicated the project's history, the context in which the project fits into the portfolio, and its high level objectives.

2. Project Approach

Projects were evaluated on the degree to which:

- The project performers have implemented technically sound research, development, and deployment approaches, and have demonstrated the results needed to meet their targets.
- The project performers have identified a project management plan that includes well-defined milestones and adequate methods for addressing potential risks.
- The project performers have clearly described critical success factors that will define technical and commercial viability, and have explained and understand the challenges they must overcome to achieve success.

3. Technical Progress and Accomplishments

Projects were evaluated on the degree to which:

- The project performers have made progress in reaching their objectives based on their project management plan. The project performers have described their most important accomplishments in achieving milestones, reaching technical targets, and overcoming technical barriers.
- The project performers have clearly identified viable plans to accomplish their objectives, and shared their progress to date. (*New Project evaluation only*)
- The project performers have clearly described the progress since the period of the last review. (*Existing and Sun-Setting Project evaluation only*)

4. Project Relevance

Projects were evaluated on the degree to which:

- The project performers have described how the project contributes to meeting Program/Technology Area goals and objectives and the Bioenergy Technologies Office, as cited in the Multi-Year Program Plan (MYPP).
- The project performers have considered applications of their expected outputs.
- The project performers have presented the relevancy of the project and how successful completion of the project will advance the state of technology and impact the viability of commercial bioenergy applications.

5. Future Work (New and Existing Project evaluation only)

Projects were evaluated on the degree to which:

- The project performers have outlined adequate plans for future work, including key milestones and Go/No Go decision points through September 30, 2016.
- The project performers have communicated key planned milestones and addressed how they plan to deal with upcoming decision points and any remaining issues.

6. Overall Impressions (Not Scored)

- Reviewers were asked to provide an overall assessment of the project based on the above criteria.

ABOUT THE BIOENERGY TECHNOLOGIES OFFICE

Overview

The Bioenergy Technologies Office is part of DOE's Office of Energy Efficiency and Renewable Energy (EERE), which is organized around clean energy sectors: Transportation, Renewable Power, and Energy Efficiency. BETO, along with the Vehicle Technologies and Fuel Cell Technologies Offices, falls under EERE's Sustainable Transportation area within EERE. The Office portfolio is organized to reflect the biomass-to-bioenergy supply chain from the feedstock source to the end user. To meet the DOE goals, the Office is focused on developing, demonstrating, and deploying biofuels, bioproducts, and bioenergy technologies in partnership with other government agencies, industry, and academia.

Historically, the Office's focus was on RD&D for ethanol production from lignocellulosic biomass. Since 2012, the Office has demonstrated technologies that can be scaled up to produce modeled price-competitive cellulosic ethanol. This achievement is the culmination of two decades of conversion technology research and development (R&D). DOE-funded R&D in this area has led to a well-developed body of work regarding the performance of ethanol as both a low-volume percentage (E10) gasoline blend in conventional vehicles and at higher blends (E85) in flexible-fuel vehicles. Since the achievement of the cellulosic ethanol cost targets, the Office has shifted its focus toward developing other advanced biofuels that will contribute to the Renewable Fuel Standard (RFS) volumetric requirements. By focusing on these biomass-and algae-based hydrocarbon fuels (renewable gasoline, diesel, and jet fuel), the Office seeks to engage the refinery industry in developing solutions utilizing existing infrastructure as much as possible. The Office's investments in technologies that can reduce the recalcitrance of lignocellulosic biomass are being leveraged toward developing new hydrocarbon biofuels that can directly replace products created from the whole barrel of oil.

Vision, Mission, Goals

The creation of a robust, next-generation domestic bioenergy industry is one of the important pathways for providing Americans with sustainable, renewable energy alternatives. The Office is accelerating the commercialization of first-of-a-kind technologies designed to use the nation's abundant renewable biomass resources for the production of advanced biofuels and biobased products. The Office is also investigating how to improve the economics of biofuel production by converting biomass into high-value chemicals and products that are historically derived from petroleum. As the United States continues to experience the highs and lows of a volatile transportation energy market driven by fossil fuels, the need to find stabilizing solutions becomes increasingly important.

The Office's vision, mission, and goals are provided below.

Vision: A thriving and sustainable bioeconomy fueled by innovative technologies.

Mission: Develop and demonstrate transformative and revolutionary bioenergy technologies for a sustainable nation.

Goals: Develop commercially viable bioenergy and bioproduct technologies to:

- Enable sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure, can reduce greenhouse gas emissions relative to petroleum-derived fuels, and can displace a share of petroleum-derived fuels to reduce U.S. dependence on foreign oil; and
- Encourage the creation of a new domestic bioenergy and bioproduct industry.

A critical measure of the Office's success is the development and demonstration of technologies within integrated biorefineries that can be subsequently commercially deployed and replicated. Similar to biorefineries that produce ethanol from starch and biodiesel from oil seeds and waste oils, integrated biorefineries are expected to produce multiple products to take advantage of the diverse biomass components and processing intermediates. This approach maximizes the value and decreases the waste derived from the biomass feedstock.

Approach to Achieving Goals

The Office has developed a coordinated framework for managing its portfolio based on systematically investigating, evaluating, and selecting the most promising opportunities across a wide range of emerging technologies and technology-readiness levels. This approach is intended to support a diverse technology portfolio in applied R&D, while identifying the most promising targets for follow-on industrial-scale demonstration with increasing integration and complexity. This strategy is designed to allow the Office to progressively enable the production of increasing amounts of biofuels, bioproducts, and bioenergy across the nation from a widening array of feedstocks. This will not only have a significant near-term impact on oil displacement and reducing greenhouse gas (GHG) emissions, but will also facilitate the shift to renewable, sustainable bioenergy technologies in the long term.

Key components of the portfolio include:

- R&D on sustainable, high-quality feedstock supply systems
- R&D on productive and competitive advanced algal systems
- R&D on biomass conversion technologies
- Demonstration and validation of integrated biorefinery technologies up to industrial scale
- Cross-cutting sustainability, analysis, and strategic communications activities

Market Barriers

Biorefineries using cellulosic biomass as a feedstock face market barriers at the federal, state, and local levels. Feedstock availability, production costs, investment risks, consumer awareness and acceptance, and infrastructure limitations pose significant challenges for the emerging bioenergy industry. Widespread deployment of integrated biorefineries will require demonstration of cost-effective biorefinery systems and sustainable, cost-effective feedstock supply infrastructure.

BETO has identified the following key market barriers to the successful and significant expansion of the advanced bioenergy industry:

- Terrestrial feedstock availability and cost
- Inadequate supply chain infrastructure
- High risk of large capital investments
- Codes, standards, and approvals for use
- Cost of production
- Offtake agreements
- Uncertain pace of biofuel availability
- Biofuels distribution infrastructure
- Lack of acceptance and awareness of biofuels as a viable alternative
- End-to-end process integration
- Risk of first-of-a-kind technology
- Technical risk of scaling
- Lack of understanding of environmental/energy tradeoffs
- Inconsistent or competing policies and drivers to facilitate multi-sector shifts
- Optimization of supply chain interfaces and cross-system integration

FORMAT OF THE REPORT

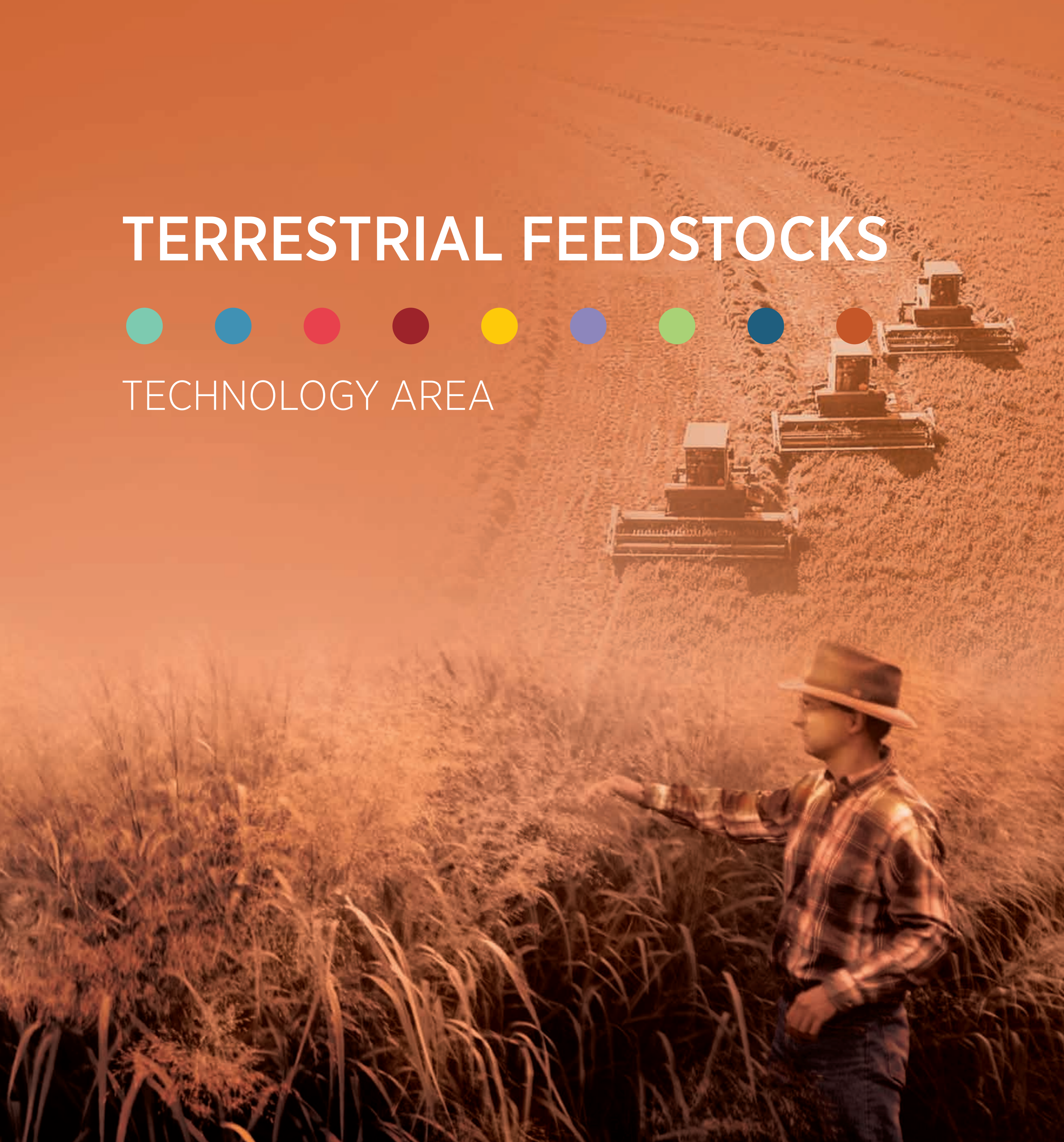
Information in this report has been compiled, based on the following sources, as follows:

- **Peer Review Report Introductory Chapter**: This section contains overview information on the peer review process, roles and responsibilities, review criteria, and the Office's portfolio.
- **Technology Area Chapter Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area.
- **Project Scoring Information**: The final score charts depict the overall weighted score for each project in each technology area.
- **Technology Area Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers, based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **Technology Area BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**: The project reports constitute 2-3 page reports which summarize the results of each project evaluated during the 2015 review process, including the following elements:
    - ***Project descriptions*** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space allotted.
    - ***Scoring charts*** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each evaluation criteria across all projects reviewed within each technology area.
    - ***Reviewer comments*** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks and, in most cases, did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.
    - ***PI responses*** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.
- **Steering Committee Summary Report**: The Steering Committee Summary Report represents the overall summary feedback and final recommendations of the external Steering Committee, following the conclusion of the Program Management Review. This report was based on the participation of the Steering Committee in each component of the peer review process, and in several closed-door, facilitated review sessions following the Project Peer Review and the Program Management Review.

- **Overall BETO Programmatic Response**: The Overall BETO Programmatic Response represents the official, comprehensive response from BETO leadership on the feedback and recommendations provided by the external Steering Committee throughout the peer review process.

TERRESTRIAL FEEDSTOCKS

TECHNOLOGY AREA



CONTENTS

INTRODUCTION

The Terrestrial Feedstocks Technology Area (or Feedstocks Program) is one of seven related programs that were reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of 24 projects were reviewed in the Terrestrial Feedstocks session by six external experts from industry, academia, and other government agencies. This review addressed a total U.S. Department of Energy (DOE) investment value of approximately $36 million (FY2013-2014 spending), which represents approximately 9% of the BETO portfolio reviewed during the 2015 Peer Review. The Principal Investigator (PI) for each project was given between 15 to 60 minutes (depending primarily on the funding level and relative importance to achieving BETO goals) to deliver a presentation and respond to questions from the Review Panel. Projects were evaluated and scored for their project approach, technical progress over two federal fiscal years (2013-2014), relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI. Overview information on the Feedstocks Program, full scoring results and analysis, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Drs. Alison Goss Eng and Steven Thomas as the Feedstocks Program Review Leads. In this capacity, Dr. Goss Eng and Dr. Thomas were responsible for all aspects of review planning and implementation.

TERRESTRIAL FEEDSTOCKS

OVERVIEW

As the starting material for biomass-to-biofuels, bioproducts, and biopower value chains, a sufficient and secure supply of affordable, high-quality feedstocks is a critical necessity to accomplish Office goals and enable a meaningful and sustainable biomass conversion industry. Feedstocks supply and logistics research and development (R&D) relates directly to, and strongly influences many, if not all, of the downstream elements of the Office's portfolio and their respective goals and objectives.

The scope of the Feedstocks Program includes terrestrial, lignocellulosic feedstocks (i.e., agricultural residues, forest resources, and dedicated energy crops), select municipal solid waste (MSW) resources, but excludes algae (except as a blending agent). The Algal Feedstocks Program was reviewed separately. The Feedstocks Program encompasses sustainable feedstock production, resource assessment, and feedstock logistics operations up to the throat of the conversion reactor. These activities are directed at reducing the delivered cost of feedstock, improving and preserving the quality of harvested feedstock, improving environmental performance of feedstock production and logistics operations, and expanding the volume of affordable, high-quality feedstock materials accessible to the developing bioenergy industry.

Sustainable feedstock production R&D activities are focused on enabling the availability of abundant, affordable, high-quality biomass materials in the feedstock supply chain. There are three primary activities associated with sustainable feedstock production: resource assessment; feedstock production to validate the yield

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

potential and sustainability of a variety of potential feedstock crops; and characterization of the physical and chemical properties of cellulosic feedstock materials.

Resource assessment involves estimating current and future domestic biomass resources by type and geographic distribution at different price points, understanding quality attributes (e.g., moisture, ash, and carbon content) associated with those resources as a function of geography and price, and evaluating the environmental sustainability constraints associated with accessing those biomass resources over time.

Feedstock logistics refers to the supply chain operations that occur between feedstock production sites and the biomass conversion reactor inlet. Activities in this area are primarily focused on how to most efficiently, inexpensively, and sustainably harvest and deliver high-quality biomass from a variety of crops to biorefinery end users. These operations include feedstock harvest and collection, storage, handling, preprocessing, and transport to the biorefinery.

Biomass may be transported between field or forest and conversion facility by truck, train, or barge using existing transportation infrastructure. Optimization of container (or biomass package) volumes and dimensions designed for moving biomass feedstocks that simultaneously reach both weight and volume limits would increase efficiencies in the feedstock supply chain and therefore decrease delivered feedstock cost. Existing transportation infrastructure demonstrates these efficiencies for many commodity materials. Preprocessing raw biomass to feedstocks with infrastructure-compatible characteristics can leverage key components of the existing infrastructure.

FEEDSTOCKS PROGRAM SUPPORT OF OFFICE STRATEGIC GOALS

Feedstocks Program project investments are part of the strategy used by BETO to develop, demonstrate, and validate its overall technology goal: to develop and deploy sustainable, commercially viable biomass conversion technologies to produce biofuels that support meeting the Energy Independence and Security Act of 2007 Renewable Fuel Standard (RFS) targets. This goal is best accomplished through public-private partnerships.

The Feedstocks Program's strategic goal is to:

> Develop technologies to enable a sustainable, secure, reliable, affordable supply of acceptable quality terrestrial feedstock for the U.S. bioenergy industry, in partnership with the U.S. Department of Agriculture (USDA) and other key stakeholders.

FEEDSTOCKS PROGRAM SUPPORT OF OFFICE PERFORMANCE GOALS

The Feedstocks Program currently has three performance goals.

- By 2017, validate efficient, low-cost, and sustainable feedstock supply and logistics systems that can deliver feedstock to the conversion reactor throat at required conversion process in-feed specifications, at or below \$80/dry ton (\$2011) (including grower payment/stumpage fee and logistics cost).
- By 2017, establish geographic, economic, quality, and environmental criteria under which the industry could operate at 245 million dry ton per year scale (excluding biopower).
- By 2022, develop and validate feedstock supply and logistics systems that can economically and sustainably supply 285 million dry tons per year at a delivered cost of \$80/dry ton (\$2011) to support a biorefining industry (i.e., multiple biorefineries) utilizing a diversity of biomass resources.

The specific feedstock supply milestones under investigation are:

- By 2015, integrate feedstock quality criteria and blending strategies to generate more comprehensive supply scenarios, meeting biorefinery in-feed specification targets at the lowest possible feedstock price.

- By 2016, produce an updated, fully integrated assessment of potentially available feedstock supplies under previously established environmental and quality criteria.
- By 2017, establish available resource volumes for non-woody MSW and algal feedstocks at $80/dry ton delivered cost—including grower payment/stumpage fee and logistics cost. (Note that woody MSW is currently incorporated into resource assessments).
- By 2018, establish sub-county-level environmental impact criteria and logistics strategies.
- By 2019, determine the impact of international trade and competing feedstock demands (e.g., biopower and pellet exports) on feedstock supply and price projections.
- By 2021, determine the impact of advanced blending and formulation concepts on available volumes that meet quality and environmental criteria, while also meeting the $80/dry ton cost target (including grower payment/stumpage fee and logistics cost).

The specific feedstock logistics milestones under investigation are:

- By 2015, develop a blendstock formulation for one conversion pathway based upon meeting pathway cost, quality, and volume targets.
- By 2017, validate sustainable feedstock supply and logistics cost of $80/dry ton at conversion reactor throat (including grower payment and logistics cost) for at least one biochemical conversion process and one thermochemical conversion process.
- By 2022, validate one blendstock for thermochemical conversion and one blendstock for biochemical conversion at a scale of 1 ton per day, while also meeting the $80/dry ton cost target (including grower payment/stumpage fee and logistics cost).

APPROACH FOR OVERCOMING CHALLENGES

To achieve the Feedstock Program's R&D goal to develop sustainable technologies that provide a secure, reliable, and affordable feedstock supply for the U.S. bioenergy industry, the challenges and barriers identified above need to be prioritized and addressed as funding permits. However, the following issues are considered most critical and will be emphasized within the program's efforts:

- Increase the volume of sustainable, acceptable-quality, cost-effective feedstock available to biorefineries by developing advanced feedstock supply systems and strategies.
- Incorporate sustainability and feedstock supply risk into the resource assessments.
- Work with the Conversion Program to understand the range of acceptable physical and chemical in-feed specifications for the various conversion technology pathways under investigation.
- Develop high-capacity, high-efficiency, low-cost, commercial-scale feedstock supply and logistics systems that deliver stable, dense, flowable, consistent-quality, infrastructure-compatible feedstock.

In the past, Office-funded Feedstock Program research focused on modifying conventional terrestrial feedstock logistics systems that were designed and manufactured for traditional agricultural and forestry industries. Conventional systems are possibly suitable for high biomass-yielding regions, but not for medium-to-low-yield areas. Supplying feedstock to a growing bioenergy industry requires increasing the accessible volumes of lignocellulosic feedstock, while increasing the emphasis on quality, as well as reducing variability and risk throughout the value chain.

For more information on the Terrestrial Feedstock Technology Area, please review BETO's Multi-Year Program Plan at: *http://www.energy.gov/eere/bioenergy.*

TERRESTRIAL FEEDSTOCKS TECHNOLOGY AREA REVIEW PANEL

The following external experts served as reviewers for the Terrestrial Feedstocks Program during the 2015 Project Peer Review.

TERRESTRIAL FEEDSTOCKS	
REVIEWERS	
Bruce Dale (Lead Reviewer)	Michigan State University
Harry Baumes	U.S. Department of Agriculture
Daniel Cassidy	U.S. Department of Agriculture
Beth Dodson	University of Montana
Harrison Pettit	PacificAg
Bob Rummer	University of Kansas

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: Overview information for each Program was drafted by BETO review leads to provide background information and context for the projects that were reviewed. Total budget information is based on data provided by the PI for each project.

Project Scoring Information: The final score charts depict the overall weighted score for each project in each Program. Titles for each project and the performers are also provided in the scoring charts.

Review Panel Summary Report: The Review Panel Summary Report was drafted by the lead reviewer for each Program, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the Program review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.

BETO Programmatic Response: The BETO Programmatic Response represents BETO's response to the evaluation and recommendations provided in the Review Panel Summary Report.

Project Reports:

- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PI for each project. In some cases, abstracts were edited to fit within space constraints.
- **Project budget and timeline information** are based on data provided by the PI for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and whiskers charts depict the range of scores for each evaluation criteria across all projects reviewed within each technology area.
- **Reviewer comments** are presented as provided in the overall impressions criteria response for each project. Each bulleted response represents the opinion of one reviewer, but they are not attributed.

Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.

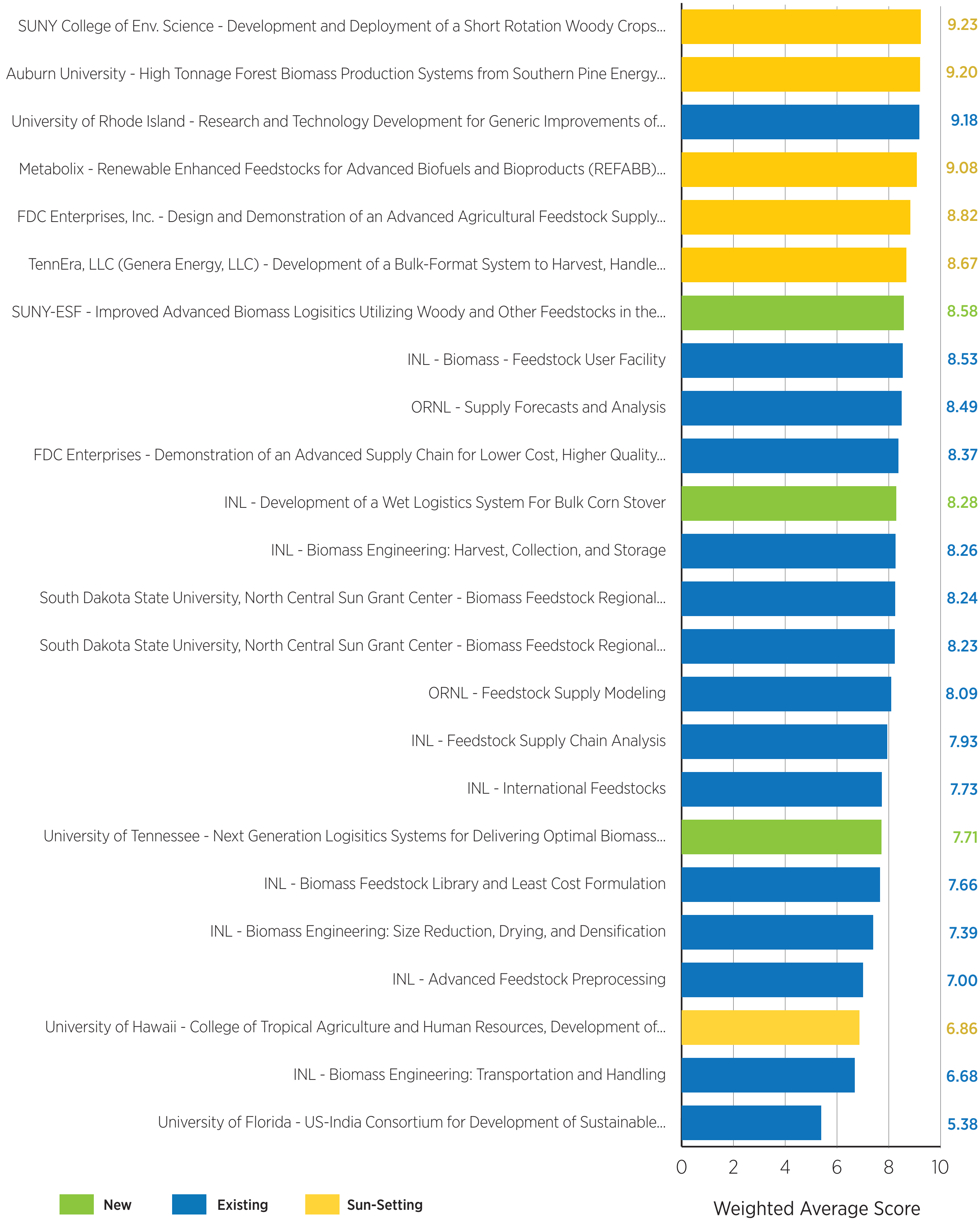
- **PI responses** represent the response provided by the PI to the reviewer comments, as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the Review Panel.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Terrestrial Feedstocks Technology Area.

TERRESTRIAL FEEDSTOCKS TECHNOLOGY AREA SCORING



REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

IMPACTS

The Biomass Feedstock Regional Partnership has provided valuable geographic and longitudinal data on important biomass yield and sustainability parameters. Significant positive near-term impacts are anticipated from several Idaho National Laboratory (INL) and related projects that: (1) characterize and store biomass; (2) develop fundamental engineering knowledge on biomass wet storage, biomass handling, and size reduction; and (3) improve supply chain modeling. Likewise, the various BETO-sponsored resource availability analyses have provided credibility to the national bioenergy goals and have outlined pathways for enhanced sustainability outcomes. While some of the high tonnage projects were very successful, other projects may not achieve BETO's eventual goal of providing new commercial equipment because the original equipment manufacturer partner likely does not have the capacity to commercialize. The Terrestrial Feedstocks Program should continue to exercise due diligence on program investments in commercial systems development.

Not meeting obvious or sensitive sustainability criteria must become part of go/no-go decision making within BETO. Efforts by BETO and the current PI to rescue the U.S.-India project are commendable, but while it is now well-administered, the project remains weak in several technical areas and is founded on some dubious basic assumptions. Market analysis of competing demands for biomass feedstocks is a key activity, one for which BETO might seek outside partners. "Mission creep" is a concern for several projects. BETO needs to set and enforce clear limits on the scope of its projects.

INNOVATION

The two fundamental genetics projects (Kausch at URI and Metabolix) are highly innovative and have also shown clear commercialization pathways. Near infrared measurements taken along the supply chain will help monitor changes in biomass quality and add great value to the industry. Detailed engineering analysis of the fundamentals of size reduction to identify "sweet spots" for improved equipment designs and configurations is both innovative and highly important. The southern pine and willow projects have been innovative and successful, so much so that BETO needs to ask how much additional investment is warranted given other pressing needs. In contrast, the work on biomass bridging in hoppers has probably not "moved the needle."

GAPS

The Review Panel identified several issues that warrant increased attention:

- Minimize water use throughout the bioenergy system; for example, by developing environmentally acceptable means of removing ash from biomass.
- Develop low-cost, environmentally acceptable means of separating water from solid streams. This is the key techno-economic hurdle for algae to biofuels processes and is also important for other aqueous biomass processing technologies.
- BETO must preemptively use important selected sustainability metrics to shape its portfolio.

There are two overriding areas where increased, continual attention is needed. These two areas, listed below, will be discussed in more detail in the Recommendations section.

- Develop, link, and test models to better understand the sustainability and economic performance of entire bioenergy systems.
- Identify promising technologies and concepts for biomass processing depots and then demonstrate and pilot them.

SYNERGIES

The modeling work in BETO and field data collection efforts are often very productively linked. For example, Dr. Tim Volk of State University of New York (SUNY) is using the Oak Ridge National Laboratory (ORNL) IBSAL model to design his new field experiments. BETO staff and investigators have demonstrated a commendable ability to integrate within and outside BETO and to leverage limited funds.

In the future, even better coordination and integration with USDA will be required. "Win-win" strategies must be identified and pursued. For example, bioenergy development can encourage more sustainable farming practices by using cover crops to feed a bioenergy system. As another example, bioenergy systems designed and developed to benefit farmers and rural communities will encourage bioenergy crop production, thereby helping the bioenergy industry grow. BETO should also connect with international trade agencies to interest them in studying the global market impacts of bioenergy development.

RECOMMENDATIONS

BETO and its predecessors have worked for decades to develop bioenergy production processes based on cellulosic materials. These are the so-called "biorefinery" biomass processing technologies. These technology investments are now bearing fruit as the first generation of cellulosic biorefineries is beginning to emerge in the United States and globally. However, a sustainable biorefining industry can grow only as rapidly as a sustainable biomass supply industry emerges. It is increasingly apparent that the most important factors limiting large-scale, sustainable bioenergy production in the United States are upstream and outside of the biorefinery. Therefore, BETO investments and efforts upstream and outside of the bioenergy facility gates must now grow significantly, even if doing so requires decreased investments in BETO's more traditional areas.

The following two areas, which are outside the biorefinery, are in critical need of immediate investment: (1) BETO must develop and demonstrate at scale the depot concept for promising technologies; and (2) BETO must significantly expand its efforts to develop and validate linked models from the sub-field scale through the national scale that can reliably predict the economic and environmental performance of actively managed bioenergy systems.

Depot-Level Demonstration Projects

A sustainable, very large-scale domestic bioenergy industry absolutely requires large-scale, sustainable commodity biomass feedstocks. These feedstocks must be dense, stable, storable, shippable commodities, preferably with multiple markets. With few exceptions, commodity cellulosic biomass feedstocks with these properties do not now exist. Intermediate processing facilities called "depots" are therefore required between the field/forest and the bioenergy facilities. Depots will process raw biomass materials so that commodity feedstocks with these properties result. The depots must add enough value to the biomass so that the cost of processing is more than compensated. BETO must move quickly to develop and demonstrate several promising depot systems at scale. A large-scale cellulosic biorefining industry is unlikely to emerge unless it is supplied by a network of depots.

Federal agencies supporting a sustainable bioeconomy must identify and pursue "win-win" opportunities. For example, BETO should work closely with USDA to identify and exploit synergies between depots and workforce and rural community development. Potential synergies with sustainable feedstock production must also be identified and exploited. Sustainable production of feedstocks is a key element of our second recommendation.

Develop Multi-Scale Integrated Models and the Necessary Data

BETO's efforts to support sustainable bioenergy production by developing both the needed data and the models to that data have been very successful. As the bioenergy industry grows, even greater efforts to develop both the underlying data and useful models based on the data are now required. The models and underlying data collection efforts must give increased attention to understanding and improving the sustainability of bioenergy production, particularly for potential "win-win" activities. Data and information needed include, for example:

- Yields and agronomic inputs to achieve these yields based on long-term field research under different soil and climate conditions.
- Soil organic matter, nitrogen, and carbon emissions from soils under different management practices and climate conditions.
- Increased soil fertility and water-holding capacity by low-cost biological carbon capture and storage, e.g., by tilling in digestate from anaerobic digestion facilities or cover crops.
- Biodiversity impacts through more diverse landscapes that include bioenergy crops.
- Changes in nitrate and phosphorus emissions by strategic placement of perennial bioenergy crops on the landscape.

While identifying "win-win" activities is critical, it is also important to better understand all implications, both positive and negative, of growing and managing bioenergy crops. Modeling can help substantially in this effort. Thus, BETO must increasingly partner with the USDA to develop linked, verified, biophysical models at all levels of the bioenergy system from the sub-field scale, to the farm, to the watershed, to the depot, to the biorefinery through to final bioenergy use at the national scale. The models must reliably predict the economic and environmental performance of different actively managed bioenergy systems appropriate for different regions of the country. A valuable initial benchmarking exercise for BETO would be to use its existing models and data to estimate the net energy output of different proposed bioenergy systems.

BETO PROGRAMMATIC RESPONSE

IMPACTS

The Feedstock Program is proud of its accomplishments, especially in regard to the five competitive logistics awards made from the FY2009 Logistics Funding Opportunity Announcement (FOA), as well as the Regional Feedstock Partnership work. Data from the Regional Feedstock Partnership has provided real world yield data for several crop species across a wide geography and 5-8 consecutive growing seasons. These data will be used to refine estimates of sustainable biomass supplies in the upcoming update to the 2016 U.S. Billion Ton Update (BT16). The engineering work currently being performed at INL represents unique research on feedstock handling and storage.

The program is aware of the sustainability concerns that come with supplying feedstocks to a Billion Ton Bioeconomy and is tracking and analyzing most, if not all of the pertinent variables. BETO recently released a Landscape Design funding opportunity to help understand the impact of bioenergy systems on landscapes and has planned to add a second volume on feedstock sustainability into the BT16. The sustainability analyses in Volume 2 of the BT16 represent the first attempt to examine the intersection between resource potential estimates and sustainability for the U.S. at county-level resolution. Targeted for publication in 2016, Volume 2 of BT16 is to be concentrated on environmental sustainability, climate change impacts, and strategies to enhance environmental sustainability. The sustainability analysis performed will not be limited to the BT16 as BETO's Technology Managers will utilize active project management practices to ensure inclusion of sustainability in Annual Operating Plan milestone goals.

INNOVATION

The Feedstocks Program is excited to highlight the innovation that occurs within its project portfolio.

The five logistics projects that were recently completed are a great source of pride for the Feedstock Program. Some of the new machinery is already available on the commercial market, including Tigercats' feller buncher and skidder, New Holland's self-propelled forage harvester fitted with the short rotation woody crop header, AGCO's single pass combine-baler, and Kelderman Manufacturing's self-loading trailer. Machinery developed across all the projects have led to unique and innovative technologies to harvest corn stover and energy crop grasses and trees—saving labor and machine costs in the biomass supply chain, while reducing greenhouse gas emissions from harvesting and logistics operations. Demonstrations of the projects showed cost reductions up to 34% over conventional systems.

The southern pine and willow projects mentioned by the Review Panel are certainly well established, in part due to the funding provided by BETO, and future work will take into account the current status of those respective industries.

GAPS

The Review Panel identified gaps, specifically dealing with sustainability, that they feel the Feedstock Program should focus on in the future. The highlighted gaps are as follows:

- Minimize water use throughout the bioenergy system; for example, by developing environmentally acceptable means of removing ash from biomass.
- Develop low-cost, environmentally acceptable means of separating water from solid streams. This is the key techno-economic hurdle for algae to biofuels processes and is also important for other aqueous biomass processing technologies.
- BETO must preemptively use important selected sustainability metrics to shape its portfolio.
- Develop, link, and test models to better understand the sustainability and economic performance of entire bioenergy systems.

The Program understands the need for environmental stewardship in regard to biomass production and will continue to push it among project performers. The Sustainability and Strategic Analysis Technology Area, which was reviewed separately, has primary responsibility for ensuring sustainability within the BETO portfolio. The Feedstocks Program has regular meetings with the Sustainability and Strategic Analysis Team to ensure advantageous coordination between programs. A prime example of BETO's commitment to sustainability is the Landscape Design Funding Opportunity that was released last year.

The purpose of the funding opportunity is to support interdisciplinary R&D projects that apply landscape design approaches to integrate cellulosic feedstock production into existing agricultural and forestry systems while maintaining or enhancing environmental and socio-economic sustainability including ecosystem services and food, feed, and fiber production. The findings that will come out of the funding opportunity will be invaluable for the progress of the industry and will provide tangible outcomes to analyze.

Another gap identified by the Review Panel is the need to research advanced supply systems (e.g., depots).

- Identify promising technologies and concepts for biomass processing depots and then demonstrate and pilot them.

BETO has received input through requests for information, workshops (August 2011, March and June 2014, and February 2015), stakeholder roundtables (January 2015), and regular interactions with other Federal agencies. The findings of the workshops and roundtables proved that it is widely acknowledged in the bioenergy community that sustainable, low-risk, long-term, commercial-scale biomass feedstock supply is the largest barrier to the development of a bioindustry capable of supporting a national bioeconomy. To overcome this barrier, BETO will continue to research a depot model for gathering, treating, and delivering various feedstocks to customers.

SYNERGIES

The Review Panel discussed the importance of coordinating modeling software and field data collection between federal organizations, project performers, and national labs. A key component of successful coordination between agencies is the creation of the Bioenergy Knowledge Discovery Framework database (KDF), which is utilized by national labs, project performers, and many external stakeholders. BETO collaborated with ORNL to create the Bioenergy KDF. The KDF supports the development of a sustainable bioenergy industry by providing access to a variety of data sets, publications, and collaboration and mapping tools that support bioenergy research, analysis, and decision making. In the Bioenergy KDF, users can search for information, contribute data, and use the tools and map interface to synthesize, analyze, and visualize information in a spatially integrated manner.

The KDF contains a multitude of resources, including:

- 1,600 curated spatial data sources
- 1,500 downloadable datasets, 1,450 map services, 257 field trial datasets
- Billion Ton Update data explorer and download tools
- Geospatial and graphical visualization
- Spatial snalysis and querying
- Faceted search and news feeds
- 300 curated resources describing models and important journal articles
- 263 Web resources

Feedstock quality information available in the INL Biomass R&D Resources Library will be expanded and results will be shared publicly via KDF in alignment with the Presidential Open Data Initiative. The Biomass Feedstock National User Facility (BFNUF) will be used to obtain and test feedstocks produced by the USDA National Institute of Food and Agriculture (NIFA)-funded Coordinated Agriculture Projects (CAP), program-funded (and other) integrated biorefineries, and other users. These will be tested in a variety of configurations that can mimic commercial preprocessing operations. Tests will allow for data collection at each module, as well as for detailed physical and chemical characterization of the material at any stage, with the goal of driving down risks and costs.

RECOMMENDATIONS

Two major recommendations were put forth by the Review Panel.

Depot-Level Demonstration Projects

There is currently little understanding of the costs associated with operating a biomass depot at scale. If the U.S. advanced biofuels industry is to handle the processing of 280 million tons or more annually to meet the RFS, advanced supply systems with depots must be developed and demonstrated so that the technology is proven and financing for such facilities is more easily obtained. The Feedstock Program is partnering with the Demonstration and Market Transformation Program (also reviewed separately) to better understand feedstock challenges that biomass end users are facing, and develop R&D programs to solve these upstream barriers. We acknowledge and are addressing upstream challenges identified by stakeholders in several venues. The program will continue to work toward the design, operation, and validation of advanced processing technologies and integrated supply chain components at demonstration scale to meet the needs of integrated biorefinery operations.

Develop Multi-Scale Integrated Models and the Necessary Data

BETO works with its partners at USDA to ensure continued coordination. Examples of regular meetings between the two agencies:

- USDA/DOE Biomass Feedstocks Coordination Group.
- Interagency Feedstock Logistics and Biofuels Distribution Working Group.
- Interagency Feedstock Production Working Group.
- Woody Biomass Utilization Group (WBUG).

Current targeted coordination between agencies centers on:

- Biomass R&D Initiative (BRDI) Solicitation development and execution.
- Regional Feedstock Partnership and NIFA AFRI Coordinated Agricultural Projects information sharing.
- BETO strategic planning efforts around feedstocks, and specifically, business cases for bioenergy crops.

This regular interaction between the two agencies is critical to ensure that "win-win" activities are being sought and realized to reach the common goal of a Billion Ton Bioeconomy.

SUPPLY FORECASTS AND ANALYSIS

(WBS#: 1.1.1.1)

Recipient:	ORNL
Presenter:	Matt Langholtz
DOE Funding FY14:	$912,577
DOE Funding FY13:	$1,013,544
DOE Funding FY10-12:	$3,046,422
Planned Funding:	$5,357,327
Project Dates:	10/1/2007 - 9/30/2017

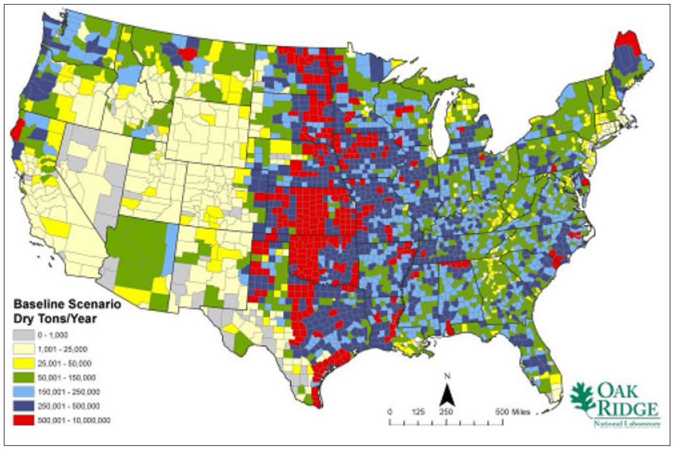
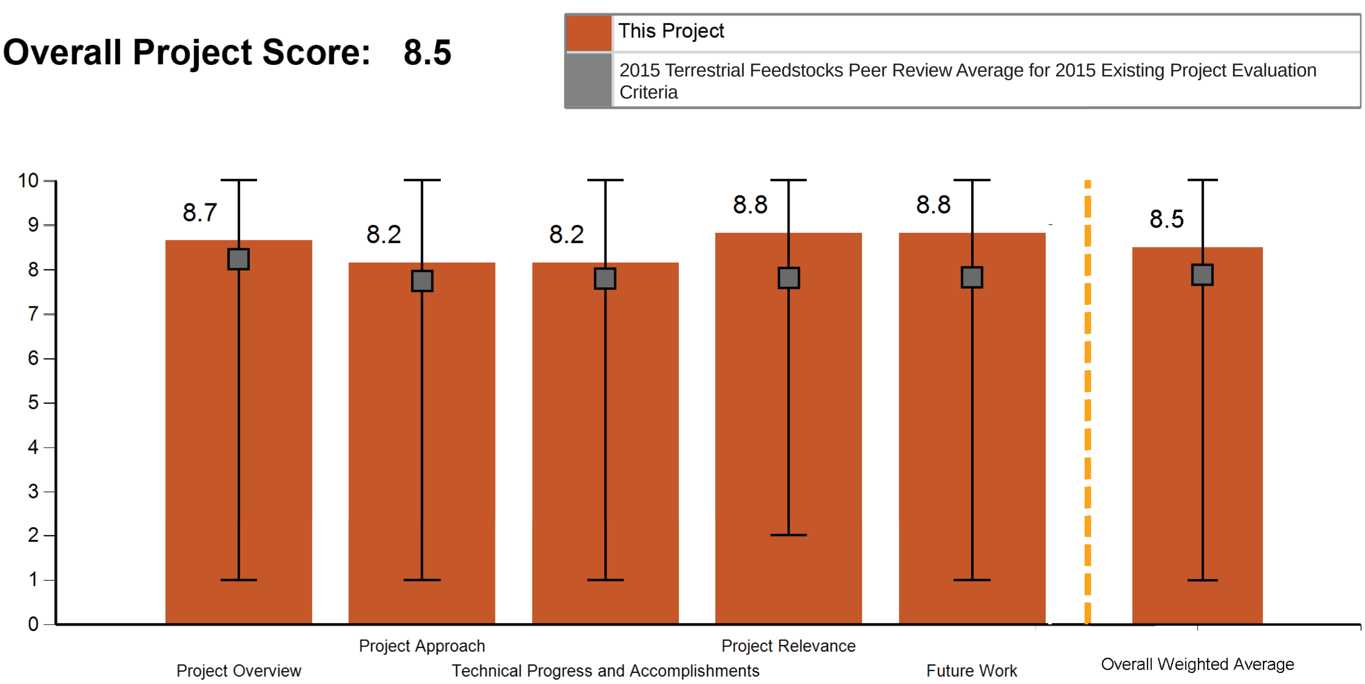


Image Courtesy of ORNL

Project Description

Biomass feedstock supply and price projections (FSPPs) are needed to enable biofuels commercialization. Feedstock prices are expected to comprise about 1/3 of a $3.00/gallon minimum ethanol selling price. Thus, changing economic conditions and evolving feedstock production strategies warrant maintenance of revised FSPPs. This effort employs an economic modeling framework (POLYSYS) to project county-level FSPPs (e.g., agricultural residues, dedicated biomass feedstocks, and forest resources) as a function of price, scenario, and year. Ongoing modeling efforts include maintenance of current underlying data, incorporating up-to-date biomass crop yield and budget assumptions, adding additional feedstock types such as algae and municipal solid waste, evaluating reactor-throat-delivered FSPPs, and quantifying environmental sustainability impacts. Detailed results are disseminated through the Knowledge Discovery Framework (KDF). Planned future activities include: (1) completing the 2016 Billion-Ton Report (BT16), Volume 1, including projected farmgate and delivered FSPPs; (2) completing the BT16, Volume 2, including environmental sustain-

Overall Project Score: 8.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ability analysis of FSPPs and climate change impacts; and (3) disseminating results and enhanced visualization through the KDF.

Overall Impressions

- The synthesis and production of BT16 is a core need of DOE; however, it is unclear as to why this basic function of DOE is funded through research dollars.
- Good project and important level of analysis to get closer to potential delivered costs and supply curves.
- Excellent project. Well done, with high impact. The double cropping idea needs to be explored further as it may allow us to produce much more biomass more sustainably without additional acres.
- Detailed inventory of available feedstocks and their costs are extremely valuable.
- This is a critically important project that is well carried out. The way this information is characterized is very important to the project's credibility because real experiences in these early developmental days of the industry will not be consistent with this work.

PI Response to Reviewer Comments

- We are grateful for your valuable feedback. We agree that our projections of potential availability need to be harmonized with actual production as commercialization advances. Double cropping is a very interesting production strategy with opportunities for economic and environmental enhancement. We will take note to evaluate inclusion of double cropping in future analyses.

FEEDSTOCK SUPPLY CHAIN ANALYSIS

(WBS#: 1.1.1.2)

Recipient:	INL
Presenter:	Jacob Jacobson
DOE Funding FY14:	$535,928
DOE Funding FY13:	$712,478
DOE Funding FY10-12:	$1,054,676
Planned Funding:	$690,880
Project Dates:	10/1/2014 - 9/30/2015

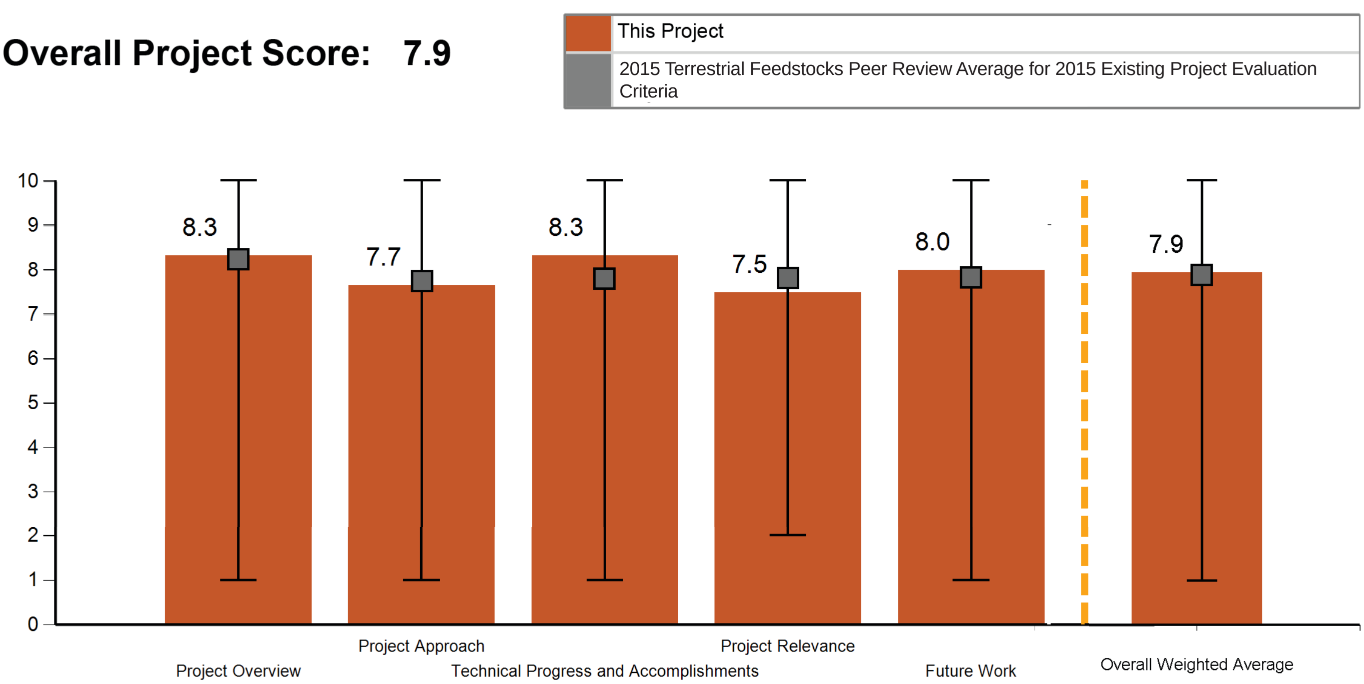
Project Description

BETO's overall goal is to help transform the nation's renewable biomass resources into cost-competitive, high-performance biofuels and bioproducts. However, before a national scale, sustainable, and economically viable bioenergy industry emerges, innovative production/logistic systems need to be developed to increase total productivity of the landscape, decrease delivered feedstock cost, and minimize environmental impacts. This project contributes to these goals in several ways, including: (1) developing integrated feedstock supply system designs that deliver feedstock to each of the eight BETO-selected conversion pathways at a total delivered target cost of $80/dry ton (DT) and meet in-feed specifications; (2) designing integrated strategies that meet cost, quantity and quality specifications, while minimizing environmental impacts; and (3) delivering to the bioenergy community robust datasets and flexible analysis tools, which will help engage and enable industry to successfully implement a biofuel supply system. More specifically, this project directly informs BETO through barrier Ft-M: Overall Integration and Scale-up. Historically, this project has supported BETO in state of technology (SOT) reporting and MYPP update, as well as evaluating barriers to feedstock logistics supply chains.

Overall Impressions

- This project is a clear example of a larger issue: a focus within the national laboratories on peer-reviewed publications as a primary metric of dissem-

Overall Project Score: 7.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ination of project results. Peer-reviewed papers are an important element of a communications plan; however, they only reach one specific audience (other researchers). Communication plans need to be developed and implemented to target other audience; specifically, industry participants who are best positioned to quickly implement promising research results.

- This is a good research line in BETO that is fundamental to overall progress for the entire portfolio.
- Project work is very relevant and should lead to adoption of depot model. The challenge now is to identify what that depot model should look like.
- Given the current challenges in the industry, this project feels more like an elaborate exercise in conceiving a far distance vision rather than serving the interests in growing an industry today.

PI Response to Reviewer Comments

- The presenter agrees that peer-reviewed publications are generally geared toward an academic audience. However, that avenue remains an important mechanism for vetting research and ideas among peers, and is part of a suite of approaches taken to vet assumptions and outputs. The INL analysis team engages stakeholders through a variety of mechanisms, including attending and presenting at technical conferences, industry meetings, such as annual biomass conferences hosted by BETO, and modeling conferences. The INL has hosted two workshops soliciting information from stakeholders; one on densification at the INL, in August 2011, and one on Advanced Supply System logistics concepts, hosted by DOE in Golden, Colorado, in February 2015. Both of these workshops resulted in feedback that was incorporated into INL feedstock logistics analysis work. INL also works in collaboration with experts from other national laboratories, including ANL, PNNL, NREL, ORNL, SNL, and LBNL.
- The role of SOT is to document and highlight annual progress in moving toward longer-term goals, acting as a near term snapshot of what the industry could achieve immediately or in the very near term. Engaging industry is a key factor in ensuring that model inputs are capturing the reality of current capabilities, and accurately estimating the progress towards long-term and medium-term goals.

BIOMASS ENGINEERING: HARVEST, COLLECTION, AND STORAGE

(WBS#: 1.2.1.1)

Photo Courtesy of INL

Recipient:	INL
Presenter:	Bill Smith
DOE Funding FY14:	$1,554,458
DOE Funding FY13:	$1,929,348
DOE Funding FY10-12:	$8,642,016
Planned Funding:	$3,875,276
Project Dates:	10/1/2014 - 9/30/2017

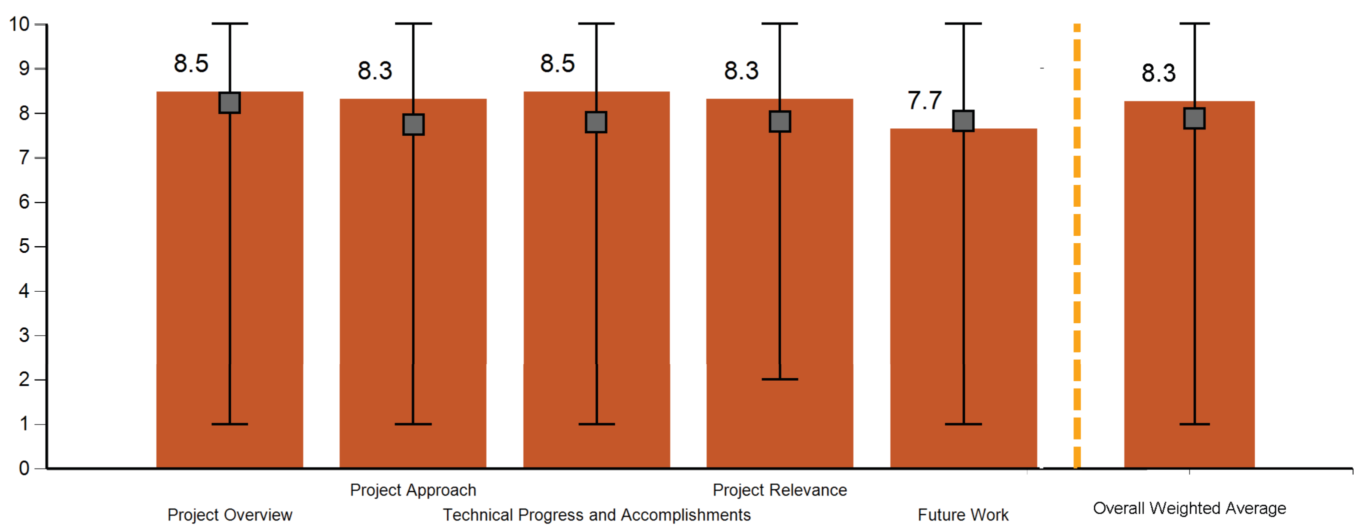
Project Description

Biomass supply systems are adapted from agricultural forage systems that supply hay and forage to dairies, feedlots, and farms. Through DOE investments in feedstock logistics, much has been learned to differentiate the attributes of a national-scale biomass market from hay and forage markets. The need for distinct quality, sustainability, and stability metrics have led to changes to equipment and processes that supply low-cost/high quality feedstocks to an emerging national biofuels market. Development of biomass-specific equipment and practices for harvesting, storing, and processing biomass crops helped achieve aggressive yield and cost targets in 2012. The project presentation highlights specific feedstock R&D accomplishments, challenges, and future research that support the delivery of biomass feedstocks at conversion in-feed specification at a cost of $80/DT by 2017. These include field research, analytical charac-

Overall Project Score: 8.3

This Project

2015 Terrestrial Feedstocks Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

terization of harvested material, and statistical analysis of corn stover feedstock from an industrially relevant supply shed. Results include an economic analysis of the impact of collection method on delivered cost and show how dry matter loss resulting from high-moisture storage conditions impacts conversion performance in switchgrass and corn stover. Finally, results of laboratory-scale storage research shows the impact of engineered queuing systems that can reduce annual feedstock costs by delivering "at-risk" feedstock before significant deterioration occurs.

Overall Impressions

- I suggest continued work on developing similar data/projects for other feedstocks over additional modeling.
- This is an excellent project that highlights the unique expertise of national laboratories combined with good collaboration from commercial partners to address a critical and relevant dimension of feedstock supply, which is the delivery of quality materials.
- A very high impact project. It needs to be expanded so that we can link economic and environmental models from the sub-field scale all the way through to national impacts.
- The work should continue to improve efficiency in moving feedstocks from field to "storage/processing/conversion."
- This is important work and the results need to be communicated outside of academic journals. However, the scale and sample size must be increased for the harvest portion of this project to become relevant to best practices, which is ultimately where this work must arrive if it is to be judged successful.

PI Response to Reviewer Comments

- The overall approach that INL has taken to feedstock harvest, collection, and storage engineering has been to engage early-adopting producers and users of biomass to identify the most pressing barriers, which have been feedstock availability, delivery costs (FY13 peer review) and quality in a biochemical conversion process (FY15 peer review). As noted, we have focused on corn stover but are including more studies with switchgrass (started in FY15) and sorghum into FY18, and beyond. However, as more feedstocks and equipment come online, it becomes increasingly challenging to provide rigorous and detailed analyses of the current state of technology at a meaningful scale. We intend to build on our existing results and move forward with research that provides added value for our industrial partners by creating tools that advance improvements to future SOTs.
- We agree with the reviewers' comments that feedstocks are regional; each has its own sensitivities, local practices, and regionally important climate conditions that create challenges for harvesting, collection, and storage. Based on our experience, we believe that it is important to transition from passive management tools, such as best management practices, to active tools that enable real-time response to changing harvest and storage conditions. This will permit biomass producers and users to adapt to changing conditions (soil, climate, crop, and storage conditions) to collect the highest quality biomass, maintain it during storage, and deliver it in time to retain its inherent value.
- For harvest and collection, active management is necessary to enable autonomous subfield response to variables affecting quality, such as yield, soil contamination, and moisture. In storage, monitoring

of self-heating and moisture loss will permit on-time delivery of feedstocks at risk of degradation before they lose their inherent value for conversion. This work will be performed in concert with INL's analytical and sustainability groups to ensure that our proposed solutions support and, to the extent possible, enhance the economic and environmental sustainability of feedstock supply.

- Solutions will be developed and tested in cooperation with our national laboratory, university, and industry partners, and we will continue to publish our results of the analysis, monitoring, and supply management tools as they mature. Additionally, we are participating in industry and trade conferences, such as the International Biomass Conference & Expo, Advanced Bioeconomy Feedstocks Conference, and the BETO-led Biomass Industry Panel on Codes and Standards to disseminate our research results as well as work with and continue to learn from the practical experiences of a broader set of biomass users.

BIOMASS ENGINEERING: SIZE REDUCTION, DRYING, AND DENSIFICATION

(WBS#: 1.2.1.2)

Recipient:	INL
Presenter:	Jaya Tumuluru
DOE Funding FY14:	$436,483
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,662,084
Project Dates:	10/1/2014 - 9/30/2017

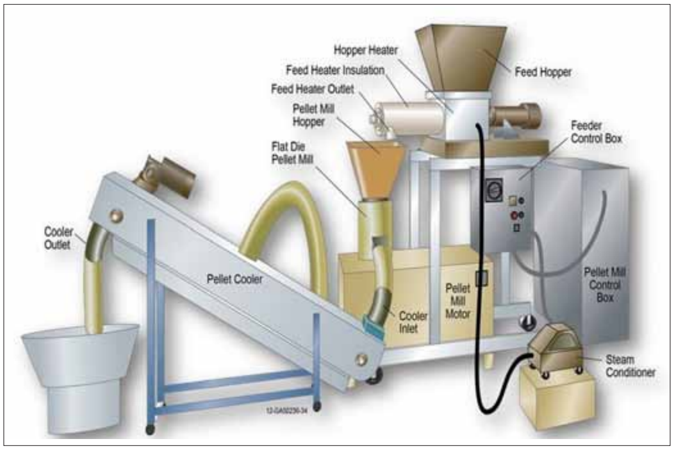
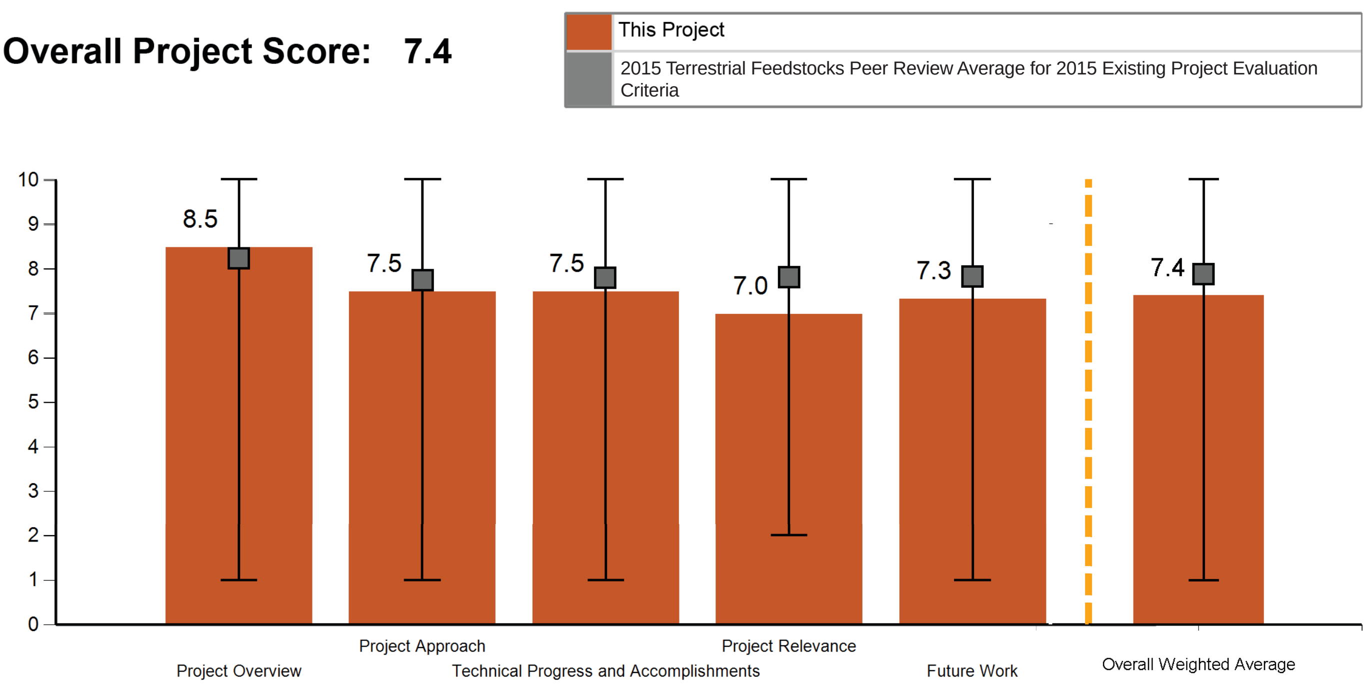


Image Courtesy of INL

Project Description

The goal of this project is to reduce preprocessing costs by 50% compared to the 2013 state of technology and support the DOE feedstock cost target of $80/dry ton (DT). Based on TEA analysis, high preprocessing cost is the bottleneck to utilize high moisture biomass. Developing cost-effective solutions to preprocess high-moisture biomass is critical to increasing the availability of a billion tons of biomass in the U.S. for biofuels production. The project's technical approach to lower the preprocessing costs was fractional milling, high moisture pelleting, and energy efficient drying. In fractional milling, a bigger screen is used in the stage-1 grinder and a separator is inserted between stage-1 and stage-2 grinders to bypass the fraction that has already met the specification, thereby avoiding redundant processing. Fractional milling studies in FY14 reduced the preprocessing costs by $10.40/DT. In the high moisture pelleting process, biomass is pelleted at >28%

Overall Project Score: 7.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

moisture. During pelleting, biomass lose some moisture due to preheating and frictional heat generated in the die. Pellets with high moisture can be dried using grain dryers. FY13 and FY14 results on high moisture pelleting of corn stover and lodgepole pine in a laboratory scale pellet mill indicated that high dense (>30 lb/ft^3) and durable (>95%) pellets can be produced. The final outcome of the project in 2017 is to demonstrate at scale integrated fractional milling, high moisture pelleting and drying, and meeting established cost targets.

Overall Impressions

- This project highlights the need to look to other material handling applications. While I understand fractional grinding is revolutionary in the handling of herbaceous feedstocks, it is a process that has been widely adopted in the handling of woody material, specifically pulp chips and hog fuel. Could the same results be reached by industry with well-placed "idea" pieces in trade journals and conferences?
- Good fundamental research that industry would not be able to conduct; that is, defining innovative opportunities that can address the MYPP goals. There should be an aggressive commercialization plan to transition this as quickly as possible to equipment manufacturers.
- This is a very strong and highly relevant project. We need to ask how much more high-impact work is needed here. Is it time to refocus? Mission creep may be a problem.
- The overall impression of work and goals is positive.
- This work has been diligently and expertly carried out. However, I remain doubtful of the viability of the preprocessing technology for which this project seeks to find improvement. Drying and pelleting technology has been widely used for decades. I would rather see research dollars and the expertise applied to more novel approaches to intermediate processing of biomass into feedstock that has a higher likelihood of adding value over cost.

PI Response to Reviewer Comments

- Drying and pelleting has been used for decades to produce wood pellets, which have a high value ($250/ton) in the European market. To meet the DOE feedstock cost of $80/DT, this technology will not be suitable as our techno-economic analysis (TEA) indicated that the drying costs are very high for high moisture biomass. In the conventional pelleting process, about 65% of energy is needed to dry the biomass from 30-10% wet basis (w.b.) moisture content. Our TEA analysis indicated that it costs $43.60/DT to dry biomass from 30-10% (w.b.) and further grind it to ¼-inch screen (Kenney, et al, 2013). Based on the TEA analysis, efficient moisture management is critical for reducing the preprocessing cost.
- One of the technologies identified to manage moisture efficiently is high moisture pelleting. In high moisture pelleting, biomass is pelleted at 30% (w.b.) moisture content. Biomass is initially preheated for short times (3-4 minutes) prior to pelleting. The combination of preheating, frictional heat generated in the pellet die, and further cooling partially dries the biomass, removing 5 to 10 points of moisture (Tumuluru, 2014). The high moisture pellets produced are further dried if necessary to stable moistures of <9% (w.b.) using energy efficient dryers such as grain dryers (Tumuluru, et al, 2014). The main advantage of this method is that it provides an economical alternate to biomass drying. Further, by moving drying to the end of the process, drying becomes flexible and can be used only when high durable pellets are required. The novelty of this approach is to understand the tradeoffs between pellet quality and cost to inform pelleting options for domestic bioenergy markets. According to interna-

tional standards (Pellet Fuel Institute and European Committee for Standardization), pellets with durability values >96.5% and 97.5% and bulk density of >640 and 700 kg/m^3 are required for international transport. To transport pellets shorter distances (e.g., interstate), such a high density and durability value may not be needed. This gives an opportunity to customize the pellet production process to produce pellets with varying durability and density values to meet different transportation scenarios. Our research has indicated that pellets with different density and durability can be produced at different feedstock moistures, die speeds, and preheating temperatures and these process conditions have significant impact on the pelleting energy. The TEA analysis done using the experimental data indicated that a combination of factional milling and high moisture pelleting will reduce the preprocessing cost of high moisture biomass by about 50% compared to the 2013 state of technology (Kenney, et al, 2013) and helps to meet the DOE feedstock cost target of $80/DT.

- A technology development roadmap will be developed this fiscal year to guide the scale-up activities and ensure that the project plan has clearly defined end states and outcomes, and a maturation process that addresses both the EERE mission and industrial adoption needs. This includes a systematic approach and schedule for engaging industry collaborators at the appropriate time and way that it neither transitions to industry prematurely (i.e., still requiring substantial R&D), nor retards scale-up and market adoption. In FY16-FY17, the project will work closely with preprocessing equipment manufacturers. We will also engage the commercial manufacturers through National User Facility agreements to accelerate the early adoption of the new technologies developed in the project.

References:

- *Kenney, K.L., et al. Feedstock Supply System Design and Economics for Conversion of Sugars to Hydrocarbons. 2013. INL/EXT-13-30342.*
- *Tumuluru, J.S., Effect of Process Variables on the Density and Durability of Pellets Made from High Moisture Corn Stover. Biosystems Engineering. 2014. 199, 45-57.*
- *Yancey, N.A., et al. 2013. Grinding and Densification Studies on Raw and Formulated Woody and Herbaceous Biomass Feedstocks. Journal of Biobased Material and Bioenergy, 7(5), 549-558.*

BIOMASS ENGINEERING: TRANSPORATION AND HANDLING

(WBS#: 1.2.1.3)

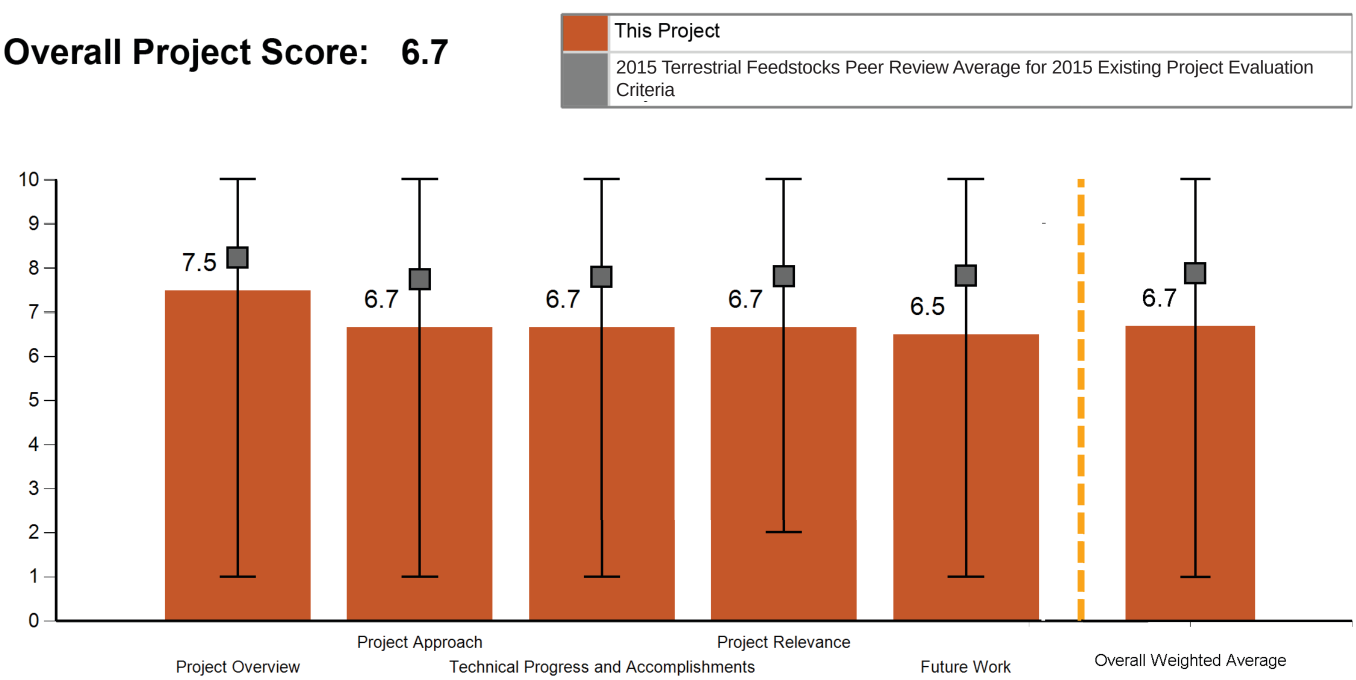
Recipient:	INL
Presenter:	Tyler Westover
DOE Funding FY14:	$63,483
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$136,517
Project Dates:	10/1/2014 - 9/30/2017

Photo Courtesy of INL

Project Description

Transportation and handling of biomass materials represent a substantial challenge in a biomass feedstock supply system. Conventional feeding, conveying, and storage systems are generally not suitable for lignocellulosic feedstocks, which typically have large particle size variations, low densities, and are highly compressible and/or elastic. A loss of even 5% of design capacity can be equivalent to an increase of $6 per dry ton of feedstock. The primary objective of this project is to provide and demonstrate solutions so that feeding and handling problems have minimal impact on preprocessing and conversion experiments, especially pilot-scale validations. The basic approach is to evaluate the feeding performance of selected materials that are prepared in separate feedstock preprocessing projects by testing these materials in feeding and handling equipment and also by completing full rheological characterization. This approach makes it possible to identify issues before

Overall Project Score: 6.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

feeding and handling equipment are coupled to subsequent processing equipment, such as conversion reactors. By verifying that feeding and handling equipment successfully handles a range of materials with known rheological properties, the feeding and handling performance of new materials can be predicted in the equipment to avoid costly and time-consuming repairs. The feeding performance of pine and switchgrass samples with various particle sizes and moisture contents have been assessed.

Overall Impressions

- Bench-scale equipment performance with a single feedstock is not particularly relevant when not tied to a specific need, nor a plan to test at production scale. Minimal ties to industry have meant that research results have not been implemented. It is unclear if this is because the research question did not address a true industry need or if results have not been adequately conveyed.
- The project is developing important baseline information to improve feedstock handling. This project sits very close to commercialization as the information will immediately inform manufacturers and plant designers. There needs to be closer collaboration with industry to facilitate the transfer of knowledge to application and to inform the key research questions that INL can pursue.
- I think it is appropriate to sunset this project. It may have accomplished the most critical work already.
- This is useful work, especially the planned activity to consider municipal solid waste (MSW).

PI Response to Reviewer Comments

- This project transitioned from fundamental R&D to applied R&D and has now ended. Future work in this area will be performed within WBS 1.2.1.2 (Size Reduction, Drying and Densification) and WBS 1.2.3.3 (User Facility). The objective was to establish a correlation between "simple" laboratory tests and feeding performance of high-impact biomass materials and then use the simple laboratory tests to provide early indication of flow problems as processes are developed/optimized. This avoids problems during scale-up, especially during conversion validations. This project collected the data to inform the solution, which will be implemented through the Biofuels National User Facility (BFNUF), which can more seamlessly engage industry collaborators and use the biomass process demonstration unit (PDU) as a test bed for developing and testing of a variety of feedstocks and feedstock conditions (i.e., moisture, particle size distribution, etc.).
- The objective of the project is too fundamental to be directly commercialized. MSW presents unique feeding challenges because its composition and physical properties are not consistent. The in-line assessment of feeding properties will be especially useful for MSW to assure in real-time that material plugging does not cause expensive feeding and handling problems.

INTERNATIONAL FEEDSTOCKS

(WBS#: 1.2.1.5)

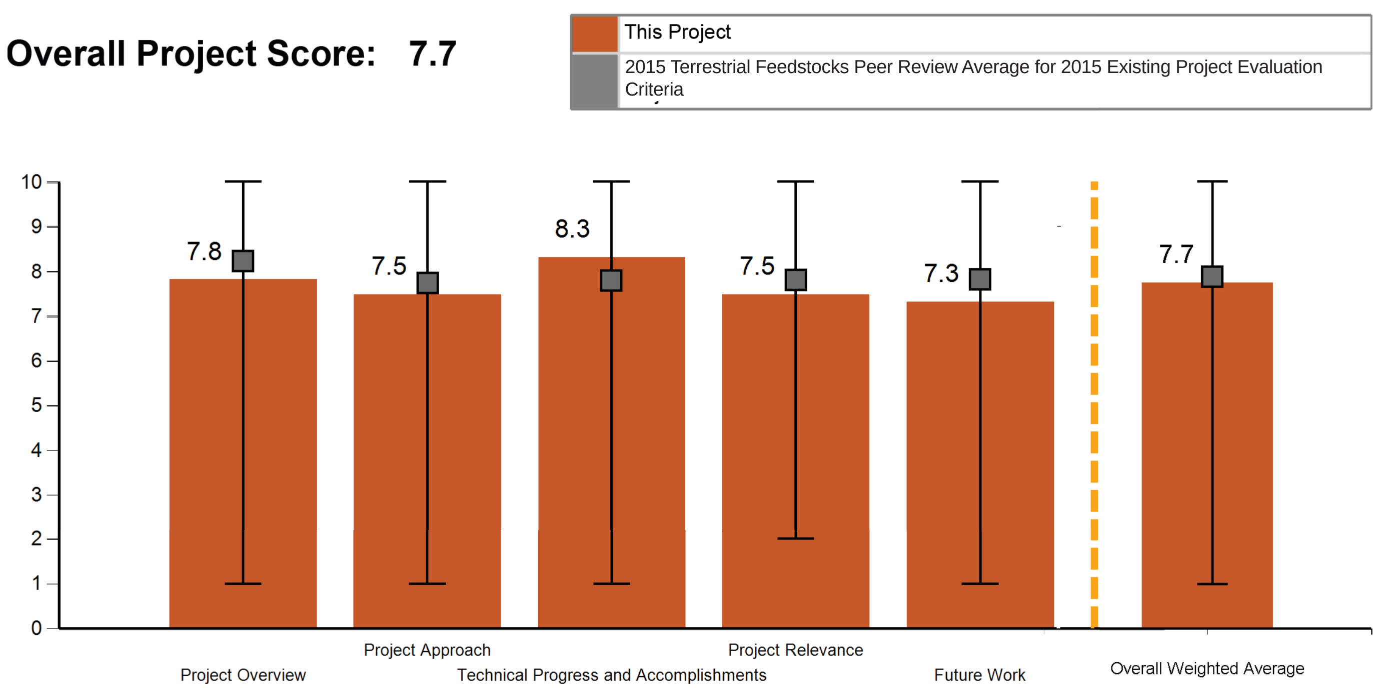
Recipient:	INL
Presenter:	Patrick Lamers
DOE Funding FY14:	$169,668
DOE Funding FY13:	$147,161
DOE Funding FY10-12:	$449,537
Planned Funding:	$433,634
Project Dates:	10/1/2013 - 9/30/2017

Project Description

This project places the U.S. bioeconomy strategy in the context of global, competitive feedstock markets. Evaluating international impacts on U.S. feedstock supply improves domestic projections and enables DOE or related U.S. agencies to take proactive measures to address potentially adverse trade and business impacts. The project leverages existing modeling expertise at INL and collaborations with other national laboratories and oversea partner universities to generate a stand-alone model. So far, INL's Biomass Logistics Model was successfully linked to Utrecht University's Biomass Intermodal Transportation System and was applied to market conditions in China and transport cost optimizations between the U.S. and the Netherlands. Work is underway to expand the model to other world regions and quantify the impact on U.S. feedstock prices and volumes. Given expected future demand from oversea regions U.S. targets, the $80 per dry ton delivered feedstock to the biorefinery in 2022 could be very difficult. The future U.S. trade portfolio will depend on the local value of advanced biofuels and U.S. producers' feedstock purchasing power. Oversea demand, however, could also help bridge the U.S. current, conventional system to an advanced feedstock supply system and long-term local use. A DOE workshop vetted this assumption as U.S. biofuels industry representatives concluded markets are a primary driver to enable a future billion-ton U.S. bioeconomy.

Overall Impressions

- The need for this project to feed into a holistic view of biomass feedstocks for BT16 is recognized. This project appears to be a positive driver for increased international collaboration. There are questions



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

regarding how model results are communicated to policy makers.

- This is an excellent project that is unique in bioenergy assessment. This work will lead to cutting-edge understanding of real-world effects.
- There are a lot of insights here. Markets will be a factor. It is time to look for external partners, in my opinion, or other ways to fund the work.
- This model/tool may have value, but I question BETO's support of this work. Perhaps, this would be better supported by DOE's Energy Information Administration (EIA).
- This project was well-presented and researched. The issue here is two-fold. First, this should be included in a broader understanding of competing uses for biomass, of which the trade portion is a critical contribution. Second, can other entities contribute funding or resources to the international trade segment, for example, Department of State or Commerce?

PI Response to Reviewer Comments

- INL acknowledges the need to engage a wider group of researchers and stakeholders. Moving forward, special attention will be paid to disseminate project results to other U.S. agencies with direct link to federal management.

ADVANCED FEEDSTOCK PREPROCESSING

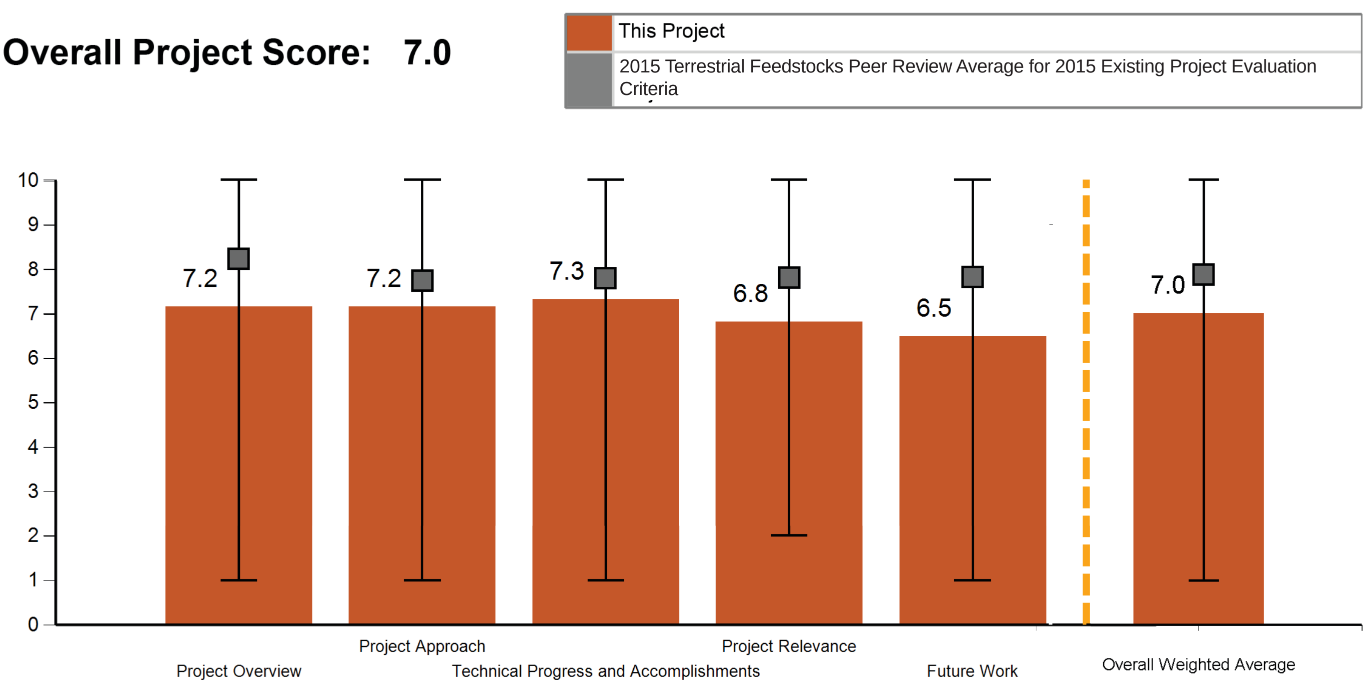
(WBS#: 1.2.2.1)

Recipient:	INL
Presenter:	David Thompson
DOE Funding FY14:	$1,521,703
DOE Funding FY13:	$1,732,577
DOE Funding FY10-12:	$3,823,742
Planned Funding:	$1,756,978
Project Dates:	10/1/2014 - 9/30/2015

Project Description

This project addresses feedstock cost/quality requirements spanning BETO-relevant feedstocks and conversion technologies. To minimize costs and address the $80/dry ton cost target, combinations of existing and new technologies and/or strategies are being investigated to minimize the need for treating large amounts of feedstock with costly technologies, or reduce the number and/or cost of other processing steps. To date, quality attainment performance data have been collected for mechanical and chemical ash management technologies as it relates to the Biochemical and Pyrolysis/Upgrading Thermochemical Pathways. These data serve as a basis for the development of predictive models that will extend these findings to other available feedstocks, including herbaceous, woody and municipal solid waste sources. In addition, to supplement the current data set, a literature review will be conducted to assess how certain manageable quality characteristics affect conversion costs and yields. Planned future work includes using existing and new data and results from the literature review to inform economic assessments to determine the cost of meeting a range of quality specifications using a variety of preprocessing methods. The model developed will, for the first time, enable the association of quality parameters with process costs and associated yields. Based on the results of this model, blends of feedstocks will be formulated that meet both cost and quality metrics.

Overall Project Score: 7.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The need for this project is not clear; therefore, the potential impact is also not clear. Researchers need to focus on answering the "so what?" question.
- The interaction of feedstock quality and net conversion cost is a critical aspect of efficient bioenergy operations. This work is delivering good basic knowledge that could impact design of systems. A key outcome is the realization of low-cost sorting/separation approaches coupled with blending to achieve optimal feedstock specifications.
- This is very good work, but something concrete needs to be explored for wastewater from ash removal to be pursued. I frankly do not see how that is remotely sustainable.
- This project needs to clarify its plan.

PI Response to Reviewer Comments

- This work is TRL 2-3 and not all possible options have been considered. We are not looking for point solutions because the meaning of quality depends on specific conversion processes. The preliminary case described, which considered deep well injection of small volumes of leachate, does not imply that it was the only case that would be considered. It was presented as an example of the complete approach to show how the data are used. We agree that deep well injection of large volumes of leachate would be unsustainable. In lieu of this, there are other options such as concentration via reverse osmosis, followed by land application of the concentrate to return the nutrients to the soil or precipitation and landfilling of the minerals.
- When considering the net cost of mitigating any quality attribute, undesired or unexpected consequences can be seen such as extraction of water-soluble simple sugars and proteins from feedstock intended for the fermentative biochemical platform. These are process-specific considerations that drive the need to consider feedstock quality attributes and quality mitigation methods individually for each conversion process. Without understanding conversion cost/yield trade-offs in comparison to quality mitigation process costs (and the cost of replacing other beneficial components that may be extracted along with the ash), making informed decisions on these questions is difficult and due diligence must be performed.
- Due diligence requires understanding the cost-benefit relationships for mitigating quality mandates, both prior to and following delivery to the biorefinery. The most popular approach to mitigate feedstock quality variation is through improved conversion process robustness; however, even the most robust conversion process cannot convert unconvertible material, and the observed wide variation in feedstock quality, both within feedstocks and between feedstocks, will challenge even the most robust system. Local and seasonal variations in feedstock availability will also challenge these systems. Another approach is through the development of dockages for not meeting quality specifications, and this approach is currently being developed at INL. However, dockages cannot entirely account for the cost of yield losses for a biorefinery, because observed feedstock quality variations are quite wide. Simply increasing the amount of feedstock processed requires additional capital and operating bandwidth that can exceed the capacity of an already-constructed biorefinery. Mitigating feedstock quality issues prior to the reactor throat, whether distributed in feedstock depots or within the biorefinery gate, is a third approach to meeting conversion platform quality mandates. Because the feedstock quality assumptions that conversion platforms use in techno-economic analysis are averages and do not account for the observed ranges of variation, it is unclear whether improved conversion robustness can deal with this variation without

adding significant CAPEX and OPEX. Hence, we are working to assign feedstock quality cost drivers for the conversion platforms first from the literature, and following this via direct collaboration with the conversion researchers. In this manner, we are trying to drive the development of cost-benefit relationships for meeting (or not meeting) feedstock quality mandates. This will provide a clearer picture of whether the issues can be more cost effectively addressed upstream or downstream of the conversion reactor throat, or through the application of dockages.

- Our project management plan, as required by BETO, has a three-year timeline for a range of project outcomes. We have quarterly milestones and a go/no-go decision point each 12-18 months, as required by BETO and EERE. We did not present this plan in detail due to the limited time available for the presentation.

BIOMASS FEEDSTOCK LIBRARY AND LEAST COST FORMULATION

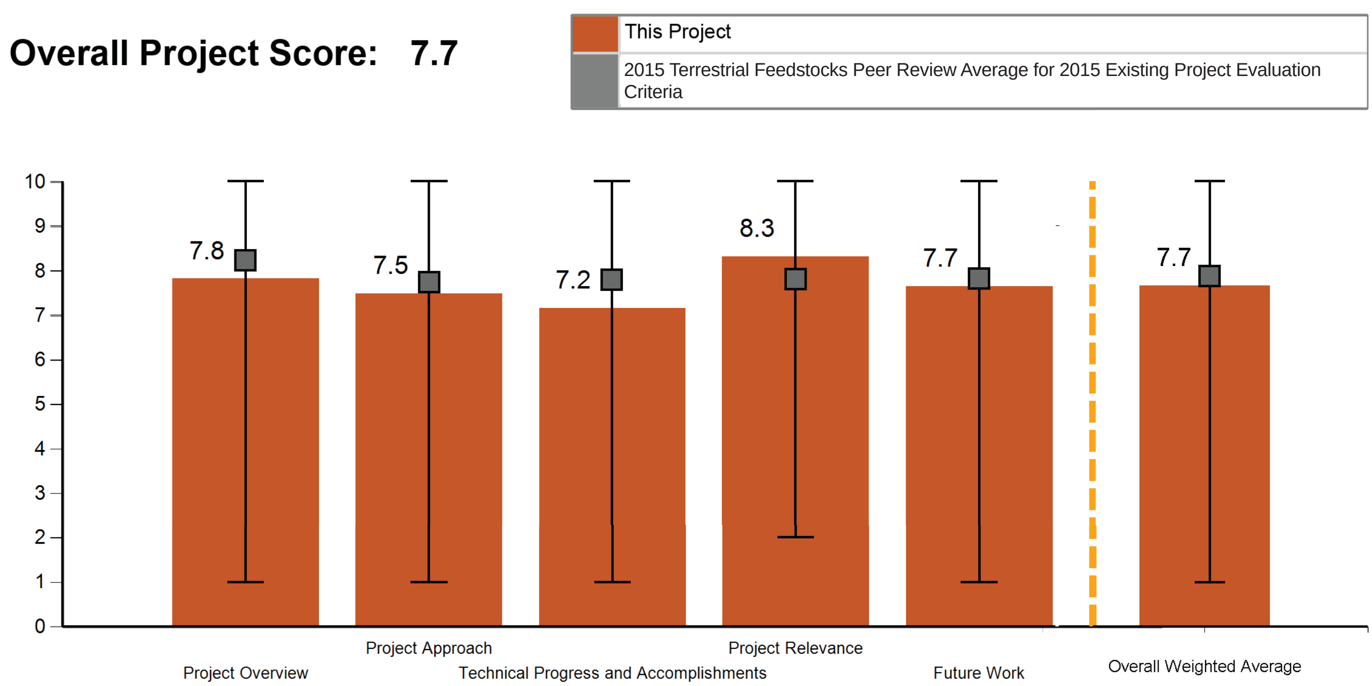
(WBS#: 1.2.2.2)

Recipient:	INL
Presenter:	Gary Gresham
DOE Funding FY14:	$715,519
DOE Funding FY13:	$683,244
DOE Funding FY10-12:	$698,606
Planned Funding:	$3,107,631
Project Dates:	10/1/2014 - 9/30/2015

Photo Courtesy of INL

Project Description

This project serves as a physical, data and knowledge management system for gathering, storing, recording, accessing, and analyzing critical information regarding biomass and feedstock resources for use in BETO research. The project has three primary objectives: (1) Collect/Manage Samples: Work with the Sun Grant Regional Partnership initiative and others to collect physical samples and sample data. Maintain a repository of biomass materials and process intermediates, which can be requested and used by researchers around the world. (2) Process/Information Management: Serve the international research community by supplying information gathered from samples, such as pedigree and history, operations, and chemical, physical, and conversion performance characteristics. A web-based application is used to manage the access of information and tools. (3) Analyze/Advanced Tools: Implement a program to utilize the data and elements associated with the Library to make effective decisions and answer ques-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

tions relevant to BETO research. This includes the least cost formulation blending models and meeting conversion specifications This project began as an initiative to track internal samples, but through partnerships with many BETO projects, this has evolved into a critical component of understanding feedstock variability and impacts to conversion technologies. The project is now investing in providing relevant and effective tools and reaching a larger audience.

Overall Impressions

- This is a key contribution of a national laboratory to the development of a biofuels industry. Keeping this data in a central location that is publicly available seems to be an appropriate role of a government laboratory. The utility and appropriateness of the "least cost" tool is questionable.
- This project has developed very solid data management, laboratory practices, and open distribution of information. There is significant value in a common feedstock reference set with properties derived through well-controlled analytical work. The project should carefully consider its functional purpose, however, to ensure that future work is meeting high-priority goals.
- This is a very strong project. It may need to watch for expansion of project goals, i.e., "mission creep."
- In general, there is a need for this type of work, e.g., collect sample, meta, and quality data in one place and the need for development of analytical tools. At the same time, there is a risk that trying to be all things to all people can cause the work to crumble under its own weight. Investigators might be a bit more selective as to what they are trying to do in terms of developing analytical tools, and perhaps more clearly identify what the future work deliverables will be.
- This is a valuable resource that is being carefully developed. However, the greatest measure of its value is its use, and this needs more work.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

FEEDSTOCK SUPPLY MODELING

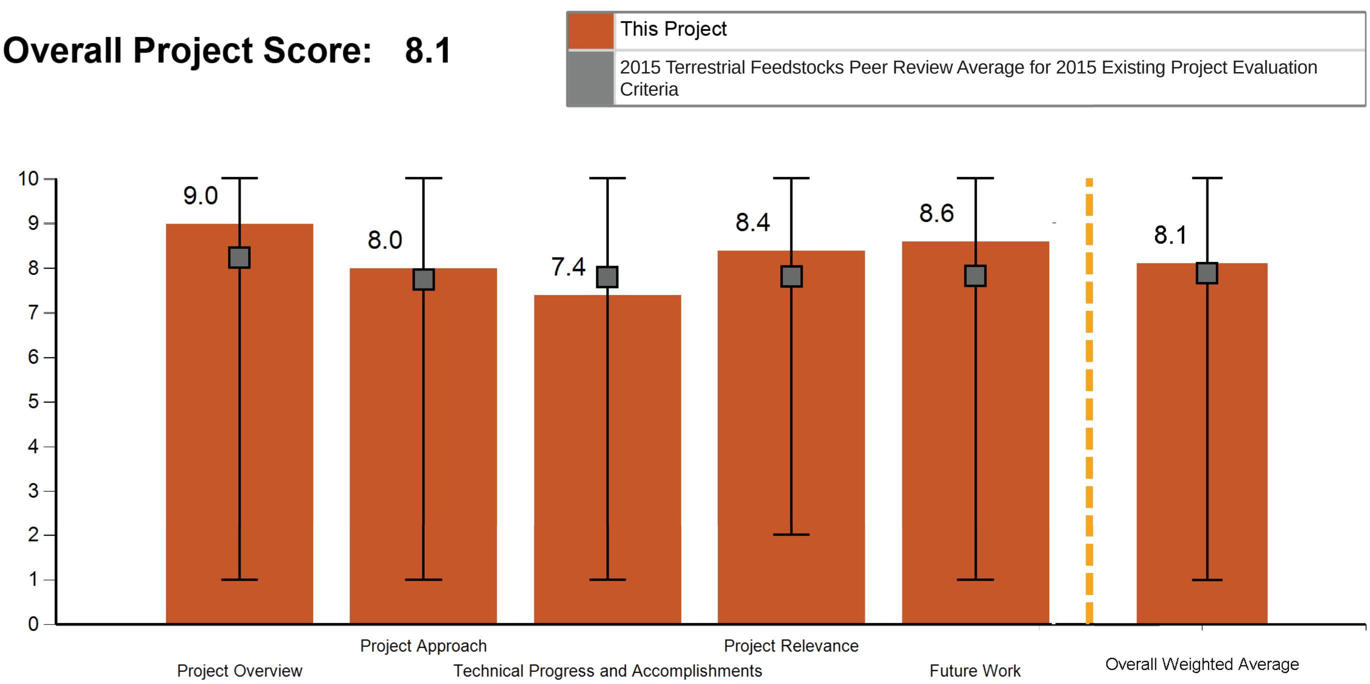
(WBS#: 1.2.3.1)

Recipient:	ORNL
Presenter:	Erin Webb
DOE Funding FY14:	$543,109
DOE Funding FY13:	$502,421
DOE Funding FY10-12:	$1,716,474
Planned Funding:	$3,271,444
Project Dates:	10/1/2010 - 9/30/2015

Project Description

Developing a commercial-scale industry capable of supplying one billion tons of biomass annually to produce fuels, power, and products sustainably and affordably will require careful consideration of the complex interactions along the supply chain. Improved biomass supply chains are needed to increase system efficiencies and capacities, preserve or enhance quality, and minimize the risks of supply disruption and cost fluctuations. Field trials are the best way to study equipment and process development, but they are expensive and resource intensive. As an alternative, simulation tools to evaluate the impacts of equipment and system performance are useful in identifying and prioritizing R&D, determining required resources, and estimating costs of commercial-scale systems. This project will develop simulations of terrestrial and algal biomass supply chains to estimate costs of commercial-scale systems based on demonstration and research data; and quantify impacts of variability and uncertainty, and predict moisture changes along the supply chain. To explore the impacts of spatial variations in feedstock cost and availability and transportation options, results of these supply chain simulations were used in a spatial analysis methodology and a transportation/siting model linked with advanced visualization tools. The primary challenge of this research, obtaining full-scale equipment performance data, is addressed by building relationships with industry, labs, and academia.

Overall Project Score: 8.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- Overall, the project is a useful integrating activity and should continue to focus on improving input data to represent realistic business scenarios.
- Overall, this is a good project. The team is responding to current needs and refining their analytical tools to reflect state-of-the-art.
- BETO has accomplished a lot with its modeling work and has led the way in many important aspects. This is a good time for BETO to commit itself to developing linked, verified, tested models that describe the economic and environmental performance of managed bioenergy systems all the way from the sub-field scale to the national scale. These models are needed also to bring along the rest of the society. We have to show how sustainably managed bioenergy systems can help achieve national economic and environmental goals.
- The structure and approach is quite solid, but this project is all about getting ground-truthed data. I see a major weakness around the data for the logistics portion that needs to be improved. As the presenter mentioned, models can be made around anything, but the relevance has everything to do with the data and assumptions informing the model.

PI Response to Reviewer Comments

- Thank you for the encouraging and constructive feedback from the reviewers. We appreciate that the reviewers recognized our efforts to construct high-quality, accurate simulation models for better understanding of the impact and challenges of biomass supply chains. We agree that a key factor to success of this project is to base analyses on commercial-scale data. To do this, we are continuing efforts to build and strengthen partnerships with feedstock suppliers and biorefineries for knowledge and data sharing.

DEMONSTRATION OF AN ADVANCED SUPPLY CHAIN FOR LOWER COST, HIGHER QUALITY BIOMASS FEEDSTOCK DELIVERY

(WBS#: 1.2.3.106)

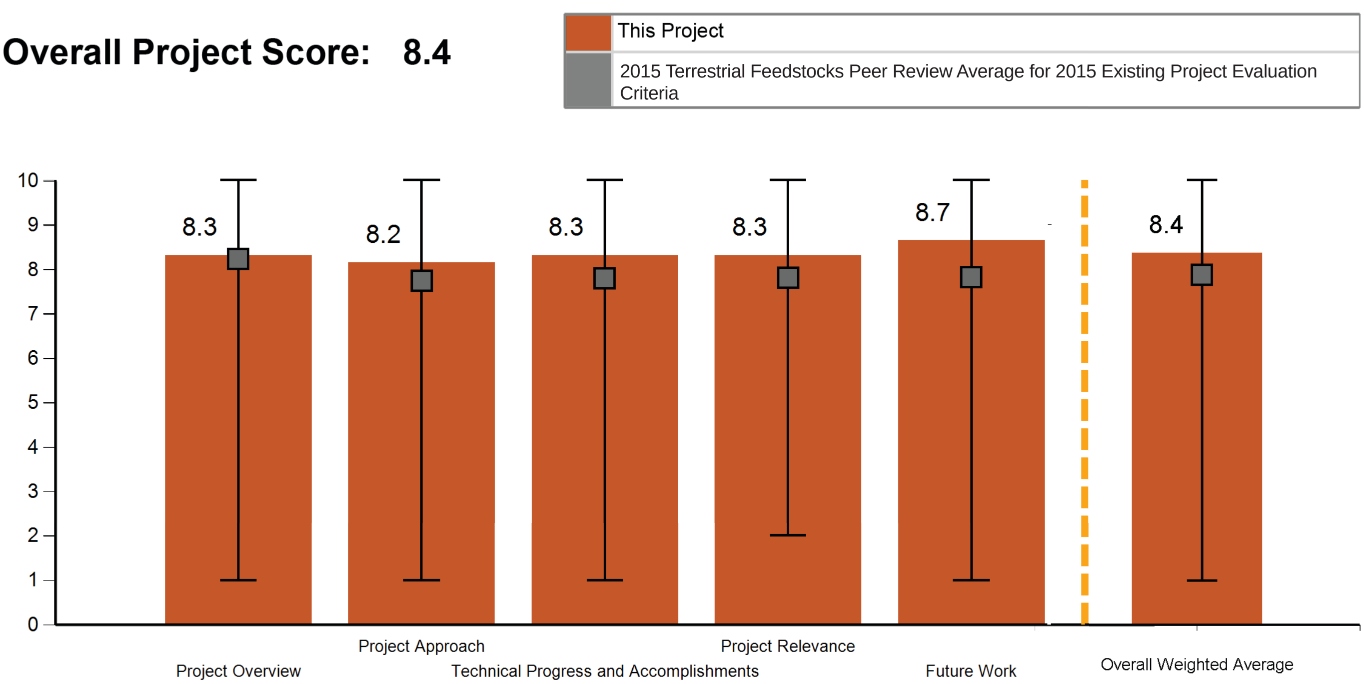
Recipient:	FDC Enterprises
Presenter:	Fred Circle
DOE Funding FY14:	$1,282,948
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,117,052
Project Dates:	10/1/2013 - 9/30/2016

Photo Courtesy of FDC Enterprises

Project Description

This project will demonstrate an advanced biomass supply chain for high impact, high quality feedstocks from the field to the throat of a biorefinery. In doing so, the project will address nearly all of the technical barriers identified by BETO. Furthermore, this project builds on the earlier supply chain innovations of project team members to reduce feedstock costs. This work highlighted key gaps throughout the supply chain, where biomass harvesting and processing costs could be further decreased while maintaining the end user's feedstock quality specifications. This effort includes designing and deploying new systems associated with end-use processing (new milling equipment, advanced bale handling, Near Infrared (NIR) monitoring and sampling, etc.); further refinement of feedstock production equipment developed and demonstrated under prior efforts and testing by this and other project teams; and demonstration of new feedstock harvest and logistics equipment. Importantly,

Overall Project Score: 8.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

this includes development of equipment and processes to provide biorefiners and harvesters the flexibility to produce and use round and/or square bales more efficiently and cost-effectively than it is possible using today's "off the shelf" conventional equipment. The project has designed, fabricated, and tested several new equipment innovations, conducted commercial-scale biomass harvest demonstrations, developed and tested new methods for analyzing biomass feedstocks with NIR, and assessed soil sustainability impacts.

Overall Impressions

- The development of a NIR probe for in-field estimation of feedstock quality metrics has the potential to be of large benefit to existing markets/producers, if the technology can be brought to market.
- The project is a reasonable continuation of the high tonnage investments in herbaceous feedstock production systems. The overall project appears to be leading to a suite of prototype concepts that are still far from commercially viable production.
- Commercially available equipment is ready now or will be in the short term. The Technology Readiness Level (TRL) is around 7. Is it time to taper off these projects and invest elsewhere?
- This project is a continuation of an earlier funded project. Much of the background is the same as discussed earlier. The project goal is to assess cost reduction.
- This project has a very ambitious scope, especially when it comes to equipment, but it is a continuation of a previous project that produced some progress. The commitment by the project participants to move all these complex parts forward is quite admirable. Even if a small part of this effort proves commercially successful, it will have been a very worthwhile project.

PI Response to Reviewer Comments

- This project is focused on developing and demonstrating equipment improvements across the entire herbaceous biomass supply chain for square and round bale systems. The design/equipment improvements under development by the project team span a continuum ranging from important but incremental improvements to existing technology (e.g., improved biomass pick-up mechanisms for balers, improved bale density capabilities from balers, design changes that reduce in-field downtime and maintenance), to entirely new equipment to perform the needed operations in significantly different ways than existing commercial equipment (e.g., new bale gathering vehicles, new bale hauling trailers, new harvesting equipment, new process and handling equipment for pre-processing operations, new NIR-based biomass quality instrumentation, etc.). As such, the commercial-readiness of our team's developments (even at the end of the project) will range from developments that are already commercialized and in the market place during the project period (this has already occurred for several pieces of equipment from project team members), to prototype equipment that has demonstrated the technical capability to improve one or more supply chain operations significantly, but that will still need further refinement beyond the project period before being commercial-ready.
- The reviewer's question, "Is it time to taper off these projects and invest elsewhere?," is a good and valid question and is one that should be asked often about all government R&D investments. It is our team's strong opinion that it is far too early to turn away from feedstock supply chain R&D. DOE has only recently (within the last five years) begun to invest in near-term deployable feedstock supply chain improvements and the industry is just at the front end of potential supply chain improvements. The volumes of herbaceous biomass that will need

to be harvested, managed, and processed to feed commercial-scale biorefineries are far beyond what has been done to date for corn stover and herbaceous energy crops in a single region, year after year. The rate of innovative technology development in the needed supply chain improvements has been, therefore, very modest for decades, and has consisted mostly of incremental changes to existing equipment, and mostly for forage biomass, which is much easier to harvest. At some point in the future, when an established and significant cellulosic biofuels marketplace exists, it will be more appropriate to taper off government investments in supply chain R&D because near-term market opportunities will drive more private sector investment in supply chain technology advancements. Until such time, as there are multiple commercially operating biorefineries at large scales and with several years of successful commercial operations, the rate of R&D investment in innovative supply chain improvements will be dampened without Federal support. Few, if any, of the improvements developed by our project team (and the other supply chain logistics projects) would have been completed or under development without Federal support. The required investments in the absence of a large existing market for the resulting equipment would have been too high if all of those costs were borne solely by equipment OEMs (we have heard this repeatedly from OEMs), and the improvements DOE is targeting (for cost reductions and quality improvements) are necessarily very aggressive. Every bioenergy project is dependent on its supply chain and benefits in improvement in supply chain performance (cost, quality, and reliability) ripple, which sometimes multiplies throughout the conversion process. A poor supply chain can cripple a conversion process, technically and economically. We believe a strong argument can be made that supply chain improvements have been an area that has received inadequate funding to date, and this area is still ripe for improvement.

BIOMASS - FEEDSTOCK USER FACILITY

(WBS#: 1.2.3.3)

Photo Courtesy of INL

Recipient:	INL
Presenter:	Kevin Kenney
DOE Funding FY14:	$0
DOE Funding FY13:	$2,484,882
DOE Funding FY10-12:	$9,091,477
Planned Funding:	$2,935,663
Project Dates:	10/1/2014 - 9/30/2017

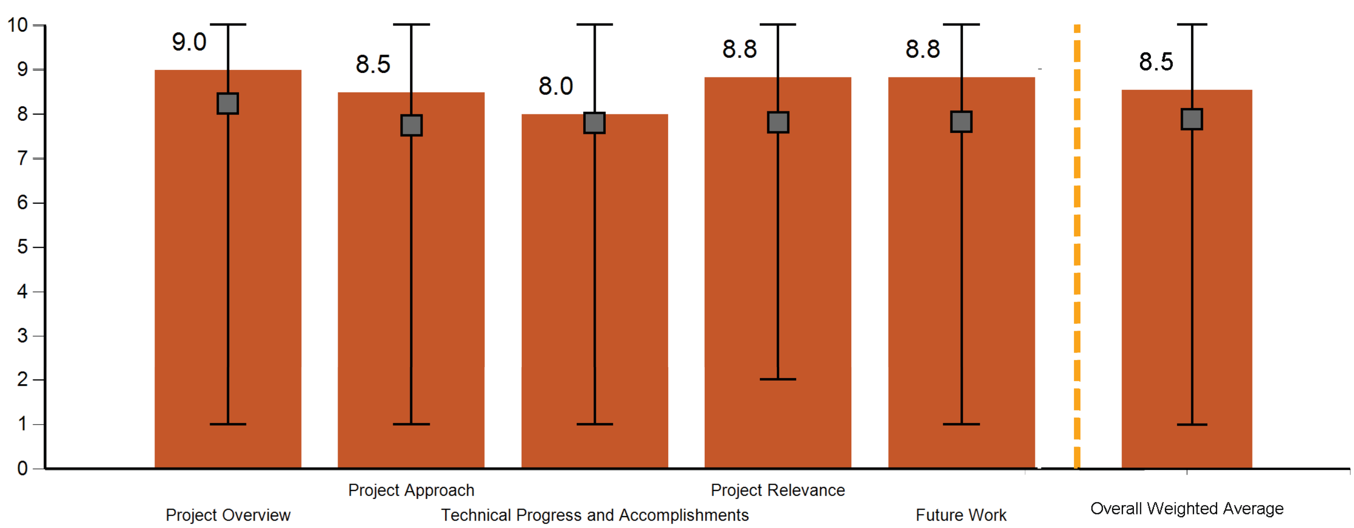
Project Description

This project focuses on the scale-up and integration of biomass preprocessing technologies and systems for the purpose of accelerating commercialization of bioenergy technologies. The User Facility provides a mechanism to engage industrial, educational, and other federal entities in collaborative research, testing, and demonstration through access to BETO developed feedstock preprocessing and characterization capabilities. The flagship of these capabilities is the Biomass Feedstock Process Demonstration Unit (PDU), which consists of collection of preprocessing machinery that is used to: (1) process feedstocks for conversion testing; (2) develop preprocessing designs and specifications; and (3) test and demonstrate improved preprocessing equipment and systems. Supporting capabilities include the characterization of chemical and physical properties to provide material datasheets for feedstocks produced and supplied. These collaborations are structured to advance the achievement of BETO goals while reducing risk and accelerating commercialization of industry technologies.

Overall Project Score: 8.5

This Project

2015 Terrestrial Feedstocks Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The User Facility fulfills a clear need within a growing bioenergy market and, if DOE's goal is to grow and support this industry, it makes a useful contribution. As demand for the facility increases, INL needs to develop a clear process for setting goals and evaluating proposed work so as to continue working toward DOE's goals while meeting industry needs. This project has the potential to significantly increase INL's communication with industry and, if this communication is used wisely, improve the relevance and dissemination of research results.
- The transition to a User Facility is good recognition of its function and purpose. The management approach has been modified to deal with the unique requirements of customer service. The project appears to be meeting performance and utilization goals. While utilization is an important metric, another important performance measure is the total cost of the User Facility and the percentage covered by user fees.
- This is top quality work and of the highest importance.
- Biomass Feedstock User Facility is a good project, leading to development of a National User Facility (NUF), which should be self-funding in the future.
- This is a great project and asset for the industry. The challenge is clearly utilization and the effective marketing of the facility's value proposition.

PI Response to Reviewer Comments

- BETO has recognized a core competency of the Idaho National Laboratory (INL) in scale-up and integration of biomass preprocessing technologies and process design. The foundation of this core competency is the PDU, which is a one-of-a-kind full-scale, integrated preprocessing system. The PDU is used extensively for preprocessing RD&D, feedstock supply for a large number of both BETO- and industry-funded projects, and scale-up and integration of feedstock preprocessing systems. This core competency is further supported by the EERE designation as a National User Facility in FY13. The User Facility designation was intended to increase the industry engagement and commercial impact of INL by providing industry access to unique and advanced equipment (such as the PDU), instruments, and world class scientists and engineers.
- The User Facility funding provides open access for non-proprietary research, development, and testing. These projects are qualified based on their ability to: (1) advance the achievement of BETO goals and mission; and (2) advance collaborator's efforts in development and commercialization of biofuels, bioproducts, or biopower technologies. The User Facility funding also supports INL-directed projects that are high-impact and highly focused on BETO's mission. These projects, by design, utilize User Facility collaborations to expand technical expertise, reduce project costs, shorten project schedules, and increase project impact.
- Without DOE funding, only those with the ability to pay would have access to the Laboratory capabilities. These projects would be proprietary, with the value and impact primarily realized by the project sponsor. The ability of the Laboratory to engage industry for advancement of DOE's mission and national benefit would also be limited. The ability to provide open access and to engage industry in collaborative work extends benefits to a broader set of stakeholders and ultimately provides the greatest impact to DOE and our nation.

US-INDIA CONSORTIUM FOR DEVELOPMENT OF SUSTAINABLE ADVANCED LIGNOCELLULOSIC BIOFUEL SYSTEMS

(WBS#: 2.5.2.7)

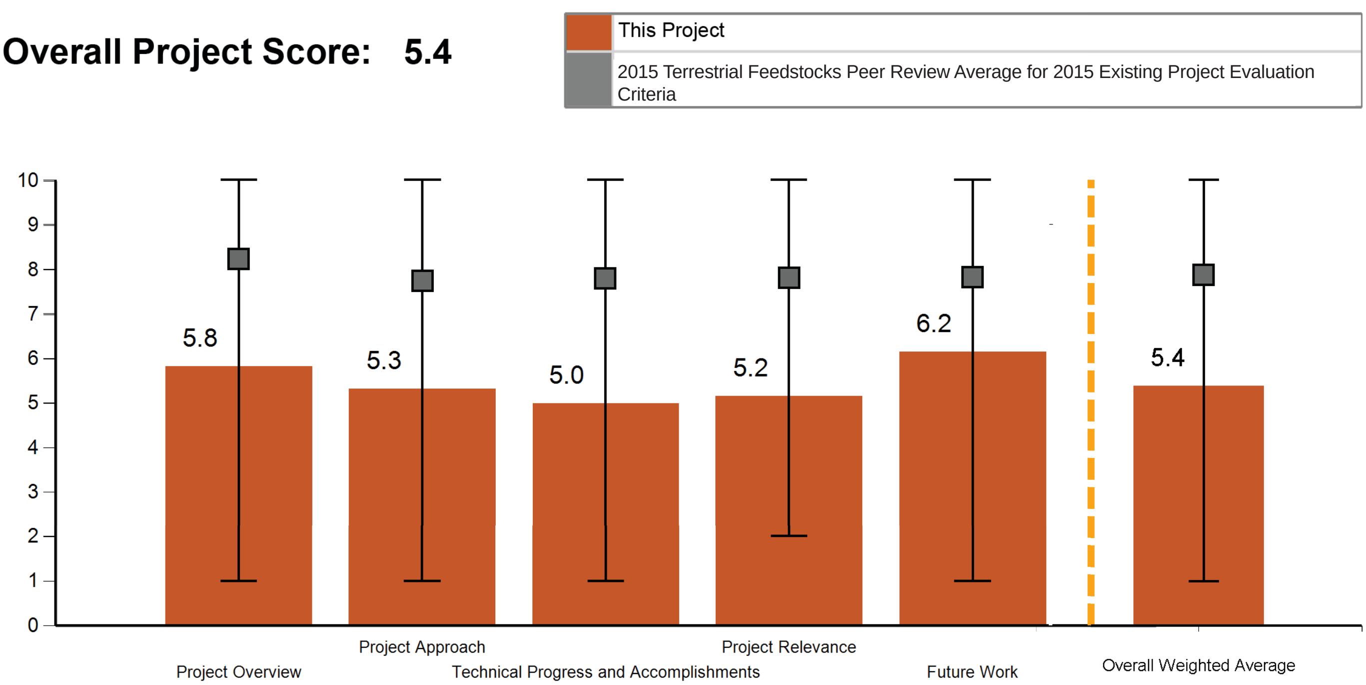
Recipient:	University of Florida
Presenter:	Wilfred Vermerris
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$811,184
Project Dates:	9/18/2012 - 9/17/2017

Photo Courtesy of University of Florida

Project Description

This project is a collaborative effort between institutions in the U.S. and in India that participate in the US–India Joint Clean Energy Research & Development Center. It emphasizes sustainable feedstock cultivation and supply, biochemical conversion technologies for production of second generation biofuels, and analysis of sustainability and supply chain management. The specific objectives of the U.S. component of project are to: (1) genetically improve biomass-sorghum feedstocks to generate cultivars and hybrids adapted to flooding or drought; (2) use switchgrass research plots on commercial farms to identify soil and environmental criteria that will ensure commercially successful feedstock production on marginal lands; (3) develop novel microbial biocatalysts for the production of butanol from switchgrass and sorghum biomass; and (4) develop products from biorefinery residues that minimize environmental impact and maximize revenues. Furthermore, a sustainability analysis is being conducted, which includes development of certification protocols and sustainability standards, assessment of energy requirements and emissions, and economic analyses as the basis for successful supply chain management. Successful completion of the

Overall Project Score: 5.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

project is expected to result in benefits for both U.S. and India by delivering a validated commercial working model for feedstock production and supply, biochemical conversion and affiliated biorefinery technologies, as part of an integrated sustainable supply chain.

Overall Impressions

- Testing the feasibility and yield of energy crops for marginal lands is a laudable goal and one that should be explored; however, without extensive reevaluation of the scope of the project and realistic milestones, significant barriers make the chance of success in this case exceedingly low.
- The project offers preliminary analysis of the concept of bioenergy production on low-productivity sites with selected plant materials. This could be an important contribution to feedstock knowledge. The conversion work seems only moderately integrated with the feedstock component.
- I saw nothing in the entire presentation about the joint work with India. In spite of heroic efforts on the part of BETO and the current PI, this project is really weak in a number of ways.
- This project has lacked from the beginning. I do not see the relevance, nor the contribution of India.
- Given the challenges and set-back that this project has endured, I am not confident that this project should continue to receive support.

PI Response to Reviewer Comments

- The PI thanks the review team for their effort in evaluating the project. This project addresses the production, processing, environmental and economic aspects of bioenergy production on low-productivity land. This is an inherently challenging topic, but, as acknowledged by the review team, represents a laudable effort that can have a major impact on sustainable bioenergy production in both the U.S. and India.
- At this stage of the project, the foundation for the individual components of the project has been laid, and the integration can begin. The integration between feedstock production in Missouri and processing in Florida has admittedly been challenging due to the need to establish the production sites and by the large distance. The availability of established sites in Missouri will enable the analysis of switchgrass composition as a function of harvest time, site, and crop management. The integration between the production and processing will benefit from the now stronger emphasis on the processing of sorghum biomass, generated closer to the biorefinery, thus reducing logistical challenges. Once production and processing data are available, the framework economic and environmental models can be further developed, so progress is also anticipated in these areas.
- As pointed out by several of the reviewers, this project is indeed part of a collaborative arrangement between the U.S. and India. The project teams in the two countries are, however, funded by their respective governments. The presentation during the review process focused on the U.S. efforts, since that is the component funded through BETO. In the interest of time, the interactions with India were not highlighted, and, regretfully, this appears to have created the impression that the interactions with India have been limited. Since the project inception, a delegation of 25 scientists from India has visited the U.S., one Indian scientist spent four months at the University of Missouri as part of an exchange; a group of 10 U.S. scientists visited India; and there have been several individual visits of U.S. scientists to Indian partner institutions, including one trip for the purpose of teaching a course. In addition, there have been several conference calls between smaller groups of researchers. These interactions have enabled exchange of information, identification of common challenges, as well as differences between the two countries in the context of bioenergy produc-

tion. The greater emphasis that is now being placed on sorghum is expected to improve the interaction with the Indian team, because sorghum is the common feedstock between the two countries. Exchange of sorghum germplasm is being planned so that available resources can be maximized. Trips to India later this year by U.S. researchers leading Work Package 3 will focus on challenges associated with the implementation of large-scale bioenergy production in India, based on models developed in the U.S. They will also lead focus group discussions involving Indian producers and industry representatives. This is expected to further strengthen the ties between the two teams.

- In summary, while there are obvious challenges associated with this project, the revised research plan and planned interactions within the U.S. team and between the U.S. and Indian teams are expected to generate worthwhile data, as well as models that can guide large-scale implementation of bioenergy production in the two countries.

RESEARCH AND TECHNOLOGY DEVELOPMENT FOR GENETIC IMPROVEMENT OF SWITCHGRASS

(WBS#: 7.1.2.5)

Recipient:	University of Rhode Island
Presenter:	Albert Kausch
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$1,500,000
Planned Funding:	$0
Project Dates:	10/1/2008 - 9/30/2015

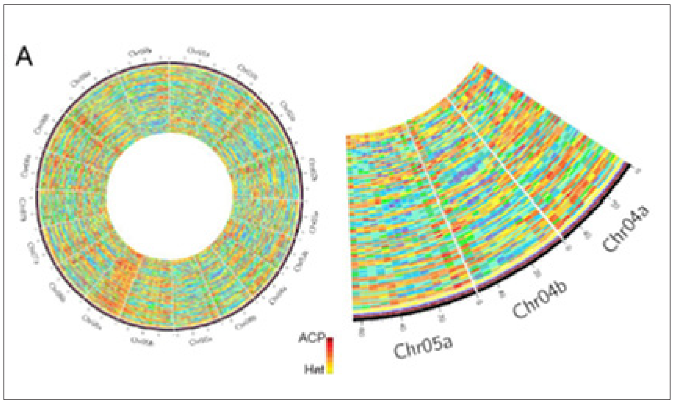
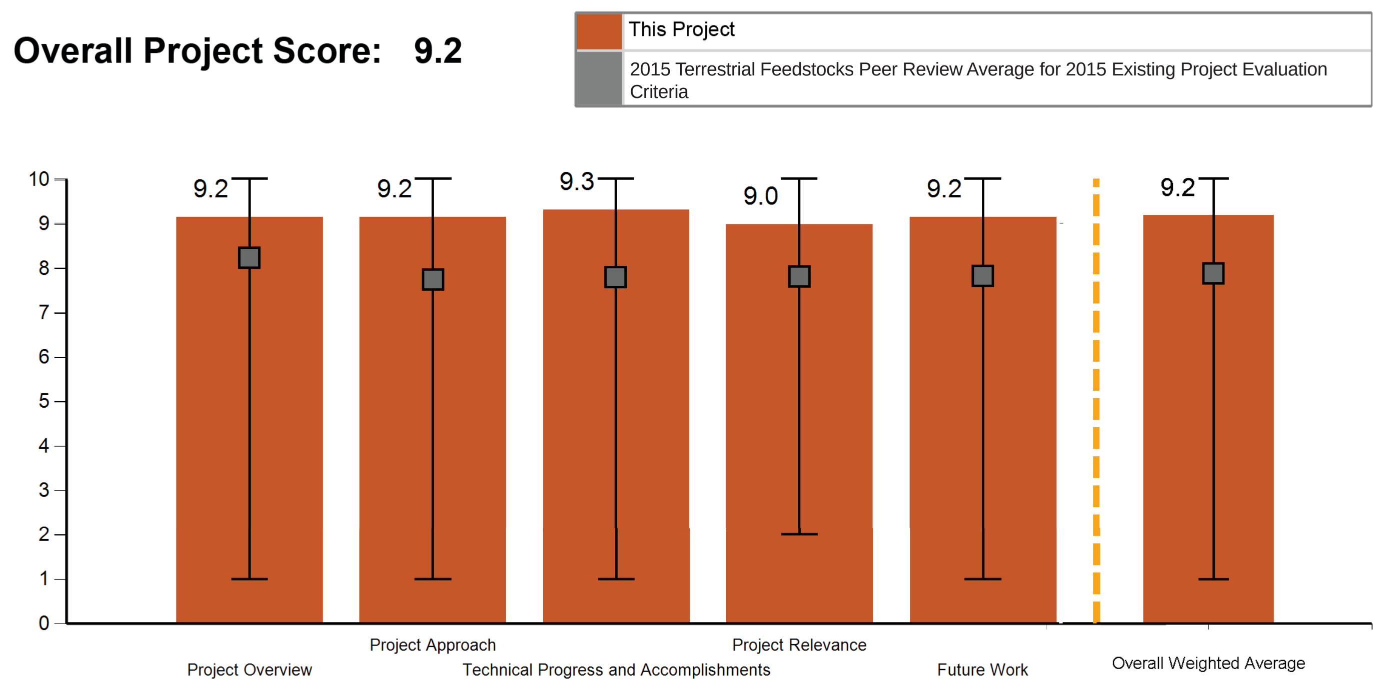


Image Courtesy of University of Rhode Island

Project Description

The overarching goal of this project is the development of technology leading to commercial switchgrass hybrid varieties engineered for enhanced, low-cost conversion of cellulosic biomass to liquid biofuels. Another goal is the development of intellectual property that is widely applicable to bioenergy and agricultural crops. This project was conceived through the collaboration of academic and industry researchers at the University of Rhode Island, Yale University, and Ernst Conservations Seeds, Inc. The goals are to meet the need for technology development related to new bioenergy cultivars, and gene confinement for genetically modified organisms (GMO) trait for improved crops and new technologies to create novel non-GMO hybrids. In this project, we have discovered new technologies to develop hybrid plants and the technology to use transgenic intermediates to create non-GMO wide crosses. One of the technical



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

achievements of this project has been the deployment of Genotyping-by-Sequencing (GBS) technology in collaboration with the Yale Genome Center to verify our results. The challenges remaining are involved with the commercialization and, hence, implementation of these technologies. The outcome of this project has been technology to generate non-GMO hybrid plants, which has been patented and is in the process of being licensed. In addition, peer reviewed papers and several talks at conferences have been given on this work.

Overall Impressions

- Project goals and milestones have been met with clear, marketable results.
- This project presents a novel approach in plant development that offers potential for feedstock improvement. Applications are certainly reasonable, but the ultimate value needs further development to realize potential.
- Amazingly good outcomes with clear commercial path forward.
- Interesting technology and valuable project focused on switchgrass.
- I have high hopes that this project can receive additional support to continue. It is very exciting with great potential for commercial application.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

BIOMASS FEEDSTOCK REGIONAL PARTNERSHIP

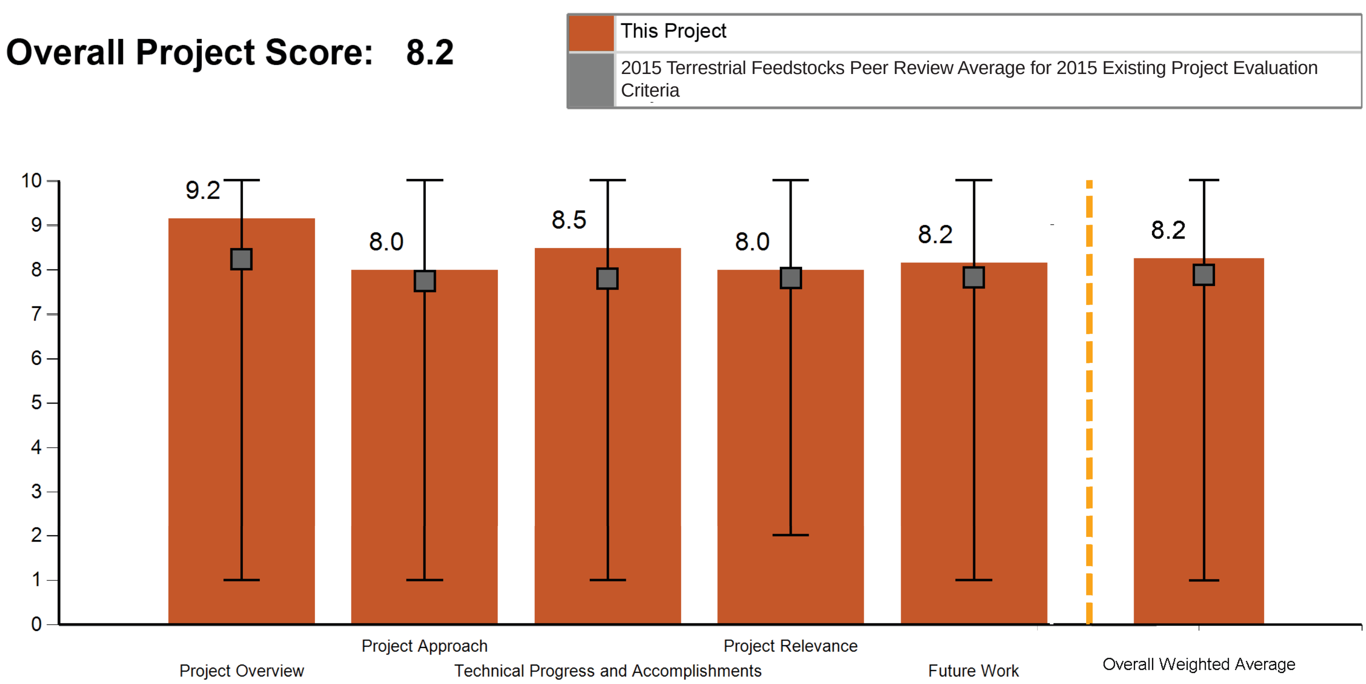
(WBS#: 7.6.2.5)

Photo Courtesy of Sun Grant Center

Recipient:	South Dakota State University, North Central Sun Grant Center
Presenter:	Vance Owens
DOE Funding FY14:	$1,752,736
DOE Funding FY13:	$3,670,939
DOE Funding FY10-12:	$11,236,894
Planned Funding:	$2,572,457
Project Dates:	10/1/2005 - 9/30/2016

Project Description

The purpose of this project is to help develop more accurate feedstock cost supply information and improved communication with partners in the biomass feedstock supply chain. To accomplish this, replicated field trials were established across regions to determine the impact of residue removal on future grain yield and to develop energy crops within geographical regions. Further, a regional assessment of feedstock resources is being completed to determine feedstock supply curves. Field trials of corn, switchgrass, miscanthus, sorghum, energy cane, conservation reserve program (CRP) land, poplar, and willow were initiated in 2008, with some sites coming online one or two years later and some sites being planted before 2008. Corn and sorghum final work was reported at the 2013 Peer Review and will not be reported in this review. Much of the data from these trials has been uploaded to the Knowledge Discovery Framework (KDF) and additional data will be uploaded in the future. A primary outcome is multi-year production data for key potential biomass feedstocks. BioWeb (http://bioweb.sungrant.org/) is an important outreach component of



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

this research. Numerous other outputs, including peer-reviewed publications, book chapters, proceedings papers and abstract, have been produced as a result of this work.

Overall Impressions

- Overall, an important start to understanding yields over short time periods (5-7 years) of key biomass crops in likely growing zones. More work is needed to understand longer-term yields, economics, sustainability, and growth across climactic ranges. This will take a long-term investment, specifically with regard to woody crops.
- This project is a good example of a coordinated research effort. The results have greater impact and validity given the wide range of field trials and the replication of measures across multiple sites.
- The synthesis effort is critical to draw together broad conclusions and to extract the most meaningful information from this investment.
- The project review raises the question of the opportunity to establish some subset of representative trials for ongoing measures and growth and yield (G&Y) studies. Can measures of sustainability be incorporated into future projects like this to achieve a comprehensive assessment of sustainable feedstock production?
- If DOE continues to fund this work, it will be critical to approach the work with the needs of the model coming first, i.e., not what the agronomists want to measure or are used to measuring, but what the modelers need to fill in the blanks for the system across the country. How well can the models predict yields, nitrogen fluxes, soil carbon, etc.?
- This project leaves a very positive impression. The long term nature of this project is viewed favorably and it gives temporal dimension.
- I would like to see greater discussion, such as the detail of PRISM modeling. Clarification of assumptions would be encouraged for any published results/estimates for maps. How definitive is the mapping results?
- This is breakthrough work from which the bioconversion industry will benefit for decades. It is, however, baseline work on which much more can and should be developed. Excellent job.

PI Response to Reviewer Comments:

- One of the unique and important efforts of this partnership was the face-to-face meetings between each species team and the modelers. Participants from all field trial sites were represented at this meeting, allowing for extensive exchange of information and ideas related to the model predictions.
- We agree and appreciate the long-term support for this project. Species were selected to try to maximize impact of the broader effort. We look forward to releasing the synthesis report to demonstrate key findings and also to identify important next steps.
- We are very appreciative of the support for this project, but also recognize the need for continued testing on specific long-term sites to understand G&Y issues. We also understand the importance of sustainability indicators, and these measures could be evaluated further with available funding.
- The support for this project over the past number of years has helped document the long-term dynamics of these woody crop systems and other perennial species. Continued support would build on this base, thus accelerating their deployment as purpose-grown energy crops. Monitoring woody crops at a commercial scale will establish the capacity to assess not only productivity, but also incorporate economic and sustainability assessments. Extended investment in this program, especially at a larger scale, will further reduce

risk for producers, enable evaluation of conversion performance in different technology platforms, and increase confidence to expand these systems across the landscape. Finally, the Feedstock Regional Partnership investment is important in maintaining the nation's ability to continue genetic improvement and to rapidly introduce new varieties into the marketplace.

- The temporal dimension is critical to the success of this industry. PRISM modeling efforts will be included in the synthesis report. Further, general model assumptions and conditions accompany the maps in order to reduce misuse or misrepresentation.

BIOMASS FEEDSTOCK REGIONAL PARTNERSHIP

(WBS#: 7.6.2.6)

Recipient:	South Dakota State University, North Central Sun Grant Center
Presenter:	Vance Owens
DOE Funding FY14:	$1,335,507
DOE Funding FY13:	$2,477,825
DOE Funding FY10-12:	$5,856,074
Planned Funding:	$1,280,202
Project Dates:	10/1/2008 - 9/30/2015

Photo Courtesy of Sun Grant Center

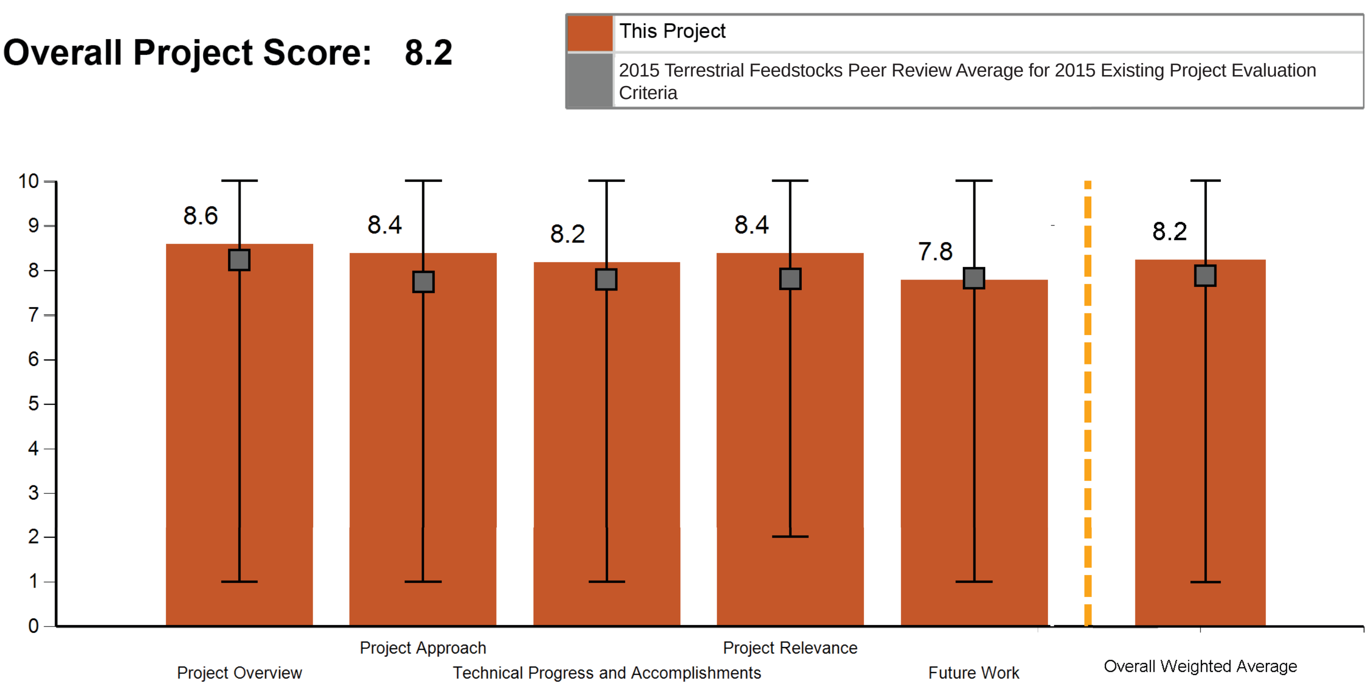
Project Description

The purpose of the this program is to utilize a congressionally directed DOE project at South Dakota State University (SDSU) and the North Central Regional Sun Grant's Competitive Grant program to address key issues and research gaps identified via the Sun Grant/DOE Biomass Feedstock Regional Partnership. South Dakota State University agreed to employ the North Central Regional Sun Grant Center to administer a competitive grant program supporting the Regional Biomass Feedstock Partnership utilizing the Sun Grant's authorization as a guide. Research that has been funded is germane to the sustainable production, harvest, transport and delivery of cost-competitive, domestically grown biomass. To date, 18 competitive projects have been funded in 11 states and 9 SDSU internal projects have been awarded. In addition, the Partnership recently awarded three Proof of Concept projects through an internal competition. These 30 projects have covered a diverse array of topics.

Overall Impressions

- Overall, this seems to be a successful grant program. Multiple small awards appear to have allowed researchers to test concepts that have led to larger competitive grants. I suggest administrators look

Overall Project Score: 8.2



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

for ways to integrate lessons learned across many disparate projects.

- This project demonstrated solid management of a research program to achieve the MYPP goals. The approach likely connected a set of the research community that would not have been engaged in these topics without this program.
- This is an excellent, comprehensive project. It needs to be continued with fewer sites and more instrumented sites. It needs to collect energy input data.
- Sun Grant projects continue to contribute valuable information across the intersection of agriculture production and bioenergy. Proof of concept work leads to promising future work. It is important to follow up with PIs after projects end to recognize effects or impacts of research.
- I suspect that these regional partnerships provide a very effective use of project funds given the proximity to the work. It would be disappointing not to find a funding mechanism to advance the more promising portions of this work.

PI Response to Reviewer Comments

- We are developing a database of projects funded under this program, part of the reason for which is to determine the ways they may connect across the bioenergy supply chain.
- Finding a funding mechanism to advance the more promising portions of this work would be welcomed because some of the work has had tremendous impact on the industry as a whole.
- We have in the past and continue to follow up with PIs who have received funding under this award. We recognize that impacts of good projects will often be seen after the actual research is completed.

DEVELOPMENT OF A WET LOGISTICS SYSTEM FOR BULK CORN STOVER

(WBS#: 1.2.1.1000)

Recipient:	INL
Presenter:	Lynn Wendt
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,155,000
Project Dates:	10/1/2015 - 9/30/2017

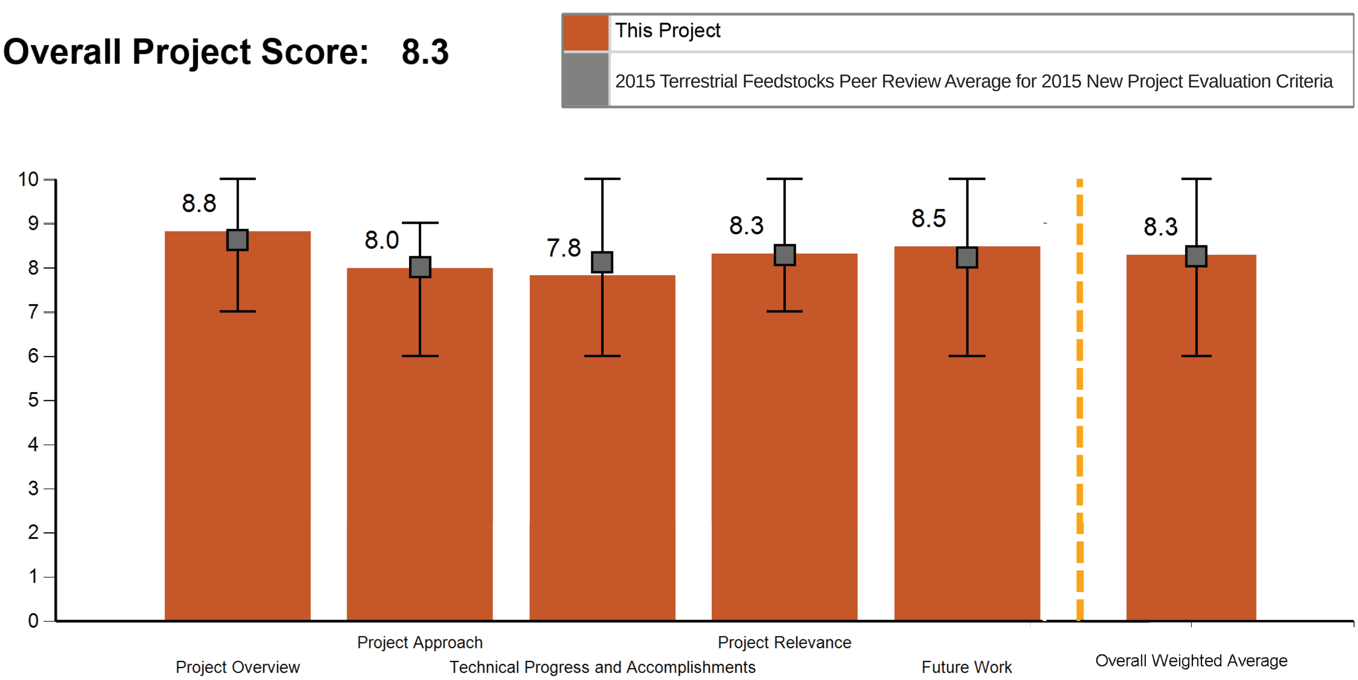
Photo Courtesy of INL

Project Description

This project aims to evaluate the technical and economic feasibility of centrally located wet biomass storage and the enabling logistics operations at an industrially relevant scale to control logistics costs, preserve feedstock value in wet climates, and reduce the risk of catastrophic loss to fire. The project will define the operations necessary to execute centralized wet feedstock storage, document mass balances, analyze operational costs, and measure the material value within a biochemical conversion system to ethanol.

These goals will be accomplished using a combination of technical and economic evaluation, laboratory-scale experiments, and field-scale storage and handling trials. This project addresses multiple barriers outlined in the MYPP, including Biomass Storage Systems, Quality and Monitoring, Sustainable Harvesting, and Biomass Material Handling and Transportation. The project approach begins with a techno-economic analysis of the wet logistics system, which will be based on: (1) harvest, collection, and transportation costs obtained using the Idaho National Laboratory Biomass Logistics Model; (2) an engineering design detailing unit operations and associated costs of building and utilizing a large scale biomass storage pile at a refinery gate; and (3) storage

Overall Project Score: 8.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

performance characteristics of two methods obtained in the laboratory. An FY16 go/no-go decision based on the techno-economic analysis will inform a large-scale field demonstration by an industrial partner..

Overall Impressions

- This project is a demonstration of how clear communication and close ties between national laboratories and industry can lead to high-impact research at a relatively low cost.
- This is a good project that is exploring a relatively innovative concept for feedstock logistics. The state of technology (SOT) has mostly pursued dry material systems for well-recognized advantages. However, this project reopens the question and explores alternatives that may have some significant advantages beyond simply fire risk reduction.
- This is a very good, strong project. Looking forward to more results.
- This is a good project that meets total biomass need and the outcome addresses a risk.
- I look forward to this project moving forward.

PI Response to Reviewer Comments

- Wet storage of herbaceous feedstock is being explored as a means to provide a consistent feedstock for biorefineries that reduces the risk associated with feedstock loss, specifically the risk of catastrophic loss to fire and dry matter loss due to aerobic microbial degradation. A bulk, wet feedstock logistics supply chain that moves size reduction to the field and large-scale storage at the biorefinery has the possibility of being cost competitive with the current SOT, which is based on a dry bale feedstock. Two storage options are being explored, i.e., traditional ensiling using a drive-over pile and a modified-Ritter approach that is based on slurring to promote compaction in the storage pile. A recommended dry or wet storage method will be determined at the go/no-go decision point, which will be based on a combination of the techno-economic analysis and life cycle analysis. Accurately balancing cost and sustainability metrics in our recommendation could be challenging. For example, dry feedstock supply system must weigh potential lower net energy inputs with the cost of insuring a dry bales in storage and the potential release of CO_2 as a result of fire or microbial degradation. We will attempt to quantify the economic and environmental impacts of both wet and dry feedstock systems as accurately as possible in order to recommend the best path forward.

NEXT GENERATION LOGISTICS SYSTEMS FOR DELIVERING OPTIMAL BIOMASS FEEDSTOCKS TO BIOREFINING INDUSTRIES IN THE SOUTHEASTERN UNITED STATES

(WBS#: NEW PROJECT #1)

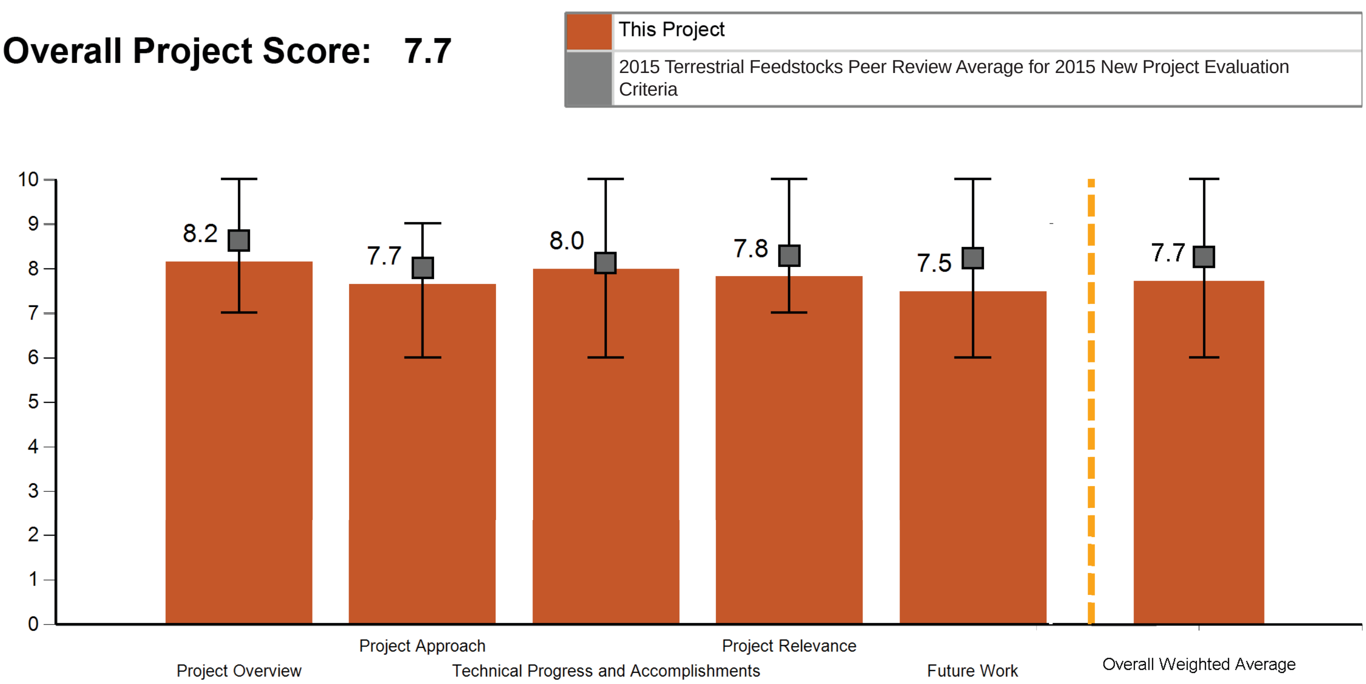
Recipient:	University of Tennessee
Presenter:	Tim Rials
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$0
Project Dates:	10/1/2015 - 9/30/2018

Photo Courtesy of University of Tennessee

Project Description

The project partners recognize that the diversity of biomass sources, and the potential to match composition with specific conversion processes, represents a strategic advantage for the Southeast U.S. region. To exploit this unique opportunity, knowledge of the variation in biomass properties, as it impacts feedstock preparation and conversion performance, must be gained. Information is neeeded on the chemical composition and the chemical changes that are induced during the multiple steps (size reduction, moisture removal, densification, etc.) required to transition biomass to feedstock. Without the insight afforded by this type of information, generating a consistent, high performance feedstock from a single biomass source, much less diverse sources of biomass, will remain elusive. This project leverages the accomplishments of two recent high-tonnage projects led by Auburn University and Genera Energy/University of Tennessee. This project will develop and demonstrate

Overall Project Score: 7.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

a state-of-the-art biomass merchandising and preprocessing depot to identify sources of variation along the supply chain of multiple, high-impact biomass sources (pine and switchgrass). It will also develop practices that manage biomass variability to deliver a consistent feedstock optimized for performance in specific technology platforms.

Overall Impressions

- The project should consider integration of sustainability measures as well as integration into existing harvesting practices.
- It is certainly making progress. This project is really much more demonstration than R&D.
- I do not really understand the value-add at the depot. I am really worried about the environmental issues with water disposal after washing.
- Some parts of this project are less thought-through than others. BETO should identify potential fatal flaws prior to proceeding with projects.

PI Response to Reviewer Comments

- We are grateful for the opportunity to present an overview of this new project, and appreciate the constructive comments from the review panel. Our team is optimistic that this project will generate valuable new information that, while targeting the unique circumstances of the Southeast, will lead to innovative approaches to reduce the cost and improve the quality of biomass feedstock more broadly.
- We are encouraged by the support for the statistical process control work, and believe that it will advance our knowledge of the sources of variation in the system to enable better control. Incorporation of NIR sensors should also create new insight into property modification during preprocessing, which will ultimately advance feedstock quality and consistency through formulated blends. We very much appreciate the leadership of BETO in this area, and look forward to working with them to ensure a successful and impactful project outcome.

IMPROVED ADVANCED BIOMASS LOGISTICS UTILIZING WOODY AND OTHER FEEDSTOCKS IN THE NORTHEAST AND PACIFIC NORTHWEST

(WBS#: NEW PROJECT #2)

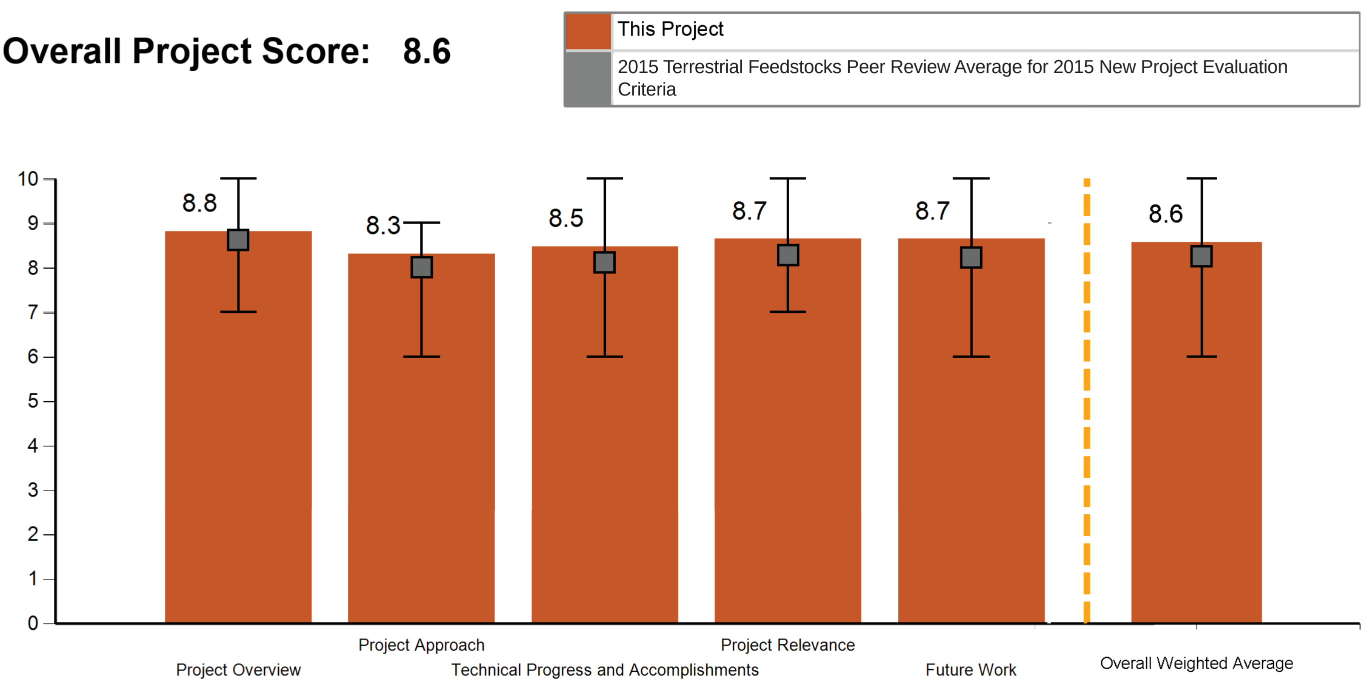
Recipient:	SUNY-ESF
Presenter:	Tim Volk
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$0
Project Dates:	10/1/2015 - 9/30/2018

Photo Courtesy of SUNY-ESF

Project Description

The principal objective of this project is to lower the delivered cost of short rotation woody crop (SRWC) feedstocks by optimizing and demonstrating a commercial-scale supply system using an iterative process. The target is to deliver hybrid poplar on the West Coast and shrub willow on the east coast to the throat of the conversion process reactor of our commercial partners for less than $80/DT. Additional objectives include overcoming current technical hurdles to develop coordinated optimized harvesting, transport, storage and delivery logistics so that feedstock of consistent quality and quantity can be delivered to end users year-round. This goal will be primarily achieved through an iterative process of optimization modeling that will inform large scale harvesting trials on both the East and West Coasts. Improvements in the operation of the single pass cut-and-chip New Holland harvesting system and

Overall Project Score: 8.6



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

in the functionality of the chip collection, handling, storage and preprocessing systems will be implemented and tested in the field. At all stages in the process, the quality of the feedstock being produced will be assessed using high throughput techniques and the impact of variations in key quality parameters on the yield of biofuels will be determined by the project's key biorefinery partners. The feedstock team will use the feedback from biorefinery partners to alter harvest and preprocessing operations to produce feedstock to meet key biorefinery partners' specifications.

Overall Impressions

- The project has not yet been awarded, but project plans appear solid.
- This project is an important investment to move SRWC feedstocks closer to successful implementation. Without this project support, the technology would not be at a high enough level of maturity (i.e., TRL) to easily transition to practice.
- I wonder if this willow project and the southern pine work have been successful enough that further BETO investment may not be warranted. It seems they are already at TRL-7 or so.
- This is a valuable project that focuses on woody biomass, one of the more abundant feedstock resources. I suggest the project validate earlier work and perhaps extend application to other areas, like the Southeast. Cost reduction should focus on key elements of supply chain. It supports BETO's goal of reducing biomass cost to $80/DT.
- This is a continuation of a very interesting and promising project and a good investment by BETO.

PI Response to Reviewer Comments

- Significant progress has been made to improve the throughput of the harvester in woody biomass crops, but there was still about a 60% drop in efficiency between the harvester throughput and delivery to the end user. Thus, the entire system still needs to be improved and optimized to reduce costs and maintain quality. Additionally, there is very little information available how feedstock quality changes along the supply chain especially for storage during off-season and under the range of climate conditions. This project will introduce new technologies, such as rapid assessment of feedstock quality and onboard tracking of system performance, which should help to further optimize the system, reduce costs, and meet the BETO objective of $50/DT for logistics.
- Previous support from DOE has resulted in engagement from growers, equipment manufacturers and end users and the results have been evident in the improvement of the harvester. There are important gains that can be made in the logistics systems in this project, especially through the engagement of both modelers and in field operators in the iterative process that is planned. This kind of collaboration, and the resulting benefits, would not be possible without support from DOE at this point in the development of these systems.

RENEWABLE ENHANCED FEEDSTOCKS FOR ADVANCED BIOFUELS AND BIOPRODUCTS (REFABB)-DEVELOPMENT PROGRAM

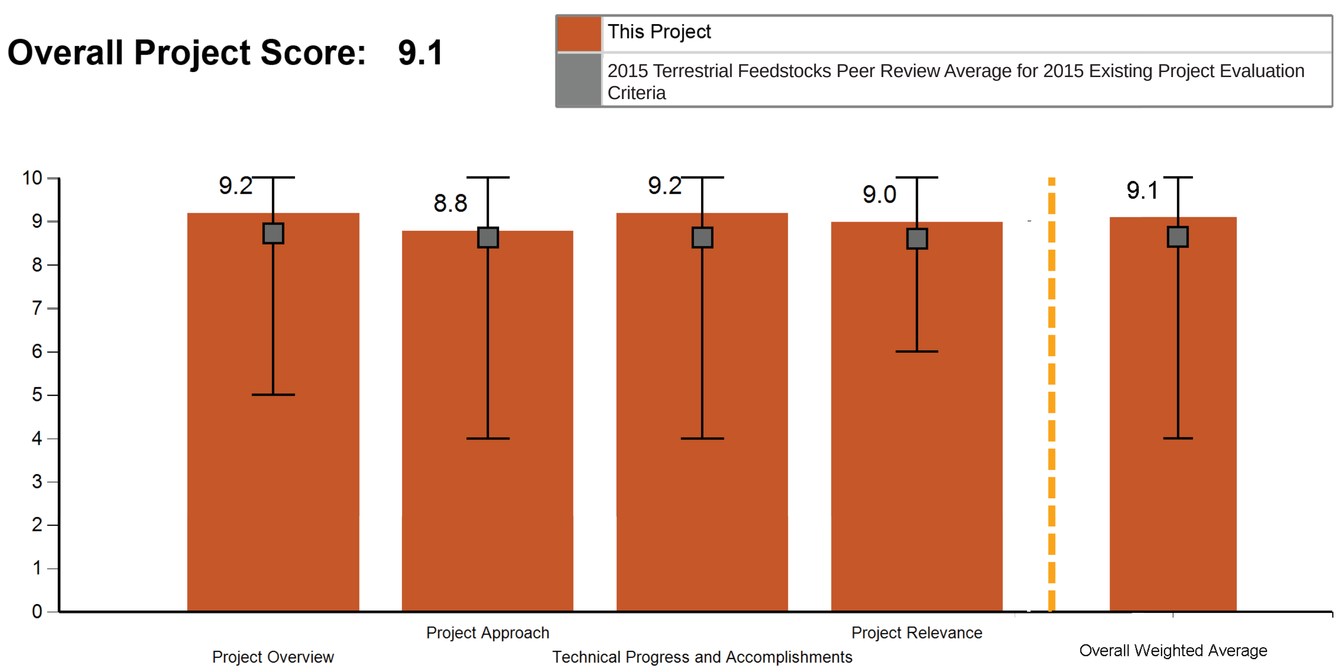
(WBS#: 1.1.2.2)

Recipient:	Metabolix
Presenter:	Oliver Peoples
DOE Funding FY14:	$1,367,087
DOE Funding FY13:	$1,392,994
DOE Funding FY10-12:	$1,392,994
Planned Funding:	$1,421,832
Project Dates:	10/1/2011 - 9/30/2014

Photo Courtesy of Metabolix

Project Description

The REFABB program provides an integrated economic and environmental value proposition for combined production of biobased commodity chemicals and biofuels not available with existing technologies. The tools of metabolic engineering are used to produce the biopolymer polyhydroxybutyrate (PHB) in switchgrass. Torrefaction of this enhanced energy crop produces a densified biomass and a platform chemical precursor crotonic acid. The densified biomass retains 80% of the energy and can be consolidated at world scale biorefineries for biofuel production. Crotonic acid can be converted to a range of industrial chemicals including bio-butanol, bio-propylene and bioacrylic acid, whose markets scale with the energy sector. Using proprietary genes, Metabolix has demonstrated increased carbon fixation in switchgrass, which may result in higher PHB levels and higher fermentable sugar content. Proof of concept gene containment technology has been demonstrated, which will reduce the cost and timelines for regulatory approval and large scale production of engineered bioenergy crops. Metabolix, in cooperation with its partners, has demonstrated and is continuing to optimize the torrefac-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

tion process with the goal of achieving 90% recovery of PHB in biomass to crotonic acid. Metabolix has also demonstrated metathesis conversion of crotonic acid to acrylic acid, hydrogenation conversion of crotonic acid to butanol, and oxidation conversion of crotonic acid to maleic anhydride.

Overall Impressions

- It appears the project has made significant gains in biomass feedstock crop lines; however, the proprietary nature of many of these gains leaves the benefit to the industry as a whole in question.
- This is an excellent, well-integrated feedstock/conversion project. A strong management approach focused on achieving performance targets is a significant factor in the success of this work.
- This is a very worthwhile project.
- Few projects have set such a high bar for success. While the challenges are formidable, the relevance to industry is extremely high and the likelihood of commercialization, if successful, is certain. These qualities alone distinguish this project high above most others.

PI Response to Reviewer Comments

- The REFABB project team members appreciate the generous comments and input from the project review board that recognize both the challenging but breakthrough nature of our program and the proof points of key elements that have been achieved to date.

DESIGN AND DEMONSTRATION OF AN ADVANCED AGRICULTURAL FEEDSTOCK SUPPLY SYSTEM FOR LIGNOCELLULOSIC BIOENERGY PRODUCTION

(WBS#: 1.2.3.101)

Recipient:	FDC Enterprises Inc.
Presenter:	Fred Circle
DOE Funding FY14:	$187,797
DOE Funding FY13:	$1,255,020
DOE Funding FY10-12:	$2,998,403
Planned Funding:	$570,542
Project Dates:	10/1/2010 - 9/30/2014

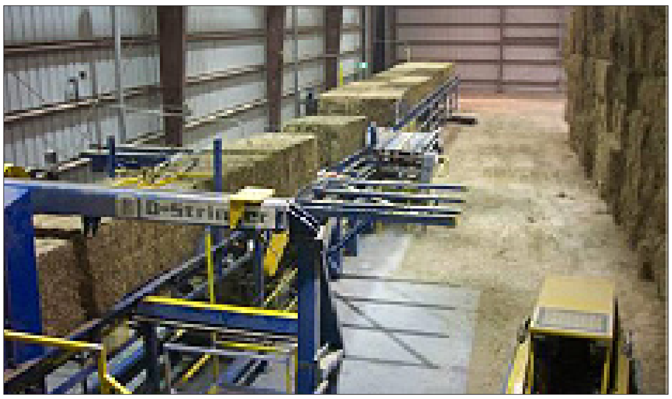
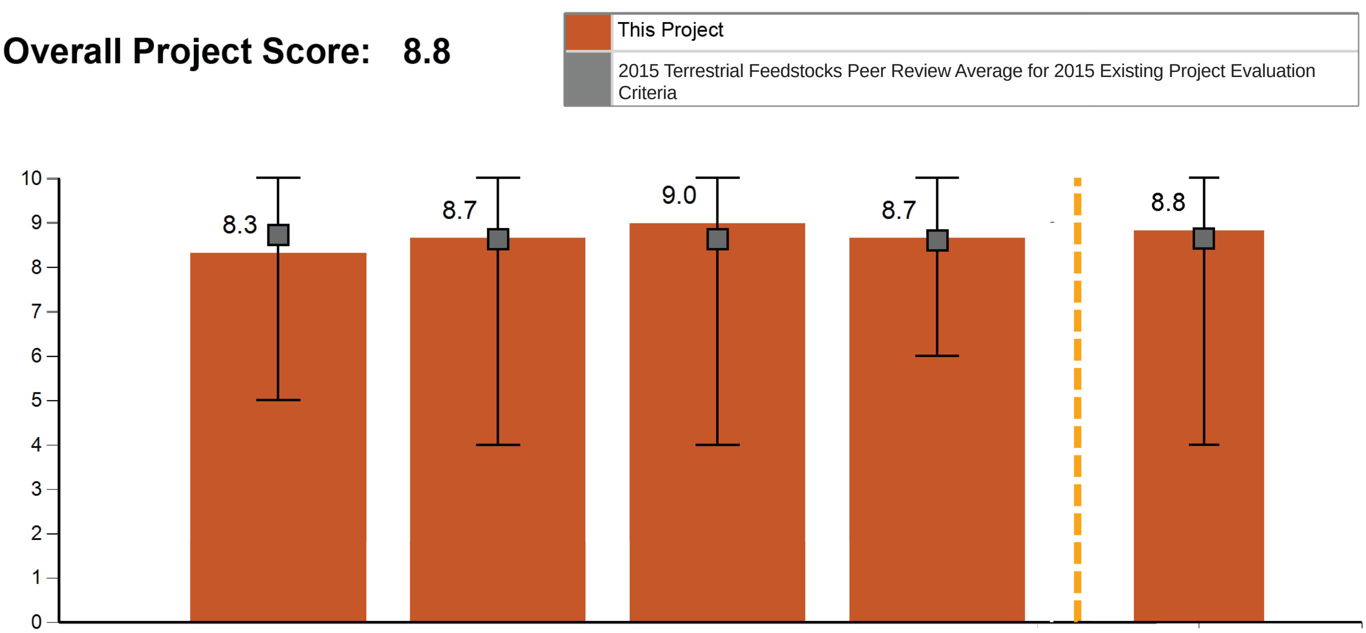


Photo Courtesy of FDC Enterprises Inc.

Project Description

This project developed and demonstrated four innovative, first-of-their-kind machines aimed at significantly reducing the cost of delivered herbaceous biomass: a Self-Propelled Baler (SPB), a Bale Picking Truck (BPT), a Self-Loading Trailer (SLT), and a Heavy Crop Header for harvesting high yielding herbaceous energy crops. Where possible and applicable, the equipment were demonstrated on priority crops and residues (corn stover, wheat straw, warm season grasses, and miscanthus) on available fields across the country. Operational performance and cost data was collected and analyzed throughout the project to measure the costs of baseline harvesting (using conventional harvesting equipment) and advanced harvesting with the newly developed equipment. This data was shared with Oak Ridge National Laboratory and revealed that the project met its original goal of developing equipment that is capable of reducing the cost of delivered biomass by $13/DT. Harvested biomass samples were provided to Idaho National Laboratory for quality analysis, report-

Overall Project Score: 8.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ing, and sample inventory. Each machine was demonstrated during one or more harvest seasons. During these tests, operational flaws were found and fixed through upgrades and improvements. The first new SPB, BPT, and SLT were ready for use during the 2013 harvest season. Since then, over 40 SLTs have been ordered and the first batch of 10 is currently being built. Continued refinement and testing is underway for three of the four machines.

Overall Impressions:

- The initial need for the project was not communicated. Large project team appeared to be well coordinated. Several equipment prototypes were developed; however, readiness for market is unclear (and will likely remain unclear until a demand for this feedstock develops).
- This is a good project that has created new technology that can significantly impact the cost structure of the bioeconomy.
- As the overall impression, the project has outstanding results and execution.
- My reaction to this project is positive. New equipment is developed, including a second generation trailer, and sold commercially.
- This is an extremely ambitious project, perhaps overly so, but this is BETO's job to address scope issues in the selections process. The project team is diverse and respected, but lacks a strong and experienced commercial field operations collaborator. The collaborator would have provided insights valuable to equipment design and use and would likely have focused the scope to those process steps necessary for near-term success.

PI Response to Reviewer Comments

- The need for and primary intended objective of this project was to design, fabricate, and demonstrate new equipment that has the potential to significantly reduce supply chain costs for high tonnage herbaceous biomass. This potential was successfully developed and demonstrated, and some of the equipment is now under commercial manufacturing production (ahead of original planned sales expectations). Our team included very strong and experienced field operations collaborators and there was a significant amount of interaction among our OEMs and field operations team members. Additional collaborators were invited at the outset of the project, but declined participation. Our team members plan for and welcome broader collaboration with experienced field operations companies as the new equipment approaches commercial readiness.

DEVELOPMENT OF A BULK-FORMAT SYSTEM TO HARVEST, HANDLE, STORE AND DELIVER HIGH-TONNAGE, LOW-MOISTURE SWITCHGRASS FEEDSTOCK

(WBS#: 1.2.3.102)

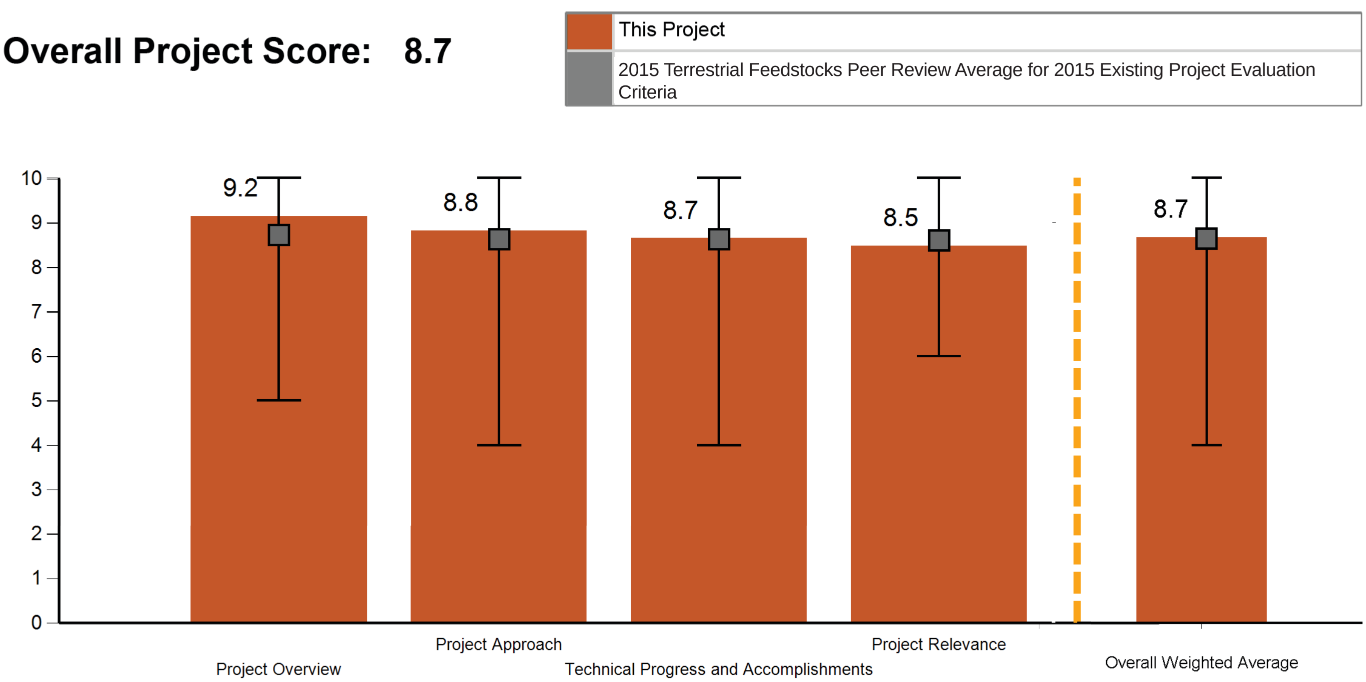
Photo Courtesy of TennEra, LLC

Recipient:	TennEra, LLC (Genera Energy, LLC)
Presenter:	Al Womac
DOE Funding FY14:	$124,482
DOE Funding FY13:	$3,553,131
DOE Funding FY10-12:	$4,443,122
Planned Funding:	$64
Project Dates:	10/1/2010 - 9/30/2013

Project Description

This project compared comprehensive feedstock logistics systems (FLS) from biomass standing in a field to conveyance of a uniform, industrial milled product into a conversion facility. Bulk-format FLS evaluated switchgrass field chopped (FC) for loose- or compacted-haul, stored in a protective facility, and reclaimed and conveyed for compaction into over-the-road ejector trailer. Bulk storage bins served as sensored proxy for large commercial stacks protected from moisture with a membrane cover. Deliberate engineering and testing of the bulk-handling FLS evaluated logistics for the entire system, including GPS-tracked field and over-the-road equipment, operational conditions, load weights, bulk densities, moisture contents, particle sizes, reclaim and handling throughputs (ton/hour), power and energy use (kW-h/ton), unit costs ($/ton), switchgrass composition and ethanol potential, and assessment of efficiencies and utilization values (%). Bulk-format FC reclaim was compared to bale-FLS with bales subjected to coarse tub grind (CTG) and fine tub grind (FTG). The discov-

Overall Project Score: 8.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ery was that bulk-format FLS exhibited desired traits of increased loose bulk density (6.2 lb/ft^3), increased compacted bulk density (10.64 lb/ft^3, comparable to bale FLS), and a significant finding of propensity for free-flow for FC compared to tub grind switchgrass. FTG switchgrass flowed at rates more than double the rates for CTG switchgrass, the FC switchgrass flowed at rates that were three to four times the rate of any tub grind material, up to 40 tons/hour.

Overall Impressions

- Overall, clear progress has been made regarding the idea of a depot system for herbaceous feedstock storage. Future work should concentrate on incorporating processing to produce an energy-dense system of transport and on maximizing the energy balance of the feedstock.
- This project had good collaboration with industry that contributed to a commercial-quality installation.
- Implementing depots is critical, as this project shows. BETO needs to invest much greater resources (absolute dollars, not just as a percent of its budget) to develop depot level systems and to move upstream of and outside of the biorefinery. Past collaborations with USDA, particularly at the staff level, are excellent, but now they need to get even deeper and stronger.
- Overall, I view the project positively. Considering the entire handling system at one time, the project brought in strategic partners that I believe helped to make it a success.
- This project, while expertly demonstrating a number of valuable process steps, ultimately suffers when compared to a high velocity, square bale program with satellite stack yards. Perhaps, then, the true value is the well-documented cost structure for this process method as a baseline for comparison.

PI Response to Reviewer Comments

- The supply of bales has a history of substantial investment and potential improvements are now incremental. On the other hand, supply of low-moisture bulk-format biomass is on the forefront of being able to capitalize on clean-sheet designs rather than being based on equipment from a myriad of industries. Potential improvements in bulk-format can help realize improved bulk densities and improved bulk flow rates with automated systems that have high potential to meet the high tonnage needs of biomass handling. The conservative cost analysis demonstrated that bulk-format is viable with existing machinery systems and did not project the substantial savings in automated handling from clean-sheet designs.

HIGH TONNAGE FOREST BIOMASS PRODUCTION SYSTEMS FROM SOUTHERN PINE ENERGY PLANTATIONS

(WBS#: 1.2.3.104)

Recipient:	Auburn University
Presenter:	Steve Taylor
DOE Funding FY14:	$149,868
DOE Funding FY13:	$2,000,244
DOE Funding FY10-12:	$4,038,900
Planned Funding:	$0
Project Dates:	10/1/2009 - 9/30/2014

Photo Courtesy of Auburn University

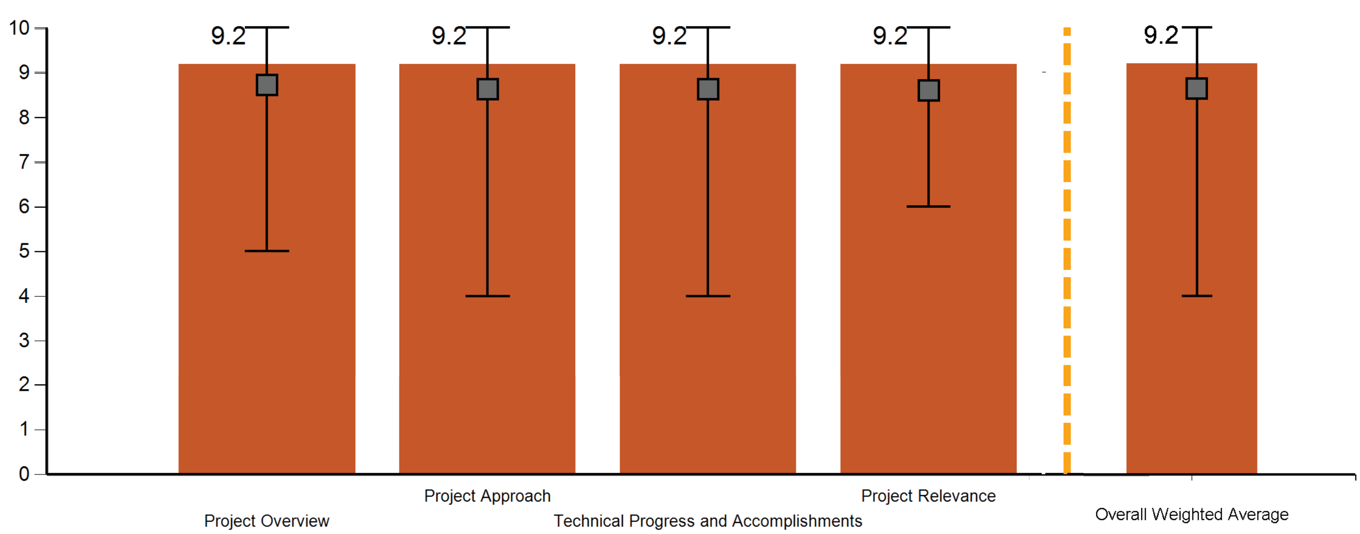
Project Description

Short-rotation southern pine plantations in the U.S. hold great potential for producing more than 100 million dry tons of woody biomass per year in an economically feasible manner. This project has designed a high-productivity system to harvest, process, and transport woody biomass from southern pine plantations. The system has been designed to harvest 10- to 15-year-old pine plantations. Field tests of transpirational drying in summer months resulted in moisture content reductions from 56% to 35% in whole trees. To accommodate wood with lower moisture contents, high-capacity chip trailers were designed and fabricated. For one-way hauls of 50 miles at costs of $4.00 per one-way mile, transport costs can be reduced by over $5.00 per dry ton by reducing moisture content from 56% to 35%. Total harvest and transport costs have been reduced by 45% when the new system is compared to traditional-wheeled feller buncher and skidder systems. Additional research developed mass flow sensors for the chipper, as well as GPS-based information systems that provide productivity feedback

Overall Project Score: 9.2

This Project

2015 Terrestrial Feedstocks Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

to the operator and machine managers. Biomass quality also is being measured through felling, skidding, and processing operations. Focus groups of loggers and landowners have been interviewed to quantify acceptance of the new harvest and transport systems.

Overall Impressions

- Overall, the project has resulted in clear cost gains over previous status quo and a new product line of a major forestry Original Equipment Manufacturer (OEM).
- This has been a highly successful project and seems to have achieved the TRL thresholds that BETO uses as its metrics of success. Is more support warranted given pressing needs elsewhere?
- The project has a positive impression overall.
- Getting a novel piece of equipment to become commercially available is an accomplishment that few projects can point to.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

DEVELOPMENT AND DEPLOYMENT OF A SHORT ROTATION WOODY CROPS HARVESTING SYSTEM BASED ON A CASE NEW HOLLAND FORAGE HARVESTER AND SRC WOODY CROP HEADER

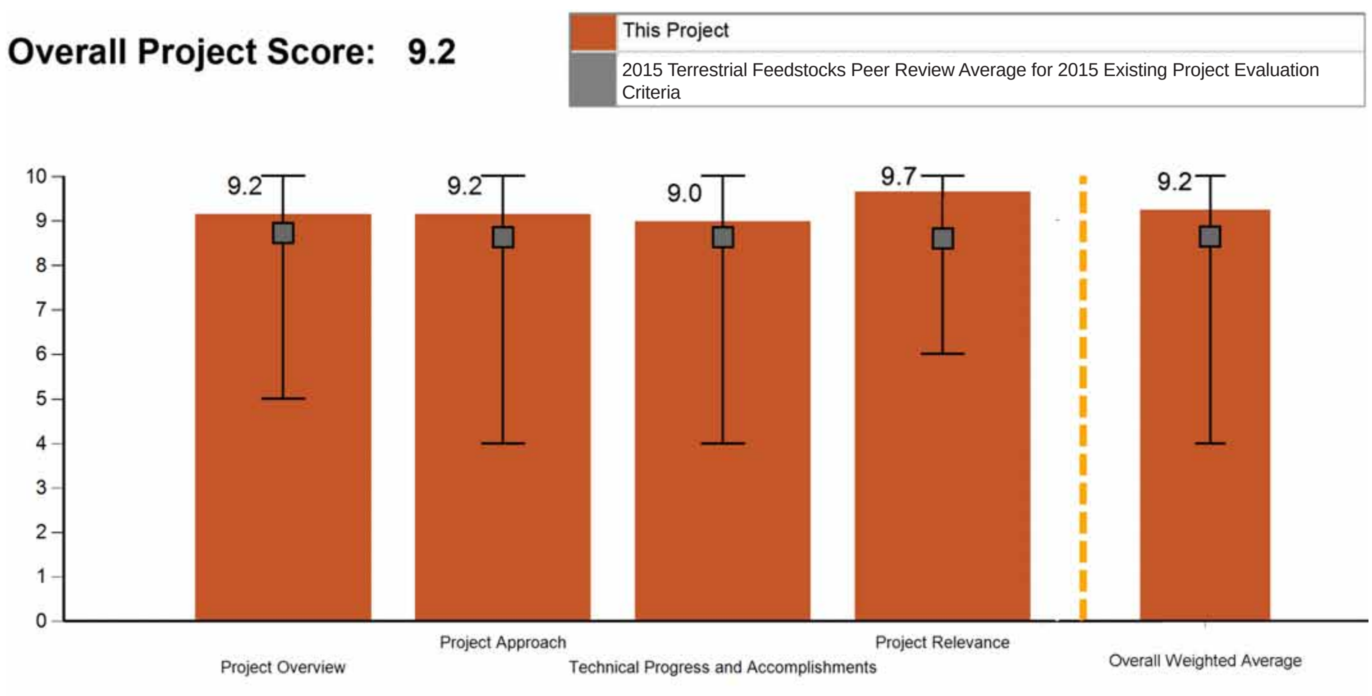
(WBS#: 1.2.3.105)

Photo Courtesy of SUNY College of Env. Science

Recipient:	SUNY College of Env. Science
Presenter:	Tim Volk
DOE Funding FY14:	$525,434
DOE Funding FY13:	$409,707
DOE Funding FY10-12:	$748,702
Planned Funding:	$333
Project Dates:	10/1/2010 - 9/30/2014

Project Description

Demand for bioenergy sourced from woody biomass is projected to increase; however, the expansion and rapid deployment of short rotation woody crops systems (i.e., hybrid poplar and shrub willow) in the U.S. has been constrained by high production costs and sluggish market acceptance due to problems with quality and consistency from first-generation harvesting systems. The objective of this project was to develop and evaluate the performance of a single-pass, cut-and-chip harvester based on a standard New Holland FR-9000 series forage harvester with a dedicated 130 FB short rotation coppice header, and the quality of chipped material. A time



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

motion analysis was conducted to track the movement of machine and chipped material through the system for 153 separate loads over 10 days on 54-ha of willow and about 50 ha of poplar. Harvester performance was regulated by either ground conditions or standing biomass. Material capacities increased linearly with standing biomass up to 40 Mg_{wet} ha^{-1} and plateaued between 70 and 90 Mg_{wet} hr^{-1}. Moisture contents ranged from 39 to 51% with the majority of samples in the 43-45% range. Mean ash content was 2.1% (SD 0.59) dry basis and ranged from 0.8 to 3.5%. Over 1.5 Mg_{dry} ha^{-1} of potentially harvested material (6-9% of a load) was left on site, of which half was commercially undesirable meristematic pieces. The New Holland harvesting system is a reliable and predictable platform for harvesting material over a wide range of standing biomass.

Overall Impressions

- Clear gains have been made in harvesting systems for short-rotation woody (deciduous) crops and resulted in new equipment to market. Continuing work on related projects needs to factor in farm-scale economics of extending the utilization of the forage harvester to times of year when it is not traditionally parked (i.e., late fall-winter harvest of energy crops).
- This is an excellent project and a good example of DOE investment moving the technical frontier closer to feasible bioeconomy.
- It looks like Technology Readiness Level (TRL) metrics that BETO uses have been achieved. How much more work in this area is really warranted given needs elsewhere, particularly the need to develop the depot concept to a similar TRL as this project has achieved.
- This is a good project and has been completed successfully.
- Assuming the economics eventually work for short rotation coppice woody feedstocks, the overall impression is that this project will have made a major contribution.

PI Response to Reviewer Comments

- Significant progress has been made to improve the throughput of the harvester in woody biomass crops, but there was still about a 60% drop in efficiency between the harvester throughput and delivery to the end user. Thus, the entire system still needs to be improved and optimized to reduce costs and maintain quality. Additionally, there is very little information available as to how feedstock quality changes along the supply chain. A new project in this area will introduce new technologies, such as rapid assessment of feedstock quality and onboard tracking of system performance, which should help to further optimize the system, reduce costs, and meet the BETO objective of $50 per dry ton for logistics.

COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES, DEVELOPMENT OF HIGH YIELD TROPICAL FEEDSTOCK (HI)

(WBS#: 7.1.2.6)

Recipient:	University of Hawaii,
Presenter:	Andrew Hashimoto
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$6,000,000
Planned Funding:	$0
Project Dates:	10/1/2008 - 9/30/2014

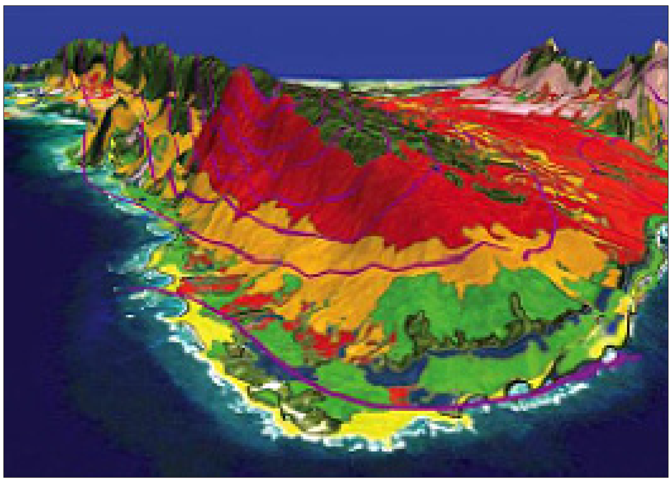
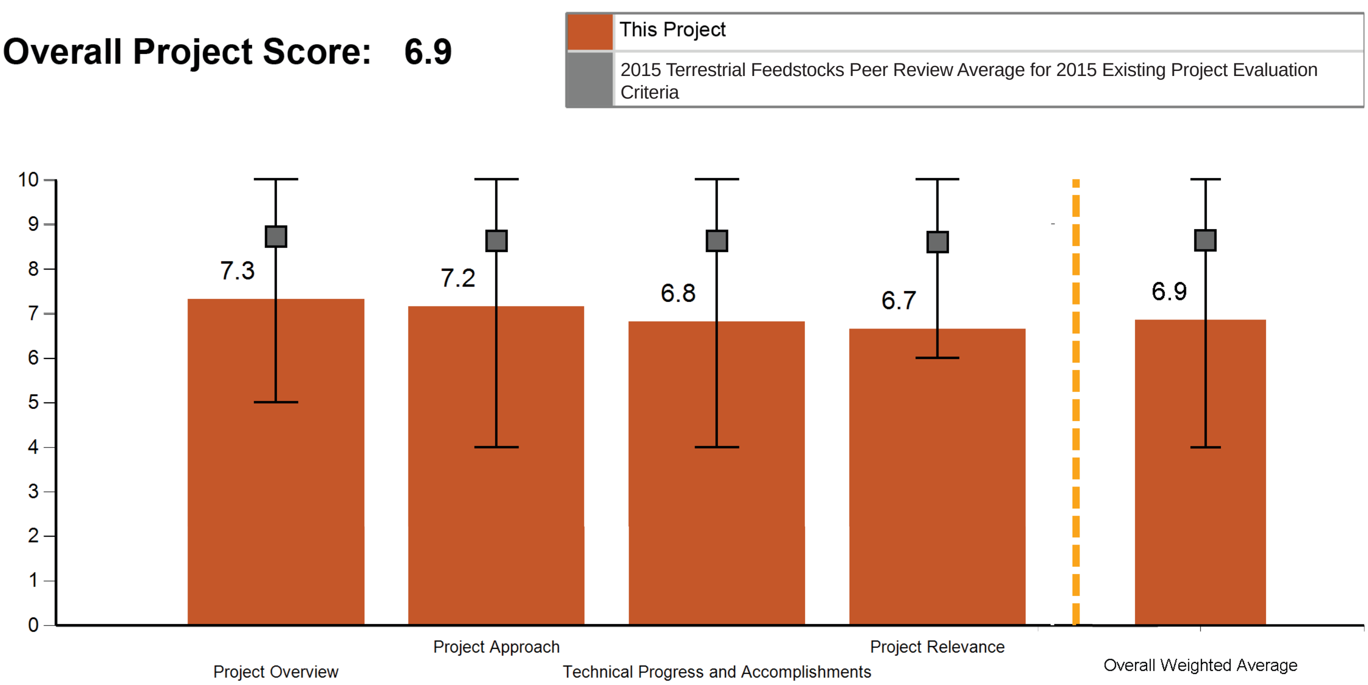


Image Courtesy of University of Hawaii

Project Description

This project had two main goals: (1) evaluate several high yielding tropical perennial grasses as feedstock for biofuel production and to characterize the feedstock for compatible biofuel production systems; and (2) assess the integration of renewable energy systems for Hawaii. Field plots were established to evaluate the effects of elevation and irrigation on energy crop yields and inputs. Plots were extensively monitored (hydrologic studies to measure crop water use and losses; changes in soil carbon stock; greenhouse gas flux from the soil surface; and root morphology, biomass, and turnover). Results showed significant genotype-environment interactions: crop yields decreased as the elevation increased; and

Overall Project Score: 6.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

energy crop yields were higher with increased irrigation levels. Daylight length greatly affected sweet sorghum growth and yields. Napiergrass was harvested at different ages to assess the changes in feedstock characteristics with age and potential to generate co-products. Although there was greater potential for coproducts from younger feedstock, the increased production was not sufficient to offset the additional cost of harvesting multiple times per year. The feedstocks were also characterized to assess their compatibility with biochemical and thermochemical conversion processes. The project objectives are being continued through additional support from the Office of Naval Research, and the Biomass Research and Development Initiative.

Overall Impressions

- It is clear that research into sustainable bioenergy for Hawaii is needed; however, the contributions of this project to that goal are unclear.
- The most significant accomplishment of this project appears to be the screening of feedstock materials for bioenergy cropping in Hawaii. The project leaves many questions about commercial potential because there is not a clear conversion pathway, commercial-scale cropping, or logistics assessments.
- The project seemed pretty scattered in parts. I was not sure how many of the key goals were really achieved.
- This did not seem like a very relevant project.
- The small scale, diversity of project elements and lack of results do not favor additional funding.

PI Response to Reviewer Comments:

- No official response was provided at time of report publication.

ALGAL FEEDSTOCKS

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Algal Feedstocks Technology Area, or Algae Program, is one of seven key technology areas reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place March 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of 28 projects were reviewed by six external experts. These projects represent about 10% of BETO portfolio and an investment of approximately $40 million (FY 2013-FY 2014). The principal investigator (PI) for each project was given 30 minutes to deliver a presentation and respond to questions from the Review Panel. Projects were evaluated and scored for their project approach, technical progress, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Algae Program Project Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the Algae Program, full scoring results and analysis, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Dr. Alison Goss Eng as the Algal Feedstocks Technology Area Review Lead. In this capacity, Dr. Goss Eng was responsible for review planning and implementation.

ALGAL FEEDSTOCKS

OVERVIEW

The role of the Algae Program is to fund the research and development of sustainable algae production, logistics, and conversion to biofuels. Projects within the portfolio address a diversity of topics including algal biology; algal cultivation, harvest, and processing logistics; conversion interfaces and conversion technologies; and analyses of high value coproducts, techno-economics, sustainability, and resource availability.

Algae production refers to, but is not limited to, the cultivation of micro and macro alga, as well as cyanobacteria via open-ponds, closed photobioreactors, attached growth systems, or macro-algae cultivation systems. Feedstock logistics primarily includes the harvest steps of dewatering and concentration. Conversion to biofuel intermediates encompasses technologies to extract neutral lipids, hydrothermal liquefaction (HTL) of whole algal biomass, as well as innovative techniques for extracellular secretion of desired intermediates. Conversion interface steps include the preprocessing required to produce clean, energy-dense, stable, and transportable feedstocks suitable for further refining, as well as transportation and residual processing.

BETO algal feedstock analysis activities include assessing geographic locations for siting production units, process economics, and the environmental sustainability of commercially relevant scales.

ALGAE PROGRAM SUPPORT OF OFFICE GOALS

The Algae Program performance goal is to increase the projected productivity of large-scale algae cultivation and preprocessing, while maximizing efficiency of water, land, nutrient, and power use to supply a stable biofuel intermediate for conversion to advanced biofuels. Specifically, BETO will validate the potential for algae supply and logistics systems to produce 5,000 gallons

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the Final Report.

of oil (or an equivalent biofuel intermediate) per acre of cultivation per year at the pre-pilot scale by 2022; this will achieve a modeled nth plant minimum selling price of $3.27/gasoline gallon equivalent (gge) ($2011) of raw biofuel intermediate. For details on this technology area's goals, see BETO's Multi-Year Program Plan (MYPP) at: *http://www.energy.gov/eere/bioenergy.*

APPROACH FOR OVERCOMING CHALLENGES

The Algal Feedstocks Technology Area approach for overcoming challenges and barriers is outlined in its work breakdown structure (WBS), organized around five key activities. Current activities are focused on: assessing current and potential sustainable biomass feedstock resources and corresponding costs; developing sustainable feedstock cultivation systems; improving the capacity and efficiency of harvesting, preprocessing, storage, and handling; characterizing algae to interface with conversion methods; and scaling integrated algae research and development (R&D) systems. These activities are performed by national laboratories, universities, industry, state and regional partners, and consortia.

ALGAL FEEDSTOCKS TECHNOLOGY AREA REVIEW PANEL

The following external experts served as reviewers for the Algal Feedstocks Technology Area during the 2015 Project Peer Review.

ALGAL FEEDSTOCKS	
REVIEWERS	
Emilie Slaby (Lead Reviewer)	Independent Consultant
David Babson	Union of Concerned Scientists
Glenn Gallagher	DuPont
Joanne Morello	Northrop Grumman
Roger Prince	ExxonMobil
Jennifer Stewart	University of Delaware

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.

Project Scoring Information: The final score charts depict the overall weighted score for each project in each technology area. Titles for each project and the performers are also provided in the scoring charts.

Review Panel Summary Report: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.

BETO Programmatic Response: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.

Project Reports

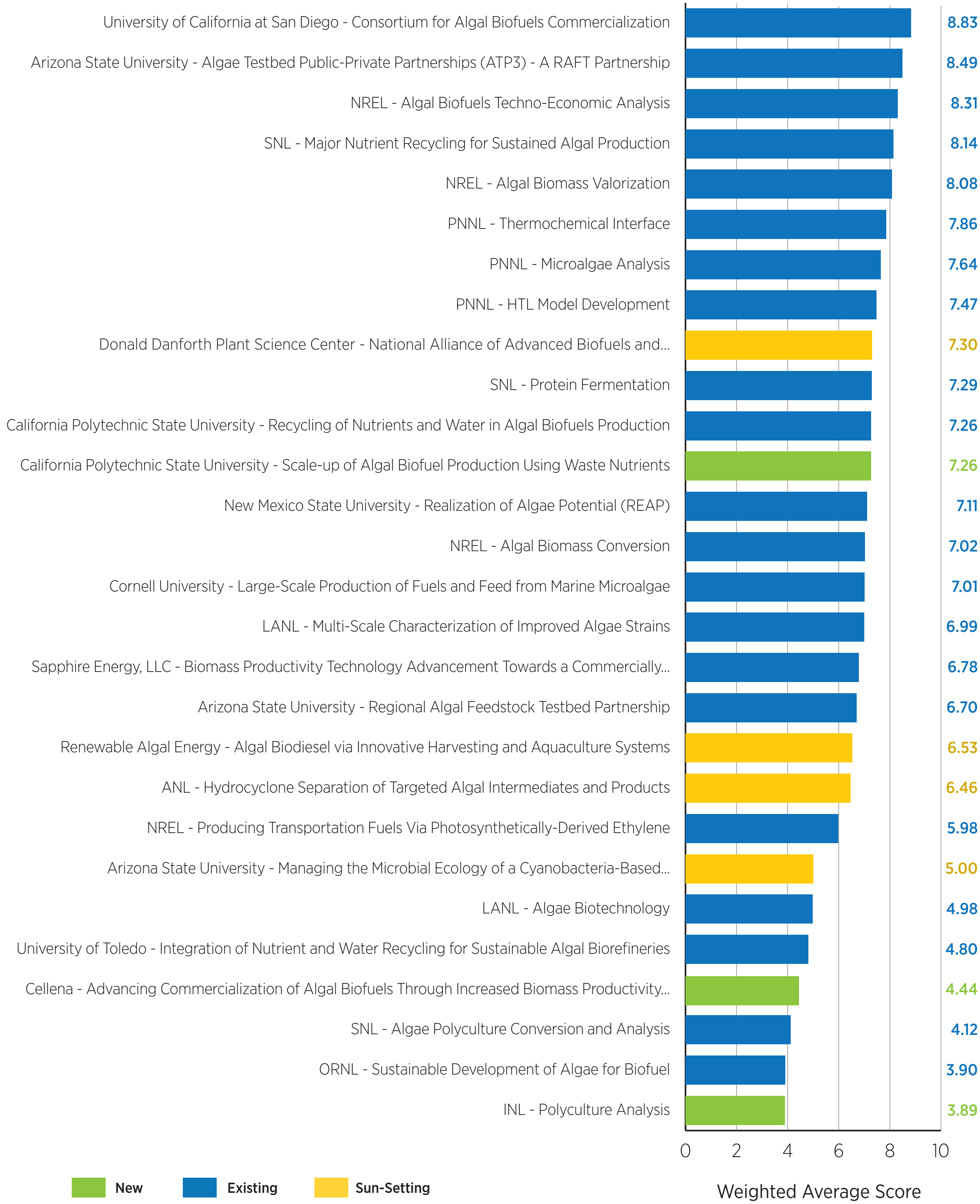
- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space allotted.
- **Project budget and timeline information** is based on self-reported data, as provided by the PI for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and whiskers charts depict the range of scores for each evaluation criteria across all projects reviewed within each technology area.
- **Reviewer comments** are presented as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.
- **PI responses** represent the response provided by the PI to reviewer comments, as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by reviewers, and in other cases, provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the Review Panel.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Algal Feedstocks Technology Area.

ALGAL FEEDSTOCKS TECHNOLOGY AREA SCORING



REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

INTRODUCTION

The Algal Feedstocks Technology Area research projects presented during the 2015 Peer Review are well-aligned with BETO's MYPP and have demonstrated progress since the 2013 Peer Review.

One of the key strengths of the Algal Feedstocks portfolio is its emphasis on diverse approaches to increasing the efficiency and productivity of algal feedstocks production. Algal feedstocks are especially promising due to their great potential to increase biofuel feedstock supply by expanding net primary productivity without competing for resources required for food production, i.e., fixing carbon dioxide for useful purpose, while utilizing non-arable land, non-potable water, and recycled nutrients. In addition, downstream process demonstrations and commercial process modeling based on a concentrated algal biomass feed (at least 20% ash free solids) suggest extraction of oil or HTL to a crude oil may provide a competitive biofuel product.

During the past two years, significant progress has been made along the entire algal biomass value chain, especially downstream of the post-harvest, concentrated feedstock, where results from terrestrial crops have been leveraged.

Several projects have made immediate, positive contributions:

- Outstanding research by Dr. Stephen Mayfield and his team at the Consortium for Algal Biofuels Commercialization received the Panel's highest marks. The team's completion of the first outdoor genetically modified algae cultivation trial leads the way for future monoculture and polyculture work to achieve increased biomass productivity at the 20 g/m^2/day required to meet BETO's intermediate goal of 2,500 gal/acre/year of algal biofuel production.
- Analytical work conducted by Dr. Lieve Laurens at the National Renewable Energy Laboratory (NREL) and culture standardization work done by the Algal Testbed Public-Private Partnership (ATP3) contributed the methodology necessary to compare results across the entire portfolio and addressed the recommendations made in the 2013 Peer Review.
- Excellent downstream modeling work led by Mark Wigmosta of the Pacific Northwest National Laboratory (PNNL) and Ryan Davis of NREL pointed to the need for a consistent algal feedstock produced for less than $500 per metric ton. In the next two years, the Panel finds that the immediate challenge is to establish a cost-effective supply chain, which can deliver the algal concentrate for under $500 per metric ton.

It will be prudent to focus on algal concentrate production design cases during the next two years of funding. New strategies should be more extensively explored to minimize investment and energy usage, while producing a consistent product and recycling nutrients (salts and minerals).

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

Projects funded in the Algal Feedstocks Technology Area made substantial technical progress over the last two years in standardizing analytical procedures and outdoor production methods, strain analysis, and techno-economic modeling of downstream processes. Academic consortia are bearing fruit with hundreds of publications, patents, and commercializable products.

These consortia have tackled basic questions regarding algal biology, strain analysis, and genetic tool development. For example, the legacy of the National Alliance for Advanced Biofuels and Bioproducts (NAABB) consortium is apparent in the utilization of well-characterized model strains by many other projects to benchmark progress and contribute to the development of a robust genetic toolbox. Wastewater algae projects are yielding tens of tons of ash free dry weight (AFDW) algal biomass per year for utilization in downstream technology optimization experiments.

Overall, the Review Panel is pleased to see the focus of the portfolio shifting from logistics development to development of the biological tools necessary to achieve target productivities (e.g., genetic evolution and abiotic manipulation). The diversity of projects in the portfolio—both at the pre-competitive and competitive award levels—is a key strength.

Despite these overall strengths, several notable weaknesses stood out to the Review Panel. The current kinetics of all processes are too slow. While every step along the algal lipid upgrading (ALU) and HTL pathways has been demonstrated, reaction rates and yields consistent with commercial viability have not been demonstrated at this time. Feedstock variability and insufficient availability inhibit development of robust conversion processes. Doubling times for algal productivity are far too long for a continuously harvested outdoor production facility to be viable. Photobiology is not well understood for the strains; they are still poor harvesters of photons. In modeling, development of an upstream model that pulls together economic, energetic, sustainability, and social costs lags behind downstream model development. Lastly, while the corporate knowledge gained in previous rounds of funding remains valuable to current projects, sharing of this knowledge appears to be limited.

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

Continued BETO funding of large-scale production experiments is necessary 10 years into the rejuvenated algae feedstocks and coproducts industry, as many sources of private-sector investment have been exhausted. Several projects stood out to the Review Panel as high-impact:

- **The Consortium for Algal Biofuels Commercialization's (CAB-Comm's) Toxic Substances Control Act (TSCA) Environmental Release Application (TERA) Permit**: The importance of the EPA-approved outdoor field trial of genetically modified (GM) algae cannot be overstated. While this success is ultimately a result of overcoming a regulatory rather than a technical hurdle, the TERA permit is critical to establishing the viability of GM-algae. Those who contributed to this effort are to be applauded for achieving the highest impact of the BETO portfolio over the previous two years. This is a game-changer.
- **Directed-Evolution of Algal Strains with Superior Phenotypes**: The creation of selected, enhanced energy content strains by flow cytometry is impressive. The Review Panel is excited to see this project's emerging impact within the portfolio.
- **ATP3 Consortium**: ATP3 standardized analytical and production methods allow comparable data to be obtained from a testbed network with an annual production capacity of 20 metric tons. This well-run consortium is the backbone of the current portfolio.

- **Techno-economic Analysis (TEA) Modeling for ALU and HTL Pathways**: These projects demonstrate system-wide thinking and the ability to contextualize individual project contributions to BETO's 2020 goals.

The Review Panel also noted several approaches that were less effective or relevant:

- There is insufficient communication between the life cycle analysis (LCA) / TEA modeling projects and the sustainability modeling projects.
- Biochemical hydrolysis of algal carbohydrates to sugars and further conversion to ethanol adds complexity and cost to the platform, while competing with currently plentiful low cost starch sources. Algae production costs seem unlikely to match available corn mash at $330/metric ton. This pathway seems unlikely to yield economical fuel.
- Building a supercritical fluid extractor from off-the-shelf pieces utilizing consultant expertise seems unlikely to yield improvements in efficiency. The TEA and sustainability models of this project were not explained in sufficient detail.
- Investigating Chlorella parasites seems unlikely to matter in the long run, given the performance of this species at process-relevant scales. While Chlorella species are grown at commercial scales for nutraceutical production, Chlorella is better considered as a model strain for bioenergy feedstock production.
- The current experimental design of the polyculture "Hub" project could be better synergized with other polyculture work within the BETO portfolio. Rather than designing synthetic mixtures of strains in the PNNL growth chambers, a stronger approach would start with native productive polycultures isolated from ATP3 sites or perhaps commercial algal wastewater treatment systems (e.g., California Polytechnic State University), and, if these polycultures are truly robust and productive, focus on their dissection and reassembly. There is much to be learned regarding successful polyculture cultivation. However, as CAB-Comm's work demonstrated this round, designed strain systems are still susceptible to native strains and, therefore, the work must start outdoors.
- The algal turf project would be best refocused as a field site for isolating natural algal polycultures or for wastewater projects seeking to close the carbon balance. The use of algal turf for biofuel production is unlikely due to these systems' low productivities.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The Review Panel admired the creative thinking and novel approach of projects in three areas:

1. **Biomass Productivity (Realization of Algae Potential)**: Pursuing cultivation of thermotolerant strains, while working to minimize the size of the light-harvesting antennae of these strains, is a promising approach. Over the next 24 months, the team will be challenged to increase photosynthetic productivity and/or solve the challenge of sourcing carbon for heterotrophic growth in a commercial setting. Their innovations will be watched.
2. **Downstream Processing (Algae Protein Fermentation)**: This well-managed project is the only downstream project to address external nutrient

requirements whose cost and availability could limit the scale of the industry. The team's proposal to lower nutrient input costs via recycling nutrients (N&P) during downstream processing hits a critical challenge to the long-term viability of algal feedstocks. This effort would be complemented by studies to reduce the nutrient requirements through strain development.

3. **Coproducts (Producing Transportation Fuels Via Photosynthetically-derived Ethylene)**: Upgrading the value of carbon-based coproducts is of active interest to BETO. At commercialization, the economics may dictate that algal biofuels are the coproducts and more valuable algal-derived chemicals are the primary products. Producing commercially relevant coproducts while maintaining an organism's metabolism—essentially, treating cyanobacteria as biological catalysts—is creative thinking.

This particular project's target—ethylene—may be commercially challenging, and other more valuable products would be a better test bed; however, the intent is spot on. Specifically, the ethylene project is a perfect example of a unique process trying to make itself into a fuel project when its main product is more valuable when not used as a fuel or fuel precursor.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

The Review Panel identified a number of areas that require additional attention:

- Robust modeling of upstream processes iteratively linked to field trials.
- Energy-effective and cost-effective technologies to concentrate algal biomass from 1.5% to 20% solids.
- Acquisition of large-scale external growth systems within the mainland United States.
- Closing the carbon mass balance for strains grown on wastewater to identify the extent to which autochthonous dissolved organic carbon versus atmospheric carbon dioxide is driving productivity.
- Cross-portfolio applicability of technical developments accomplished by competitive projects in specific geographies, specifically Hawaii versus mainland, as this is difficult to discern. Individual locations have unique business opportunities (e.g., partnering with electrical plants) that require specific modeling. Reporting true production costs (including sustainability and transportation) of the 20% ash free concentrate, as well as benchmarking progress made with specific strains to portfolio-wide reference strains, would support the Peer Review process.

The Review Panel identified several topics not adequately addressed in the current portfolio:

- Projects that Achieve Disruptive Breakthroughs in Efficiency:
    - Disruptive breakthroughs would return a greater than 20% reduction in minimum production cost (including cash cost of manufacturing and investment-related charges).
    - Full mass and energy balances for upstream production (through production of 20% ash free solids concentrate) are required to define minimum production cost. Downstream models have currently defined this target as less than $500/metric ton.

- Understanding of Photobiological Processes in Non-Model Strains:
  - The perfect algal strain/polyculture is unlikely to be found through continued strain screening. BETO would do well to refocus screening efforts towards developing GM strains with improved growth kinetics, light utilization efficiency, and thermos / halotolerance.
  - In the next two years, a tandem combination of flow-sorted phenotypes and GM species in outdoor trials could yield productivity breakthroughs.
- Carbon-based Coproducts:
  - Focus DOE efforts on upgrading the value of carbon.
  - Include additional sustainability modeling to assess carbon storage potential (e.g., in polymerized products).

SYNERGIES

5 What synergies exist between projects in this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

As the Algal Feedstocks program continues to develop, the Review Panel observed numerous synergies that should be encouraged:

- Multiple projects are using model strains such as DOE 1412 to benchmark their technologies and allow cross-portfolio comparison of new genetic tools. As projects continue to experiment with extremophiles and evolved strains, model strains will serve as robust controls.
- The analytical capacity developed at NREL continues to serve multiple projects. Embracing these method standards is critical to enable cross-portfolio comparisons of productivity.
- Polyculture efforts by academic, industry, and national laboratory groups seem to be duplicative.
- Significant synergies between downstream modeling efforts and downstream processing technologies exist. Additional opportunity will evolve as upstream models are built this year to analyze the energetic, social, sustainability, and economic costs of harvesting technologies, current testbed locations, and water supply both reported and assumed by projects presented in this Peer Review.
- Patterns of approach identified by the Terrestrial Feedstocks program can likely be applied to the Algal Feedstocks program. While there are significant differences in the challenges faced by each program, an All Feedstocks conversation could yield new insight.
- There seems to be an unexplored link between the struvite produced by wastewater studies and the struvite phosphorous recycling efforts.
- A high value energy pathway (producing coproducts and fuel in sequence, rather than simultaneously) is emerging from projects that produce coproducts, such as green ethylene, and projects that produce fuel, such as the HTL pathway.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

The Review Panel respectfully suggests the following actions to orient the portfolio's projects toward successful commercialization:

- Combine genetic evolution and phenotypic sorting efforts to facilitate selection of stable, robust strains for outdoor cultivation.
- Encourage outdoor trials with strains grown on non-potable water.
- Synergize polyculture efforts between academic, industry, and national laboratory groups.
- Encourage utilization of model strains as experimental controls.
- Obtain a 1-acre raceway on the mainland for use as a testbed. The largest raceways are currently located in Hawaii, so it is unfortunate that the state's regulations inhibit utilization of model strains. Underutilized capacity elsewhere could be leveraged to produce mainland biomass.
- De-emphasize downstream processing work until sufficient quantities of representative algal biomass can be procured (i.e., 1-10 metric tons) and biomass production strategies have developed sufficiently to approach commercializable production cost (<$500/metric ton AFDW @ 20% solids).
- De-emphasize downstream modeling projects. While downstream modeling efforts have demonstrated significant progress since 2013, upstream modeling needs to be the focus in the next two years.
- Identify quantified tangibles that industry-led projects are expected to report during Peer Review.
- Help presenters to frame their project within the intended overall fuel pathway. The current method of listing Barriers Addressed within a Quad Chart does not sufficiently demonstrate to the Review Panel that the presenters understood the contextualization of their project.

7 What are the top three recommendations to strengthen the portfolio in the near to medium term?

Overall, the portfolio focus is shifting from a target (productivity) to the tools necessary to achieve the target (e.g., genetic manipulation and evolution). This shift needs to be implemented in a more intentional manner across the portfolio. Therefore, the Review Panel respectfully proposes the following:

1. **Focus Projects on Kinetics Improvements:** The current portfolio demonstrates that every processing step along the HTL and ALU pathways is achievable. What is uncertain at this time is whether the kinetics and associated yields make both pathways profitable. That will depend on the quality and consistency of the available feedstock. Projects that focus on the kinetics of the following should be encouraged:
   a. Biomass production. Specifically, carbon, solar, and nutrient conversion efficiencies.
   b. Gene modification targets. Utilize well-understood strains and focus on fundamental identification. De-emphasize additional strain screening.

c. Downstream process work. Only fund these projects if the technology appears to achieve disruptive progress (e.g., 20% cost reduction).

d. Improving kinetics of upstream.

2. **Refocus modeling efforts on upstream processes:**

a. Build a robust upstream model suitable for raceway and photo-bioreactor designs, or their combinations. The model would forecast investment productivity and cash cost of manufacturing. It would need routine validation from real world demonstrations of productivity, quality, and cost, as well as from sustainability information.

b. Increase model bandwidth. A limited subset of algal production systems has been modeled. The current amount of modeling is appropriate, but the intent needs to switch to upstream processes. In addition, it appears that one critical limitation in synergizing existing TEA models with experimental data is the lag time between data delivery and model output. If unaddressed, this limitation threatens utility of these models.

3. **Develop a set of principles for prioritizing funding allocation; these principles could include:**

a. Programs that will benefit all locations have a higher priority than programs that favor only one location.

b. Algae will be grown outdoors in real systems—non-potable water supply, non-arable land, recycled nutrients, year-round, ambient weather, and solar intensity.

c. Work with model systems is limited to 10-20% of total funding; this includes any potable water work.

d. Outdoor trials are run continuously over a sufficient time period (e.g., several months) to demonstrate stability and robustness of strain(s).

e. Outdoor trials are run simultaneously with control experiments using model organisms (e.g., Chlorella).

f. Outdoor programs that focus on production of tons of biomass are prioritized. Tons of quantities are needed to generate basic data for commercial design and feed downstream processing equipment.

g. Proposed programs articulate how they will advance their fuel pathway closer to commercialization.

h. Funded programs, as part of milestones, report true production costs of 20% algae concentrate.

i. Productivity is reported using standardized metrics.

- BETO will choose desired productivity units—either a water-limiting assumption (energy content per m^3 per time), an area-limiting assumption (energy content per m^2 per time), or both. The current permission for individual projects to choose their limiting assumption challenges meaningful, cross-portfolio comparison.

- Biomass is reported as total AFDW, as well as grams of energy content. Three different methods of reporting biomass were noted during this review: AFDW, lipid content, and total energy content.

- Bench-top studies use unidirectional light. Avoid measuring productivity in flasks. This comment is directed to productivity estimates for commercial pond systems (i.e., receiving unidirectional light). Productivity measurements should only be applied to relevant commercializable geometries.

j. Modeling efforts are centralized and validated with outdoor results in real time. Competitive projects use the centralized models.

k. Modeling efforts work toward an overall modeling system, which allows sensitivity analysis of proposed programs' work streams to determine potential impact on production costs.

BETO PROGRAMMATIC RESPONSE

IMPACTS

The Algal Feedstocks Program appreciates that the reviewers recognize that substantial technical progress has been made over the past two years in a variety of areas the Program has focused on. Specifically, the investment BETO has made in the Recovery Act funded consortia projects has generated a wide variety of tools necessary to further the improvements in algae productivity needed to make algal fuels and products economical. The Algal Feeedstocks Program is grateful to be able to support the projects and researchers who have contributed such a great deal to generating success stories with algae products, patents, and publications that will be needed to successfully build an algae industry. The production of the first "algae surfboard" as well as the TERA permit produced by Stephen Mayfield's team at the Consortium for Algal Biofuels Commercialization (CAB-Comm) are excellent examples of these types of successes.
In addition, the Program also believes that the ATP3 standardized analytical and production methods, and the availability of a testbed network with annual production capacity of 20 metric tons, have been fundamental for industry growth.

The Algal Feedstocks Program appreciates the reviewers' recognition of focus on a diversity of projects as a key strength of the Program. The Program focuses on the entire supply chain to produce fuels and products from algae to enable effective process integration; projects span from algal biology and biotechnology (strain development, 'omics tools development, etc.) to resource and techno-economic analysis. This approach has enabled an iterative approach to research and development that ensures strains are being developed that can function in realistic production settings.

We are grateful for the thoughtful comments on issues faced by the algal industry in kinetics. The Program believes that the kinetics of all aspects of algae feedstock production need improvement, and plans to continue investing in these improvements. Specifically, the projects selected from the Advancement in Algal Biomass Yield (ABY) Funding Opportunity Announcement (FOA) are focused on improving productivity in outdoor settings, and the Targeted Algal Biofuels and Bioproducts (TABB) FOA is focused on optimizing the utilization of carbon dioxide to improve kinetics of carbon conversion.

In addition, the Algal Feedstocks Program appreciates the feedback that techno-economic and lifecycle assessment modeling projects and sustainability modeling projects could be more tightly coordinated. The Program will identify additional synergies to leverage and evaluate methods to encourage increased collaboration among these projects.

The Program is also grateful for the constructive comments regarding the makeup of the portfolio. Specifically, it was helpful to gain additional perspective on whether it is necessary to be looking for Chlorella parasites and we will take this under consideration.

INNOVATION

The Algal Feedstocks Program appreciates that the reviewers have provided such positive feedback regarding the innovative projects in the portfolio. The Program agrees that projects in the portfolio are innovative and thanks the Panel for highlighting three main areas of innovation: biomass productivity, downstream processing, and coproducts development. These areas of innovation span a number of institutions within our portfolio and the Program is enthusiastic about these technologies advancing us towards meeting our MYPP 2022 goals.

The first area, biomass productivity, has been a Program priority since the consortia FOA was issued in 2009. Through the consortia FOA, funding was awarded to NAABB, CAB-Comm, Sustainable Algal Biofuels Consortium (SABC), and Cornell University to conduct innovative screening and prospecting for novel and extremophilic strains. In addition, the ABY FOA provided funding for the REAP project, which is focused on further developing these organisms so that they can thrive with high productivity in more extreme environments. The Program is also interested in how this team will address the challenge of sourcing carbon for heterotrophic growth in a commercial setting.

Other focus areas include nutrient sustainability and production cost—variables that must be considered in the development of algae-based fuel technologies. Dr. Ryan Davis at Sandia National Laboratories is conducting innovative work in this area. His team is focused on improving the utilization of algal biomass by considering novel conversion routes for proteins—an approach that holds great potential. BETO is excited to see how this research will affect system design and what impact this may have on BETO cost targets. The Program also believes that work on nutrient recycling will be critical to understanding the use of other sources of nutrients that may help meet sustainability requirements. Dr. Tryg Lundquist, at California Polytechnic State University, is helping to advance this objective through his work on an algal wastewater treatment system.

GAPS

The Algal Feedstocks Program appreciates the feedback from the Review Panel on the perceived programmatic gaps. We also recognize the need for disruptive technologies to be developed within the industry, and our goal is for the majority of our projects to meet these ambitious targets. To this end, BETO is specifically seeking potentially disruptive and "off-roadmap" technologies through the Bioenergy Technologies Incubator solicitations. Successful Incubator projects will reduce the risk associated with potentially breakthrough approaches and technologies so they may be "on-ramped" to future Program roadmaps and the Program portfolio. However, the Program is also aware that it is not possible to predict which technologies are going to be "disruptive," and that it is difficult to define what truly qualifies as "disruptive." Thus, the Program will continue to work closely with stakeholders and our federal collaborators at the DOE Office of Science and the National Science Foundation to learn more about technologies that have been developed at the basic science level to help inform the technologies that show the most promise.

The focus during the past year has been on upstream production of algae for fuels, as evidenced by the forthcoming FY2016 design case (produced by NREL). This report describes the "aspirational design and process targets to better understand the realistic economic potential for the production of algal biomass for subsequent conversion to biofuels and/or coproducts, based on the use of open pond cultivation systems and a series of dewatering operations to concentrate the biomass up to 20 wt% solids." The Program is, and will continue to be, very focused on obtaining more clarity around full mass and energy balances for upstream production to define the minimum production cost. Data from many of the projects funded in the portfolio was used in the creation of this design case and is based on outdoor field trials. The Program appreciates the Review Panel highlighting the importance of continued focus on this part of the supply chain.

The Program found the Panel's emphasis on carbon-based products to be informative. The Program will consider placing emphasis on upgrading the value of carbon and may also support additional sustainability modeling to understand the potential for carbon storage. This is an area that BETO began focusing on through its FY2015 TABB FOA to improve the utilization of carbon, and the Program is excited to see what results these projects will yield. For example, the Program selected a Global Algae Innovations project to increase algal biomass yield by deploying an innovative system to absorb carbon dioxide from the flue gas of a nearby power plant. In addition, Arizona State University will be working on a project focused on atmospheric carbon dioxide capture, enrichment, and delivery to increase biomass productivity.

SYNERGIES

The Algal Feedstocks Program appreciates the Review Panel providing thoughtful feedback on the various aspects of the portfolio that are synergistic and should continue to be supported. Specifically, one of the strains developed in the NAABB consortia, DOE 1412, is now being used as a model strain to benchmark technologies and tools, which allows for improved comparison against other tools and technologies. From our perspective, this is one of the many steps that projects have taken toward improving the ability of researchers in the field to "speak the same language." In another effort to encourage more transparent communication among researchers, the analytical tools and methodologies developed by Dr. Laurens at NREL are being used by a number of projects. The Program agrees with the Review Panel on the importance of standardization, and would like to see all of our projects embracing these methods and standards to enable cross-portfolio comparisons of productivity. The Program will make researchers aware of the preferred methods and research tools in the updated Roadmap, expected to be released in 2016. The Program is considering incorporating standardized methods into award negotiation strategies to ensure this synergy continues.

The Program appreciates the perspective that patterns of approach learned by the Terrestrial Feedstocks Program can be applied to the Algal Feedstocks Program. The Program agrees that there are significant differences in the challenges faced by each program; however, leveraging the lessons learned by the Terrestrial Feedstocks Program can be valuable. The Advanced Algal Systems Program Manager, Dr. Alison Goss Eng, is also the Terrestrial Feedstocks Program Manager and will help facilitate the knowledge-sharing process.

The Program would also like to acknowledge the synergies that the Review Panel highlighted with respect to downstream modeling efforts and downstream processing technologies. We agree that opportunities will continue to become evident with the publication of the upstream design report. In addition, the Program appreciates the Review Panel highlighting the possible duplication of efforts with respect to polyculture and will look for ways to build upon synergies and eliminate redundant efforts.

RECOMMENDATIONS

The Algal Feedstocks Program appreciates the Review Panel's thoughtful feedback and recommendations to strengthen various aspects of the portfolio. The Program agrees with the recommendation that productivity should be reported across our projects using standardized metrics. Going forward, the Program will work with the projects selected from future FOAs to encourage the use of a standardized set of metrics for reporting important parameters, such as productivity. The Program believes that there is not one metric or parameter that will allow for meaningful, cross-portfolio comparison. Instead, the challenges associated with facilitating this kind of comparison lie in the ability to determine a set of metrics that are most appropriate for comparing differing processes. We will continue to work toward identifying these metrics and the appropriate units of standardization.

The Program also appreciates the recommendation to focus projects on improving productivity and the kinetics of biomass production. The Program agrees that it is important to improve productivity, a Program focus for the last several years. As an example, the ABY FOA focused on productivity in outdoor relevant conditions. These projects are currently working on genetic improvements and other fundamental strain work.

Going forward, improved productivity will remain a top priority for the Program. Specifically, in FY2016, the Algae Program will continue efforts initiated in FY2013 and fund improvements in biomass yield, productivity, and incorporation of downstream logistics, using preexisting facilities and infrastructure. This work is critical to achieving the program's 2022 $5/gge modeled production cost goal with up to 20 grams/m^2/day productivity targets.

The Program agrees that our modeling activities are well aligned with the Review Panel's recommendation to focus our modeling efforts on upstream processes. In fact, the Program would like to note that its focus in FY2015 and beyond is directed towards these types of efforts with the forthcoming publication of the FY2016 design case, "Process Design and Economics for the Production of Algal Biomass" (NREL). The Program initiated these efforts in FY2015 when relevant data became available.

The Algal Feedstocks Program—Alison Goss Eng, Christy Sterner, and Daniel Fishman—would like to thank the reviewers for their constructive feedback and informative recommendations. We are excited to see positive benefits from implementing these recommendations and remain committed to designing and implementing a program that is responsive to these comments.

MICROALGAE ANALYSIS

(WBS#: 1.3.1.102)

Recipient:	PNNL
Presenter:	Mark Wigmosta
DOE Funding FY14:	$707,392
DOE Funding FY13:	$566,810
DOE Funding FY10-12:	$556,175
Planned Funding:	$1,584,622
Project Dates:	10/1/2010 - 9/30/2017

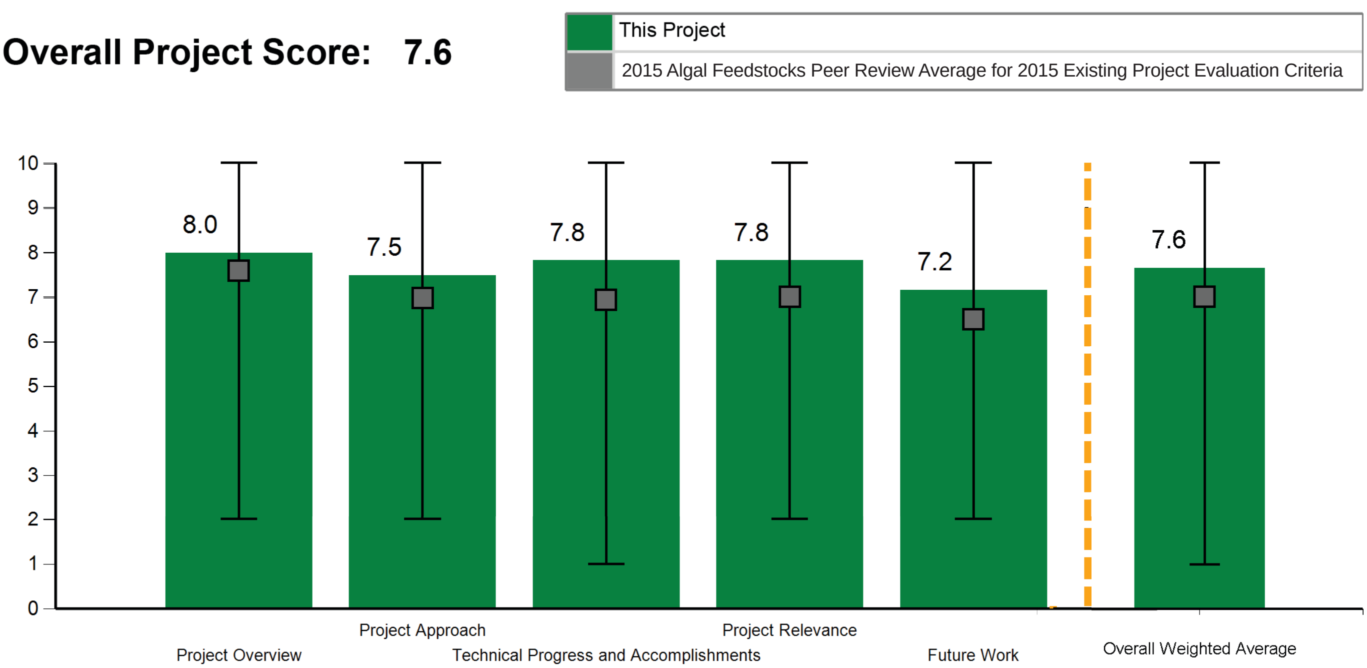
Project Description

This project is developing and applying DOE's high-resolution spatiotemporal resource assessment modeling capability (Biomass Assessment Tool) to quantify commercial scale algal biofuel production potential and associated demands for water-land-nutrient resources and upstream/downstream infrastructure. This research has resulted in 10 peer-reviewed publications, an American Geophysical Union Editor's Choice Award, and citation in a major energy policy speech by the President. Project results to date found that: (1) there is abundance of non-competitive land suitable for open ponds; however, inexpensive land often lacks water and infrastructure; (2) the climate in the southeastern U.S. favors higher annual growth rates over the southwest, though there is increased potential competition for forest and pasture land; (3) freshwater is the most cost effective water source and can support large quantities of biofuel, although risks associated with drought and regulatory constraints require further investigation; (4) given its relatively high resource use efficiency, hydrothermal liquefaction processing requires significantly less land and water when compared to lipid extraction; (5) seasonal variations in production are significant for TEA and LCA and the financial risk of overdesigning downstream processing equipment is less than that of putting ponds in standby; and (6) seasonal strain rotation can be used to dampen seasonal variability and increases annual biomass production.

Overall Impressions

- The establishment of the Biomass Assessment Tool (BAT) is a substantial achievement for the overall field. This model's ability to evaluate system

Overall Project Score: 7.6



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

operation strategies and predict risks as a function of geographic and environmental inputs is broadly valuable.

- This project has been ongoing for several years, and the technical approach has been appropriately executed to maintain a high level of production. The approach can be assessed as a function of achievement of stated objectives and milestones.
- This project is ending, but there would be value to support additional research as a continuation of this work.
- This model needs to iterate its inputs using data provided by other BETO projects: evaluate the 6 model strains (Nannochloropsis, Chlorella, Scenedesmus, Tetraselmis, Phaeodactylum, Synechocystis) used as benchmarks across BETO's portfolio; truth-test the biologists' best case scenarios. Also, be able to be utilized by sites for all three design cases (PBRs/mixed, open ponds, and pumped seawater), as well as those considered suboptimal.
- This is a solid systematic data driven effort that is critical to overall algal biofuel initiatives.
- The model is evolving nicely and has identified that the most productive sites may not be the most commercially viable from an economic standpoint. Care should be taken when interpreting results for water resources, since the notion that freshwater is the 'best' option because it is the cheapest may not hold true as freshwater continues to become a scarce and limited resource (which will elevate resource costs in the long run). Co-location with brackish aquifers, on the other hand, appears viable. Continued assessments of extreme weather impacts on potential site location as well as a comparison of sites co-located with emissions sources versus the base case will be very informative.
- This project involves solid modeling work and continues to bring value to DOE's strategic planning. It is an ongoing effort initiated a few years back and continues to be refined by new information. How that new information flows into the project, and evidence that the project is taking advantage of all possible data sources in the DOE portfolio was not completely demonstrated. Likewise, it is assumed that harmonization with other DOE modeling efforts such as the NREL TEA will continue but this was not described in detail. It would be beneficial for DOE to gauge if the industry itself also uses the model's data to make strategic/siting decisions.
- This is an important part of the program, and it seems to be done in a first class way. The work seems to be highly regarded in academia and industry.

PI Response to Reviewer Comments:

- We thank the reviewers for their kind words, thoughtful questions and welcome suggestions to increase future project benefit to BETO and industry goals. We agree with the reviewer comment recommending the use of data generated by other BETO projects, particularly those being used as benchmarks across BETO's portfolio. We have made a concerted effort to utilize the latest algal strain growth parameters, nutrient demand/recycle data, physical pond data/observations, and biophysical process representation from individual projects (e.g., LANL, UA, ASU), BETO initiatives (e.g., RAFT, NAABB, APT3, REAP, ABY), and industry (Sapphire). As noted in the reviewer comments, the BAT provides a method to "truth-test the biologists' best case scenarios." We have also integrated representation of the latest conversion technologies, including ALU (NREL) and HTL (PNNL). Participation in the DOE Harmonization effort has provided significant benefit to this project and BETO. We feel that this effort must be continued in the future.

ALGAE POLYCULTURE CONVERSION AND ANALYSIS

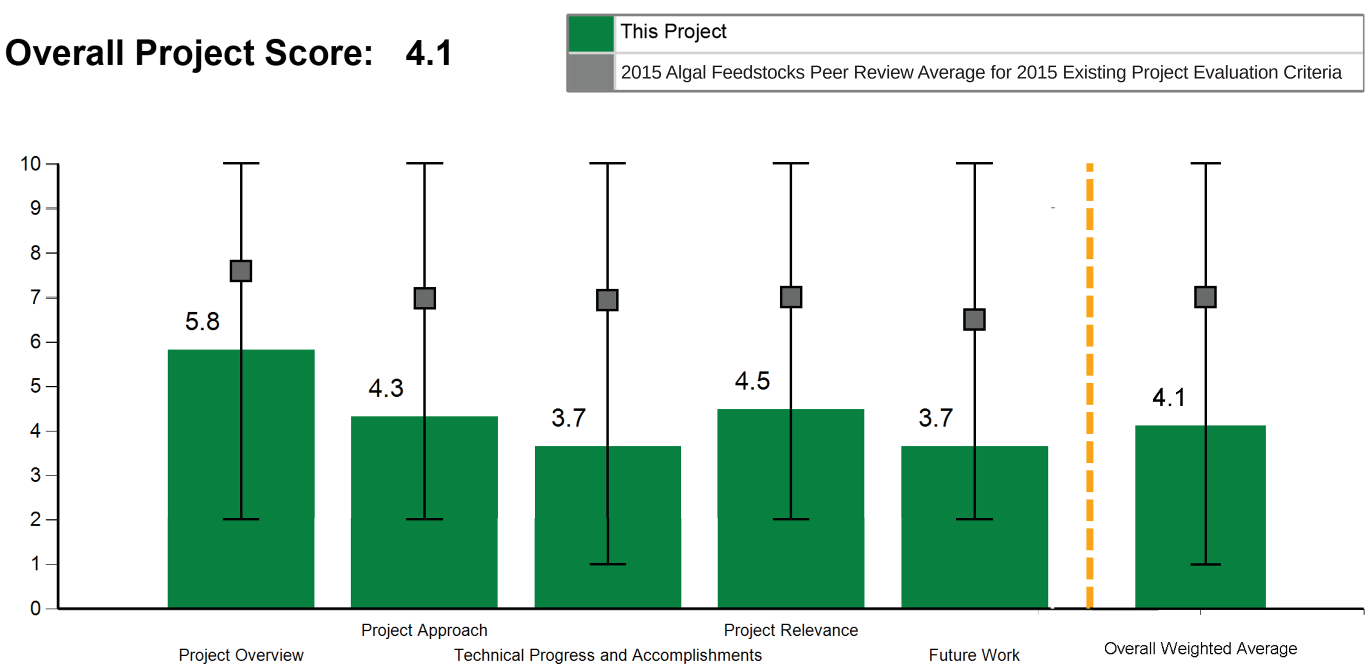
(WBS#: 1.3.1.103)

Recipient:	SNL
Presenter:	Ron Pate
DOE Funding FY14:	$432,688
DOE Funding FY13:	$12,792
DOE Funding FY10-12:	$0
Planned Funding:	$1,853,682
Project Dates:	1/30/2013 - 9/30/2015

Project Description

SNL is investigating the biofuels potential of benthic algal polyculture biomass production using Algal Turf Scrubber® (ATS) system approaches followed by processing and conversion to fuel intermediates using biochemical and thermochemical pathways. Algal turf systems have been applied at commercial multi-acre scales to remediate nutrient-loaded waters by growing indigenous consortia of benthic and phytoplanktonic algae and cyanobacteria to efficiently extract nutrients and oxygenate impaired surface waters. This approach offers benefits over more conventional phytoplanktonic microalgae production in raceways: robust biomass productivities without the need for supplemental CO_2 and commercial fertilizer. The algal turf is easily harvested and dewatered to 6-15% solids using low-energy-intensity mechanical means. A tradeoff is algal turf biomass from currently un-optimized systems typically contains higher ash, lower lipids, and relatively high protein and carbohydrate content. SNL is focused on using the whole biomass with HTL, resulting in a higher N-content biocrude, or using a combination of biochemical fermentation of carbs and proteins followed by hydrothermal liquefaction (HTL) of the residue to yield lower N-content biocrude. Project goals include improving efficiency of conversion processes, assessing the tradeoffs of combining biochem and HTL processing to optimize fuel production and costs, techno-economic feasibility analysis, assessment of scale-up potential, and Hub collaboration.

Overall Project Score: 4.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The project seeks to analyze the microbial consortia and parameters influencing the production of algal turf generated using wastewater (or nutrient rich environmental streams of water) and atmospheric CO_2. The presentation also contends that this approach could be scaled, but there are numerous oversimplifications, and areas of critical importance that have not been appropriately scrutinized.
- The proposed system configuration needs to be contextualized as an environmental water treatment strategy as well as a means of better utilizing resources rather than a viable scalable biofuel production route. This is to say there may be a use for this technology as a means to reduce eutrophication in environmental systems, but it is not likely to be a useful design for standalone development throughout the regions identified as possible locations for development.
- The systems biology of engineering the turf seems taken for granted. While the model hangs together well, it relies too heavily on an assumption that much of the biology will just come along within a very narrow time frame.
- Algae grown on wastewater will at best be a marginal contributor to algal feedstock production; this project will not successfully scale.
- Turf polycultures provide a real world opportunity to understand how polycultures have evolved and work. It is unclear how the turfing strategy is relevant to biomass to biofuel production.
- The first thing that should have been assessed is whether or not current algal turf scrubbers in operation are meeting biomass productivity minimum requirements, but there is no discussion on average and maximal productivities achieved in units to date. If the biomass productivity is currently limited in operational units, how can it be improved to meet targets? Increasing productivity is mentioned as a project goal, but it is unclear how this will be accomplished without carbon supplementation.
- This project will analyze a novel approach to algae cultivation, the ATS benthic algae production system, by attempting to solve current problems with monoculture stability and productivity, nutrient sourcing, and harvesting. Though these systems already exist, preliminary TEA analysis indicates that significant improvement in biomass yields and conversion efficiency will be required to bring down the cost to an acceptable range. Like with all algae, this will be a challenging undertaking and will require a better defined biological plan and outdoor testing strategy to quickly identify potential targets for improvement. There was no indication that the project has a well thought-out strategy to tackle this problem.
- As presented, this program is a solution in search of a problem. It is a technology that works well for polishing nutrients from contaminated water in a once-through system. By definition, such scrubbing systems are low productivity, since the organisms are nutrient limited at least for part of the time. It is thus very unlikely that they can be gingered to compete with so-called 'high-rate ponds.' But perhaps they can. That should be the focus of any ongoing work.

PI Response to Reviewer Comments

- ATS is an alternative algal biomass cultivation approach that enables the very efficient utilization of low nutrient concentration source water to support the natural assembly of benthic algal turf biomass, which also serves as habitat for planktonic species. The periodically pulsed, shallow, turbulent flow operation of ATS provides several mechanisms that contribute to the capability of ATS to achieve relatively high productivities with water having lower nutrient concentrations than required for raceway ponds. These include high exposed surface-to-volume ratio (S/V) of cultivation, turbulence-induced rapid light/dark cycles. This improves photon utilization efficiency of the cellular photosynthetic apparatus, as well as the nutrient and gaseous exchange and breakup of boundary layer gradient limitations that otherwise exist among the algal turf cellular matrix, water, and atmosphere. The robustness of algal turf to naturally self-select and self-organize into a highly diverse and dynamically adaptive species profile has been demonstrated under various conditions. Bioassays will be done with changing conditions for systems engineering assessment, and to provide biological ecosystem insight. Better understanding the systems biology in ATS could have applications to other polyculture systems. We agree that algal biomass production with wastewater will not provide scale-up required for fuels. However, we suggest that sufficient sites are potentially available with non-point surface water to allow for scale-up in local clusters to the levels needed for fuels within the context of also reducing nutrient loading in the water sources. More detailed GIS resource assessment, combined with viable concepts of operations and logistics for ATS-based fuel production scale-up will be undertaken, along with TEA and LCA informed by ATS productivity achieved.

- Data in the literature, along with the experience and expertise of our ATS partners, suggest that significant improvements can be made in the productivity of algal turf biomass by adjusting ATS cultivation and harvesting operations, system sizing and hydraulic loading, and use of improved floway attachment screen to optimize biomass productivity under the expected range of source water nutrient concentrations. Evidence suggests that single-pass ATS productivity with sufficient but relatively low C, N, and P concentrations can be increased to 18-25+ g m^{-2} day^{-1} (d) (AFDW or Ash Free Dry Weight) with optimization. An example case illustrating the potential is an un-optimized 1.85 ha HydroMentia ATS in Florida that averaged 21.6 g m^{-2} d^{-1} (AFDW) during the period of July 17, 2014 - December 4, 2014, and produced 101 tons (AFDW) in CY2014, giving an annual yield of 22 tons/acre (AFDW).
- Current conversion results suggest the MYPP 2017 milestone of 2,500 gge/acre could potentially be achieved with annualized ATS productivities of 15 to 20 g m^{-2} d^{-1} (AFDW), and that 5,000 gge per acre could be achieved with algal turf productivities of 25 g m^{-2} d^{-1} (AFDW) with whole biomass HTL processing. Achieving higher biomass productivities with the least CAPEX and OPEX will need assessment with updated TEA informed by test data, both for upstream biomass production and for downstream processing to fuels. The dual-use capability of ATS providing nutrient removal water cleaning services while producing biomass will also be an important co-product opportunity to offset production costs.
- Although ATS can also be operated in closed cycle recirculating mode similar to raceway ponds, the most significant advantages would be provided through successful single-pass operation that could allow for sufficiently high biomass productivities using relatively low concentrations of N, P, and C available in many coastal estuarine/marine and interior riverine waterways in the U.S. If productivities can be reliably achieved without the need for supplemental nutrients and CO_2, the use of ATS in single-pass mode offers the greatest potential benefit.

ALGAL BIOFUELS TECHNO-ECONOMIC ANALYSIS

(WBS#: 1.3.1.200)

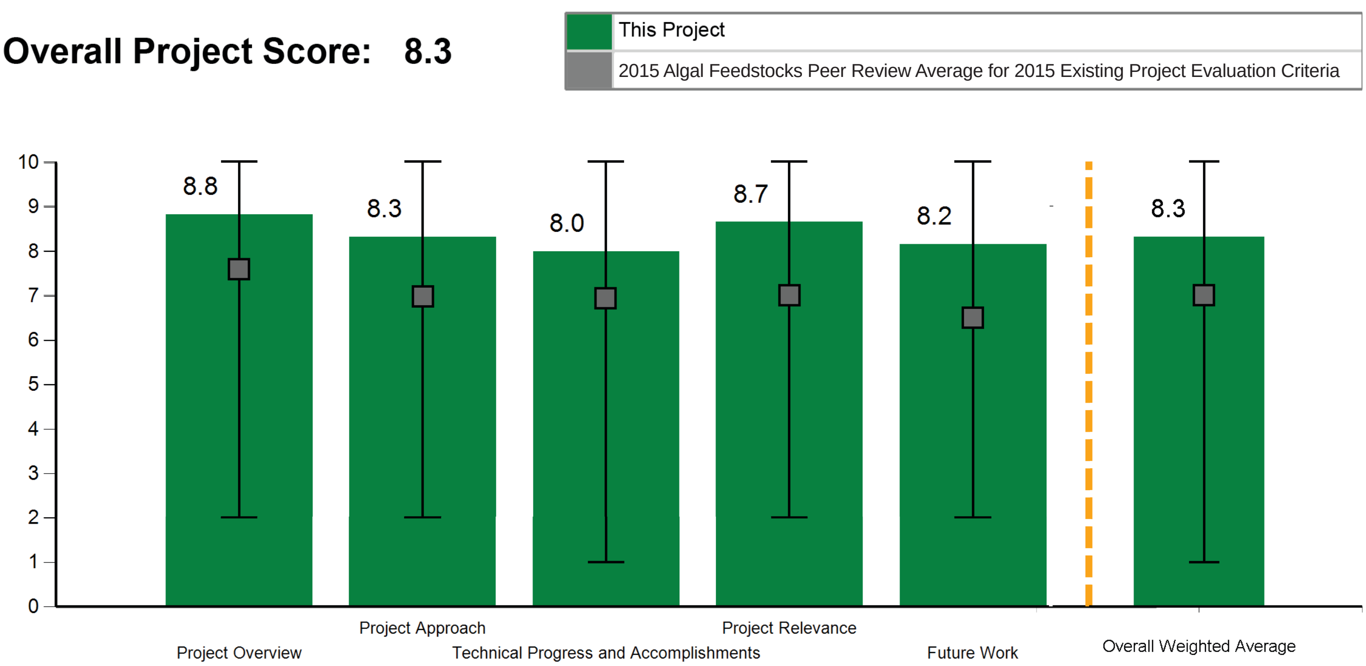
Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Ryan Davis
DOE Funding FY14:	$207,062
DOE Funding FY13:	$254,644
DOE Funding FY10-12:	$369,460
Planned Funding:	$1,012,834
Project Dates:	10/1/2010 - 9/30/2017

Project Description

The objective of this project is to provide process modeling and analysis to support Algae Program activities. The project develops and maintains benchmark models to quantify technology potential using best available public data. Proposed research and alternative processing strategies can be translated into economics that can be compared to the benchmark case to demonstrate the impact toward meeting competitive cost targets. This project is highly relevant to supporting BETO Program objectives, as the analysis work provides a process context for activities funded by the Program, as well as providing a starting baseline to allow for setting targets to be met by future Program research. Moreover, a primary

Overall Project Score: 8.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

objective of the project is to address the large disparity in public claims regarding cost potential for algal biofuels by establishing rigorous, peer-reviewed cost models. Much of the techno-economic analysis (TEA) work is done in a collaborative fashion with other laboratory partners, and is also leveraged in external DOE-funded activities, such as interactions with consortia groups. The project has made significant achievements since the 2013 Peer Review, including participation in a 2013 hydrothermal liquefaction (HTL) harmonization analysis with partners at ANL and PNNL, as well as publication of a 2014 design report documenting cost projections for a novel biomass fractionation process for conversion of algal carbohydrates and lipids into fuels.

Overall Impressions

- Multi-year downstream modeling project (part of broader algae TEA analysis) that has yielded many useful reports and peer reviewed analysis. Dynamic models and TEAs such as these are useful for framing the challenges of optimizing complex biochemical systems. The models being developed as part of this project are relevant for BETO, and can help contextualize the success of other projects. In fact, data on feedstock composition and yield from any number of researchers can be fed into this downstream analytical tool to assess viability and direct new research efforts. Past success and utility of the established models portend future success.
- The HTL design case is only $0.14/gal higher in cost than the ALU design case. Is the cost differential for the two cases really only 3%? Until that differential is definitively known, BETO may not be able to make a decision on how best to move forward.
- Necessary systematic analysis is to consider key economic issues and provide relevant comparisons between options. All programs should conduct TEAs on a consistent basis before activating a lab program.
- This work is critical for the field to progress and provides a metric against which new technologies can be assessed. The upcoming cultivation models are overdue and will be essential to bring the costs of feedstock production down to target values.
- This is an essential project in DOE's portfolio, and key to their decisionmaking. The key is for the project to access and properly utilize all available information and build a flexible and useful model. The project seems to be on that path. An over-arching problem, which they do not control, is the lack of realistic production data. Hopefully, future work with the test-beds and industry collaboration will assist with this.
- This is a foundational part of the algal biofuels project, and indeed of the whole biofuels program. Using standardized tools and assumptions, it allows comparisons across multiple platforms. My only concern is that some people take these analyses as conclusive. Issues surrounding CO_2 delivery and nutrient recycling may radically alter the benefits of different processes, so while the work should definitely continue, it should be thought of as a "work in progress" despite its apparent quantitation.

PI Response to Reviewer Comments

- We thank the peer reviewers for their complimentary and insightful comments, and appreciate the acknowledgment of the relevance for this project toward supporting BETO and the broader R&D community.
- Regarding the comment toward the cost differential between the algal lipid upgrading (ALU) and HTL pathways, both the ALU and HTL design reports represent a substantial amount of modeling work 'from the ground up' to establish a minimum fuel selling price attributed to a given set of technology projections for each respective conversion pathway. The resulting design reports document the details

of all modeling inputs and assumptions, which are subjected to a thorough peer review/vetting process with external industry and research stakeholders prior to being published. The resultant MFSP (minimum fuel selling price) estimates shown in the ALU and HTL design reports are thus the product of extensive analysis, and are coincidental in how closely they correspond with each other. The aspect that is not coincidental is that the MFSP for both pathways' base cases fall in the range below \$5/gge, which was a goal set by BETO from the "top down" in showing what would be required for each pathway in achieving such a cost target threshold (for example, biomass compositional attributes, conversion yields, intermediate product specifications, etc). An additional benefit unique to the ALU pathway, which has not yet been explored in detailed TEA nor captured in current MFSP projections is the "plug-and-play" flexibility to swap out alternative processes to convert biomass component constituents to higher-value coproducts. This is enabled by the biochemical fractionation approach to non-destructive isolation of key biomass components rather than whole-biomass thermochemical conversion. This allows for valorizing algal biomass based on its compositional makeup for fuels and coproducts, which is a renewed area of focus under BETO's bioeconomy vision that we plan to pursue moving forward.

- Regarding the comments around the use of realistic data and impacts of modeling inputs on the results, this is a point we agree with and take care to document clearly where warranted. While the ALU conversion 'back end' is now based on a process that has been experimentally validated and is continuing to be developed at NREL, a number of front-end attributes associated with cultivation and dewatering do suffer from a continued lack of commercially relevant, meaningful data as required to populate the models. Consequently, some of these aspects have been forced to rely on proxies for other established industrial practices. However, we anticipate that this will continue to improve as data becomes available from test-bed consortia and other partners. In the meantime, to quantify the impact on overall economics related to such data gaps (as well as other inputs and decisions attributed to process integration such as CO_2 and nutrient logistics), sensitivity analyses are conducted and included in all major TEA reports.

SUSTAINABLE DEVELOPMENT OF ALGAE FOR BIOFUEL

(WBS#: 1.3.1.500)

Recipient:	ORNL
Presenter:	Rebecca Efroymson
DOE Funding FY14:	$183,310
DOE Funding FY13:	$263,026
DOE Funding FY10-12:	$0
Planned Funding:	$3,878,664
Project Dates:	10/1/2012 - 9/30/2017

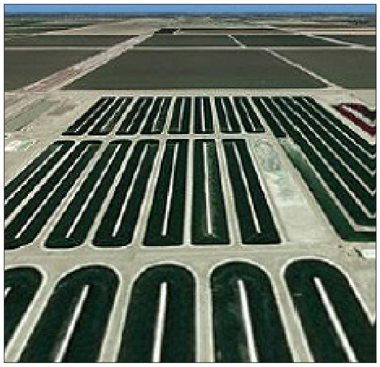
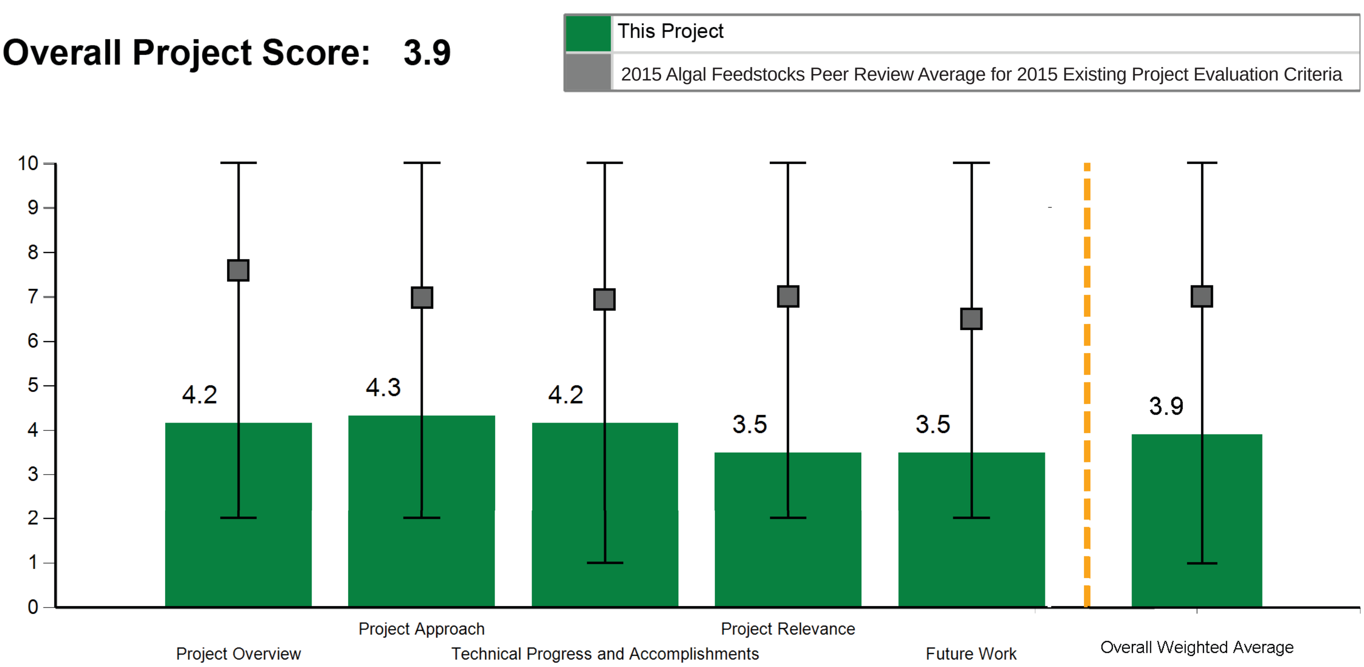


Photo Courtesy of ORNL

Project Description

The project is designed to support the development of a sustainable and cost-effective domestic supply of algal biofuels. Task 1, sustainability studies, includes identification and testing of environmental and socioeconomic sustainability indicators and development of targets and best management practices through case studies. In situ biofilm pond liners are being developed to determine whether this cost-saving option will be viable for a variety of soils and, at the same time, maintain groundwater quality and water quantity. Task 2, resource analysis, is focusing on resource co-location options that benefit the algal biofuel industry by reducing resource costs and benefitting other industries and utilities because of their waste disposal needs. Supply curves for algal biofuel facilities co-located with ethanol plants and coal-fired power plants will be included in the Billion Ton 2016 report. Task 3, the use of algal polycultures to increase annual algal biomass productivity, focuses on the basic ecological principle that increased diversity leads to increased productivity, decreasing susceptibility to population crashes. Results include identification of environmental and socioeconomic indicators and cost assumptions for co-location scenarios. Tasks are designed to address sustainability problems and will involve industry and university partners in crafting solutions. Challenges include obtaining industry data on sustainability and costs of production.

Overall Project Score: 3.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project sited three areas of specific focus: sustainability (seemingly over focused on developing bioliners for algal ponds), resource analysis, and studying polycultures. The presentation and mixture of objectives appears disjointed, and the projects do not complement one another well or benefit from being joined as a broader project.
- The overall impact of this work is limited by the lack of cohesion among the areas of research. It is unclear how overall relevance can be attributed to the broader base of work, and each area needs to be assessed individually.
- ORNL's negative sustainability assessment of the use of freshwater in algal production has not been successfully communicated to the rest of BETO's algal feedstocks portfolio. The assumption that a viable algae feedstock industry can be built on anything other than nonpotable water, according to ORNL's assessments, risks cultural acceptance at scale.
- Goals and strategies need to be more specific.
- The problems identified during the 2013 Peer Review for this project have not been resolved.
- This is a diverse project that touches on the topics of sustainability indictors, pond liners, national assessments of algae co-location potential, and algae polycultures. Other than the fact that these projects all occur at the same national lab, it seems the pieces would be better placed within other DOE projects. This is already the case for the polyculture study, which is within the polyculture Hub. It is hard to assess whether there is any interaction between the pieces as of now. Most pieces will have value if integrated into the portfolio properly, though DOE should funnel resources towards projects that will advance the field toward the MYPP goals. Integrating algae biomass into the Billion Ton Study (BTS), when almost all production scenarios are speculative at this point, unlike agriculture, seems premature.
- It seems a group of disparate pieces brought together to justify a program, rather than a well thought out collaboration aimed at commercializing algal biofuels. I urge the participants in this team to forge a clear vision of why this work should be considered together—how do different parts exert synergism?

PI Response to Reviewer Comments

- The connectivity of the individual tasks and their relative maturity must not have been adequately communicated during the Peer Review. We submit that all tasks relate to sustainability and best practices: resource analysis emphasizes co-location scenarios and relates to profitability, productivity, energy return on investment, greenhouse gas emissions, and water quality; the bioliner task relates to profitability, water quality and water quantity; and the polyculture task relates to productivity and energy security (maintaining constant supply). The investigators benefit from having hydrogeology, algal ecology, sustainability, and economics expertise in a single project. Algal biomass is significantly different from other bioenergy feedstocks, so managing the algal biofuel work at ORNL together helps assure coordination of our algae work.
- However, we also view all algae tasks as part of a larger matrix management system, whereby our interactions with PNNL and INL, for example, are as strong as our interactions within the ORNL project and beneficial for all tasks. Therefore, the investigators are open to task arrangements other than the current arrangement in a single project.
- BETO is strongly committed to the development of sustainable biomass resources (both algae and

terrestrial) and this commitment is reflected increasingly in the MYPP. The Algal Feedstocks Technology Area has a goal to model "sustainable" supplies of biomass (2017 and 2022), and the Sustainability Area has the goal (2022) to evaluate sustainability indicators across the supply chain for algal bioenergy production systems to validate particular sustainability targets. Therefore, this project is well positioned to address MYPP goals.

- One reviewer felt that integrating algae into the Billion Ton 2016 report is premature, given the speculative nature of production scenarios. While it is true that the dominant commercial-scale production technologies are still uncertain, it is not unreasonable to estimate algae biomass potential, given specific, well-defined assumptions that are consistent among DOE-funded studies. We plan to present algal biomass supply curves by themselves and integrated with terrestrial supply. This addition of algal biomass to the Billion Ton 2016 is a direct response to stakeholder feedback following the 2011 Billion-Ton Update. Moreover, we are investigating the cost savings that can be attained when different resource co-location opportunities are assumed. These assumptions are analogous to some of the practices considered in previous Billion Ton reports with respect to terrestrial biomass supply.

- One reviewer commented on the importance of using non-potable water for algae cultivation. While we have not yet undertaken a formal assessment, we believe that non-potable water will comprise a large fraction of the water used for cultivation in the future.

- We appreciate the suggestions outlined in this review and will work to address the key questions and continue to strengthen the connectivity to the work of external researchers and the algal biofuel industry.

ALGAE BIOTECHNOLOGY

(WBS#: 1.3.2.100)

Recipient:	LANL
Presenter:	Babette Marrone
DOE Funding FY14:	$1,379,973
DOE Funding FY13:	$266,211
DOE Funding FY10-12:	$0
Planned Funding:	$5,653,816
Project Dates:	10/1/2012 - 9/30/2015

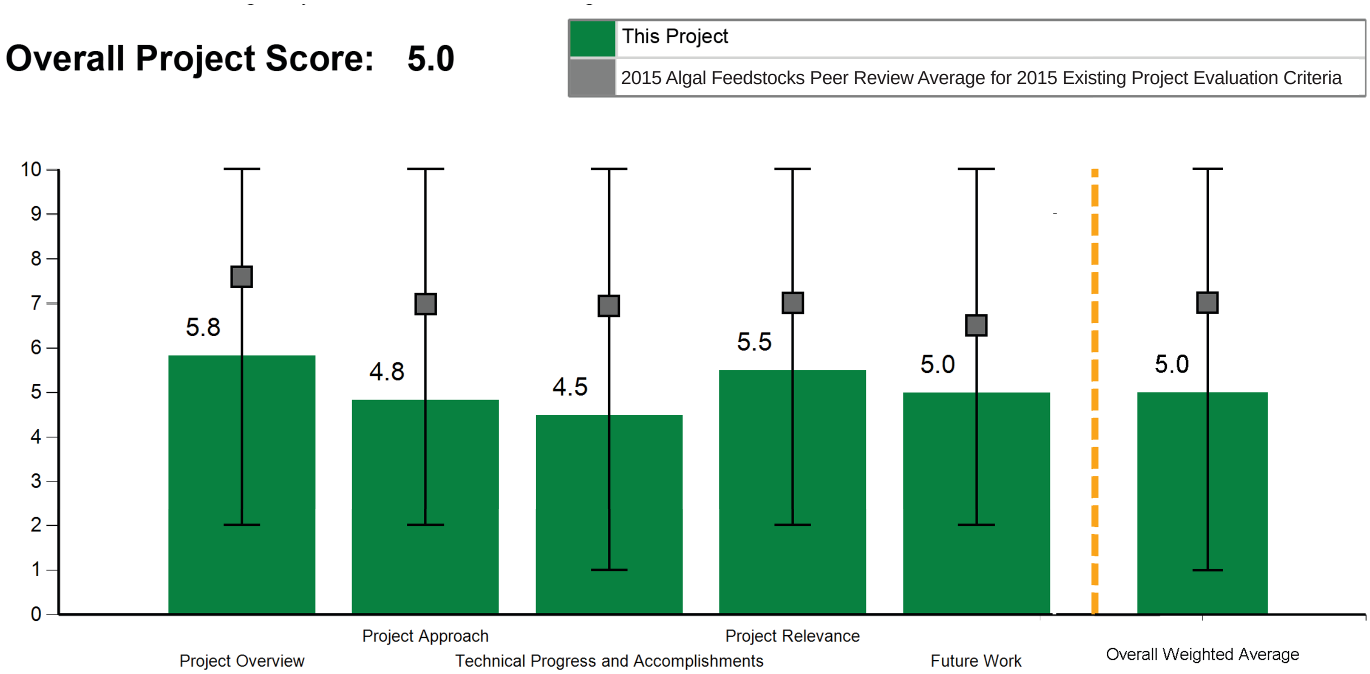
Project Description

Algae biofuel production needs improvements along the entire value chain to achieve high yield at low cost. The objective of this project is to advance specific technologies, as identified in the National Alliance for Advanced Biofuels and Bioproducts algae consortium (NAABB), further towards commercial adoption. We targeted the technologies of strain improvement; CO_2 delivery to cultivation; and harvesting. We developed a strain of C. sorokiniana with higher biological productivity and greater heat and salt tolerance; and developed a strain of N. salina with greater carbon use efficiency. We also developed a flow sorted N. salina strain with 27% greater lipid accumulation. A unique CO_2 delivery system was developed and evaluated at lab-scale; and an ultrasonic algae harvesting approach developed in NAABB was further matured in technical readiness. Finally, we created a website (Greenhouse) and bioinformatics/analysis toolbox for storage, management and integration of algae genomics and cultivation data. In FY15, the strain improvement and omics website activities were integrated with selected algae biotechnology efforts at NREL and PNNL to create an Algae Biotechnology (AB) Hub. The objective of the Hub is to coordinate AB activities that will facilitate transition of new and improved algae strains to widespread deployment in the algae biofuel and bioproducts industry. The envisioned impact of the Hub will be higher yield and lower cost of algae feedstocks for biofuels.

Overall Impressions

- This project seeks to extend valuable research started with NAABB. The areas of focus (strain and productivity improvement) are generally relevant, and are the most important areas of consideration for continued research into algal systems at this time.

Overall Project Score: 5.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

The approach to improve CO_2 utilization needs additional technical scrutiny to assess its potential viability at scale. Overall, the researchers are making progress, publishing papers, and sharing their relevant results. These accomplishments appear to be in line with expectations.

- While this project is extremely relevant to BETO's goals, the continued use of small scale test beds is significantly hampering future progress.
- Productivity needs to be reported as unit of growth per unit of insulation per time (whether growth is expressed per volume or per surface area). This cannot be extrapolated from a batch growth curve. The current optical density (OD) metric is qualitative and insufficient.
- The continuation of this project should be focused on the Algae Biotechnology Hub exclusively, because this is the strength of the overall project and has produced the most relevant technical accomplishments. Work should continue development in those areas only and should not include plans for logistics R&D (e.g., cell lysis, harvesting, and separations technologies).
- This project claimed to address gaps in basic R&D that do not receive the required amount of funding but are fundamentally important to understanding algae and meeting the ultimate goals of the field. That is an important point, but with limited resources and in an applied R&D program, the work should still be decisive and have a solid basis. This project covered several topics: strain improvement, a harvesting technology, a CO_2 delivery system, and a new web platform. Although some improvement was seen, there was not enough detail presented about why these technologies were chosen, how they are leveraging the expertise of researchers in performing this work, and why they are better than the state of technology (SOT) of competing technologies. The limited time for the presentation is a factor in this. I think the transition of this work into an algae research hub will help to focus and direct the expertise of the researchers into the most appropriate questions, and hasten the transition to scale.
- This program would benefit from a re-evaluation, and needs to be carefully stewarded to realistic goals.

PI Response to Reviewer Comments

- We will consider the suggestions on how to improve our metrics to try to more closely match the metrics used at large scale to measure productivity. As mentioned in the presentation, the ultrasonic harvesting research is being transitioned to a competitive project this year. In hindsight, it appears that the reviewers would have liked more detail on one or two accomplishments, rather than coverage of the breadth of accomplishments over the past two years in less detail.

MULTI-SCALE CHARACTERIZATION OF IMPROVED ALGAE STRAINS

(WBS#: 1.3.2.102)

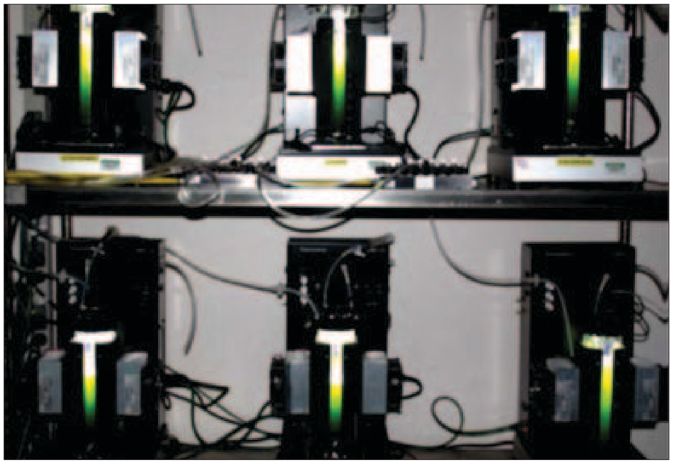


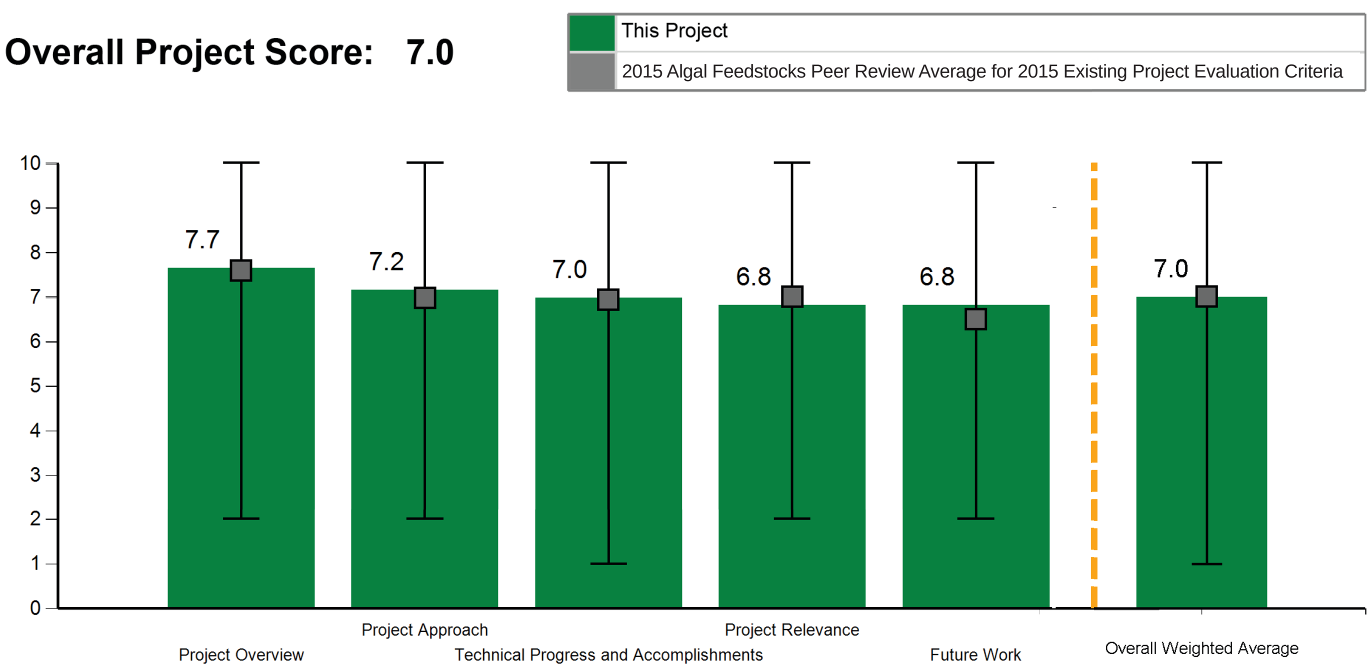
Photo Courtesy of LANL

Recipient:	LANL
Presenter:	Taraka Dale
DOE Funding FY14:	$255,538
DOE Funding FY13:	$225,000
DOE Funding FY10-12:	$0
Planned Funding:	$1,388,922
Project Dates:	10/1/2012 - 9/30/2015

Project Description

The overall goal of this project is to develop a streamlined process for improving algae strains and characterizing their performance at multiple scales, from the bench to outdoors. A problem with laboratory-developed algae strains is that they often do not perform as well or as predictably in outdoor conditions. This leads to the questions: How do we predict which strains will perform best outside? How do we effectively transition strains from the lab to the pond? These questions will be addressed by achieving the following objectives: (1) establish a pipeline for evaluating improved strains under conditions simulating outdoor climate conditions; (2) generate additional improved algae strains; and (3) transition strains to outdoor ponds for testing. In FY13, the project team launched the pipeline using the example strain, Picochlorum sp. In collaboration with PNNL, the data was utilized to refine the biomass growth model

Overall Project Score: 7.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

such that it accurately predicts the areal productivity of this strain. During this process, the project team made the necessary modifications to the panel of Phenometrics environmental photobioreactors (ePBRs) and improved the system reproducibility. In FY14, the project focused on strain improvement, generating four improved populations of Chlorella sorokiniana. In FY15, the project team submitted two C. sorokiniana strains to the pipeline, continued to develop strategies for strain improvement, and will execute a plan to move the most promising strains outdoors, in collaboration with the Algal Testbed Public-Private Partnership (ATP3) facility.

Overall Impressions

- Project scope is well defined and scope is limited to strain development and testing. This project seeks to establish a pipeline for strain development with an experimental philosophy that rapidly tests strain productivity under appropriate environmental conditions. The prediction tool could be very valuable. The ability to identify (engineer) strains that may be better adapted for useful environments, rather than finding appropriate environments, may improve strain development strategies.
- Dr. Dale delivered one of the highest impact projects in the portfolio this Peer Review. Her results, while not perfect, demonstrate that her flow-sorted phenotype technique is an opportunity to vastly improve production kinetics and the productivity performance of strains. It is highly recommended to continue support, with funding as well as access to resources (including large outdoor raceways), to further develop her work.
- This is a good strategy. The project neeeds to redirect to more commercial relevant systems.
- The project has done a good job on closing the difference between the Biomass Assessment Tool (BAT) predictions and indoor cultivation (ePBR/pond) performance for certain strains. Improving algal phenotypes via flow cytometry has been conducted successfully by several labs in the last few years, but data is missing for long term phenotypic stability of these cultures post-selection. It is intriguing that this project has produced several phenotypically stable cultures, and the project should now include plans for monitoring data on genetic and phenotypic stability of these cultures over time.
- This project is addressing a fundamental and critical issue in algae production: how to predict the outdoor performance of algae based on lab-scale results. The iterative process between the scaled up production systems and the BAT model is sound. Improvements could be made to streamline the process to get to true outdoor testing. This will likely occur with the project's integration into the new algae biotechnology hub and the kick-off of their work with the ATP3 test bed.
- This work was not funded adequately to conduct the proposed work. It needs to redirect its efforts to seriously measure productivity in units of relevance to outdoor production. I cannot imagine a process that starts cultures from scratch every three weeks with a minimal inoculum, and waits for growth to occur. Rather, all the commercial models I know of (e.g., Cornell project) predict that cultures are inoculated at high density, and harvested semi-continuously, keeping the culture near its sweet spot where it absorbs almost all the light at its dilutest, and all of it at its densest. This requires a doubling time, close to once per day, and several people to do the work.

Response to Reviewer Comments

- Thank you. We believe our progress to be exciting and look forward to continuing this work.
- We regularly collect phenotypic data on our strains. Also, the genome of the sorted Picochlorum sp population has been sequenced, and the parent

Picochlorum sp population was re-sequenced at the same time. A stronger effort toward regular monitoring of genetic stability, to complement our current phenotyping work, would be useful.

- We appreciate the support and agree that this work aims to tackle an important problem. Now that the pipeline is established, we have FY16 plans for making the process more efficient, and should be able to move strains to the outdoor testbeds more quickly in the future.
- While it is true that in a commercial setting a culture will not typically be started at a very low density and grow out to saturation, the growth experiments shown in the presentation were designed with two goals in mind. First, we aimed to compare the parent and cell sorted populations as completely as possible, and this included measuring maximal specific growth rates from the exponential growth part of the growth curve as well as the final maximal biomass accumulation at saturation. It was important to measure the full growth curves of these strains and compare that data to similar experiments conducted in flasks, as a goal of this project to examine the performance of these strains at multiple scales. The second goal was to measure an areal productivity (g/m^2-day) that would be meaningful in an outdoor setting. PNNL has previously demonstrated that areal productivities measured in outdoor ponds, during the linear growth phase of a culture, can be mimicked in the PNNL indoor ponds and accurately predicted by the Biomass Assessment Tool. In this presentation, we also showed that the ePBRs can obtain similar areal productivity values during linear growth, thereby demonstrating that this measurement of areal productivity is one that can be made across multiple scales, in the lab and outdoors. Therefore, it is a useful measure for ranking strain performance and downselecting strains for outdoor growth. It is also important to note that the Biomass Assessment Tool can simulate various semi-continuous harvesting strategies, in order to predict which dilution rate is optimal for a strain of interest. This part of the BAT is already in use in other BETO-funded projects, and as our strains are incorporated into the BAT, we can predict and measure productivities during semi-continuous harvesting in the future. The most promising strategies can then be tested outside at the ATP3 testbed.
- Our system is commercially relevant. The top performing productivity of which we are aware in outdoor open ponds is 23 g/m^2-day (Cellana/Cornell project). Prior to that, a benchmark strain was Chlorella sorokiniana DOE 1412, which showed a 15 g/m^2-day productivity outside. In our project, the indoor pond productivities for C. sorokiniana and Picochlorum sp. were 13 g/m^2-d and 16 g/m^2-d, respectively. Also, since the Peer Review, we observed a 22 g/m^2-day productivity for the sorted C. sorokiniana in the PNNL ponds. Therefore, our productivities are in line with, or on the high end of, the current industry. Also, there was some concern that we were only working with freshwater strains; however, the Picochlorum strain used in this project is a marine microalgae.

MAJOR NUTRIENT RECYCLING FOR SUSTAINED ALGAL PRODUCTION

(WBS#: 1.3.2.200)

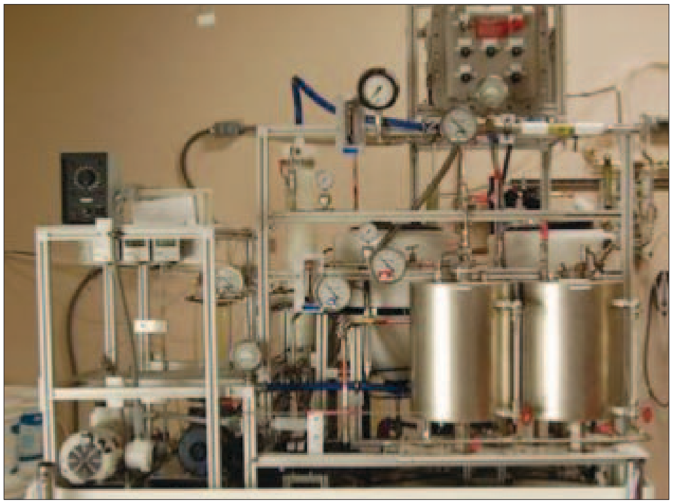


Photo Courtesy of SNL

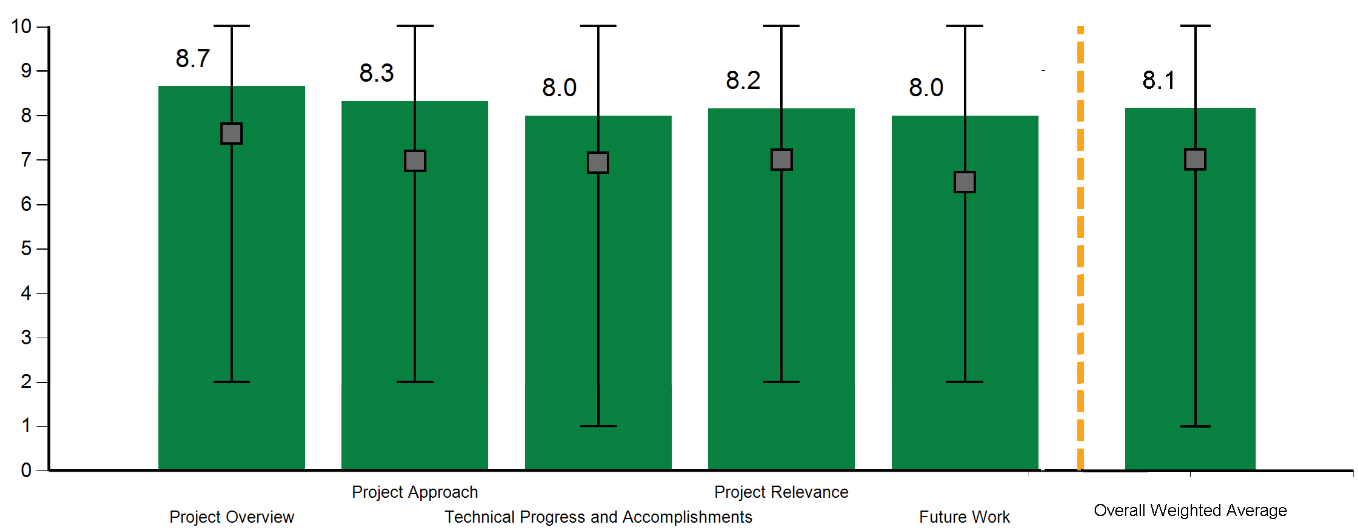
Recipient:	SNL
Presenter:	Todd Lane
DOE Funding FY14:	$624,087
DOE Funding FY13:	$203,565
DOE Funding FY10-12:	$0
Planned Funding:	$1,698,743
Project Dates:	10/1/2013 - 9/30/2016

Project Description

A consortium of researchers from Sandia National Laboratories, Texas Agrilife Research (TAMU), and Open Algae is developing a novel, cost effective, and efficient remineralization process to convert organic forms of nitrogen and phosphate present in algae, to chemical forms that can be liberated from the harvested algal biomass, then readily captured and returned to algal mass culture systems. These chemical forms would be capable of supporting algal growth. To date, the project team has developed methods for the rapid remineralization of up to 70% of the cellular phosphate from osmotically shocked, non-denatured algal biomass using endogenous enzymes under a range of relatively mild incubation conditions. The efficiency of conversion and the quality of the remineralized phosphorous was determined by standard nutrient and growth assays and the recalcitrant

Overall Project Score: 8.1

This Project
2015 Algal Feedstocks Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

cellular phosphate pools remaining in the biomass was characterized by biochemical analysis. The phosphate released in the process supports equivalent algal growth and does not contain any growth inhibitory compounds as evidenced by multiple sequential cycles of growth and nutrient remineralization. The project team has also demonstrated the remineralization of nitrogen through the fermentative conversion of amino acids to ammonium. Finally, the project team has demonstrated the potential for the integration of our nutrient recycle protocols with biomass processing methods such as those for the extraction of neutral lipids.

Overall Impressions

- The project seeks to optimize methods to effectively recycle inorganic nutrients such as phosphorus via a remineralization strategy that recovers nutrients as struvite for recycle. The concept of "peak phosphorus" is real, and is indeed the Achilles heel of agricultural systems and algal systems alike. The ability to effectively recover phosphorus and other nutrients from wastewater streams has broad applicability and is particularly relevant for establishing "sustainable" algae biofuel systems.
- Intuitively it seems likely that recycling nutrients is an energetic savings over mined nutrients. This work lacks an accurate model comparing the costs of using mined nutrients vs. recycling nutrients using this technology. Further, it seems prudent to work with cyanobacteria. Even if it is possible to increase recycling efficiency of N above 57%, N-fixers will be required to supply sufficient nitrogen at scale.
- This is solid, data-driven work addressing a key issue for all algae production platforms. The fundamentals established with this work will guide future work in this area.
- This is the best example of a nutrient recapture and recycle project in the BETO portfolio, and it has a high likelihood of continued success. The proposed process would advance the state of the art by successfully recycling large amounts of nitrogen and phosphorus while simultaneously producing multiple fuel products (i.e., lipids and butanol) at several points in the processing chain. The experimental design has been appropriately dictated by multiple go/no-go targets that reflect critical success criteria. The PIs have made superior technical progress in relation to initial targets for growth of algae on captured and recycled nutrients in the form of struvite, which is a solid that could be easily and cost effectively transported.
- This project addressed a major issue for algae biofuels scale-up: the high requirement for N and P in the culture medium. This project proposes a few techniques to capture the N and P from residual biomass after lipid is extracted, and reuse these nutrients to support growth. The first phase of results are promising. Even if this technically works, the long-term issues will be optimization for different algae, and determining if this is an economically sound choice relative to other biomass use or nutrient options. These technologies are also not, at this point, compatible with a pathway like HTL.
- Nutrient recycling will be one of several essential features of algal growth at scale, and this project is addressing the issue in a solid manner. It is very good that BETO is assessing both the cell lysis and enzymatic hydrolysis of this project and the anaerobic digestion approach of the CalPoly work.

PI Response to Reviewer Comments:

- Reviewers have pointed out the need to carry out techno-economic analysis (TEA) and lifecycle analysis (LCA) on our processes. TEA and LCA are outside the scope of the funded statement of project objectives (SOPO), so our ability to carry out such analyses is very limited. If additional resources were made available from BETO, we would be able to carry out robust and detailed analyses in collaboration with experts at the NREL and ORNL.

- A reviewer suggested that we extend our work to include cyanobacteria. We can carry out limited nutrient extraction trials with cyanobacterial biomass as suggested by the reviewer. However, we believe that our ability to carry out additional experiments with cyanobacteria are limited under the scope of the currently funded SOPO. If further funding was made available, we would be able to carry out more extensive cultivation and nutrient recycling experiments with cyanobacteria.
- A reviewer suggests that long-term issues include optimization for additional algal feedstocks. We agree that this is indeed important. Our nutrient recycling processes are already being developed for a diversity of algal lineages and preliminary results indicate that our methods are likely to be generalizable to a variety of algal feedstocks.
- A reviewer stated that “These technologies are also not, at this point, compatible with a pathway like HTL.” We respectfully disagree on the potential compatibility of our nutrient recycling processes with HTL. There are few limits on biomass treatment prior to HTL; that being one of the strengths of the process. The phosphate remineralization process that we have developed and demonstrated would have no impact on the suitability of the residual biomass for HTL. Likewise, nitrogen recycling by protein fermentation can be employed upstream of HTL and, unlike the nitrogen containing raffinate from HTL, is likely to result in a nutrient product that is not contaminated with growth inhibiting compounds.

RECYCLING OF NUTRIENTS AND WATER IN ALGAL BIOFUELS PRODUCTION

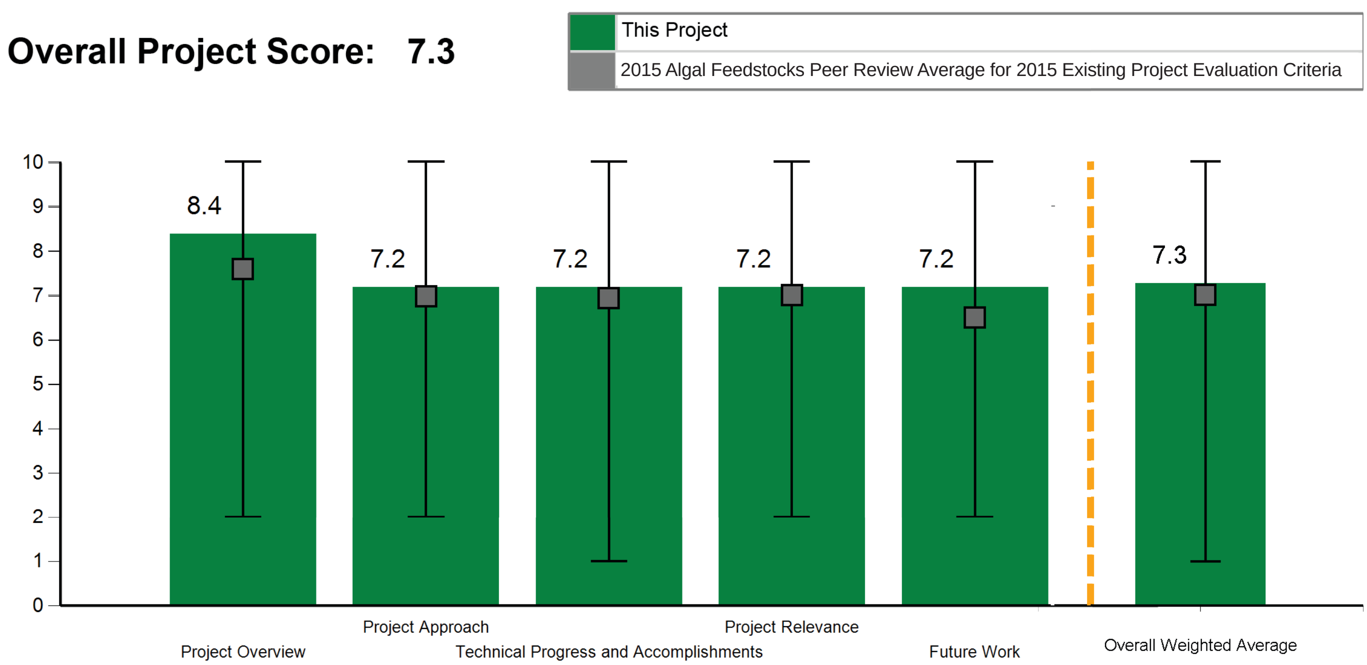
(WBS#: 1.3.2.201_Z)

Photo Courtesy of California Polytechnic State University

Recipient:	California Polytechnic State University
Presenter:	Tryg Lundquist
DOE Funding FY14:	$294,139
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$951,982
Project Dates:	1/31/2013 - 1/31/2015

Project Description

The objective of this project is to develop and demonstrate efficient recycling of water and nutrients in algal biofuels production. The main objective is to achieve at least 75% recycle efficiency (without significant loss in culture stability and productivity), both for the water recovered after harvesting the biomass and also for the nutrients. The project is conducted at the City of San Luis Obispo (California) Water Reclamation Facility. The algal biomass is harvested by a low-cost settling process ("bioflocculation"), aided by centrifugation as needed. The supernatant water is recycled back to the cultivation ponds. The harvested algal biomass is anaerobically digested to produce biogas. Prior to digestion, the biomass will be pre-treated, if required, to break the cells (for transportation fuel production, the standard model includes digestion of residual extracted biomass to recycle carbon and nutrients). The digester effluents, containing the entire suite of inorganic nutrients (N, P,



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

K and minor nutrients) will be recycled to the growth ponds. The results of those operations are compared to controls without water and nutrient recycling. Make-up water and nutrients are provided by settled wastewater or by fresh water and chemical fertilizers. Nutrient and water recycling is carried out in replicate experiments and over several months of continuous operations to demonstrate a stable process for maximal nutrient and water recycling in algae biomass production.

Overall Impressions

- The project seeks to study nutrient recycling among a unique algal / digester wastewater treatment system. This system has advantages for study in that it is already at pilot scale, and the researchers have the benefit of learning by doing. However, this constrained system configuration may limit the broader impacts of the results.
- It is concerning that this project has 15 months left to deliver 10 tons of biomass for HTL processing and still planning to screen strains. By default this approach is polyculture work; a more relevant use of funding would be to tease out the most productive parts of the ambient polyculture. Does upcycling the DOM in wastewater via a biological algal catalyst yield a higher quality energy feedstock for HTL than concentrated DOM?
- This is solid work on a critical need for all algae systems.
- This is an example of an outstanding body of work being accomplishing at a primarily undergraduate institution that is not only producing quality technical outputs, but is also contributing to the education, training, and development of a workforce with specialized skills in algal technologies. The water treatment process is an 'enabling application' for the production of algal biofuels. This process leverages an existing source of biomass consisting of naturally occurring microbial communities, and is currently producing significant amounts of biomass annually (~70 tons/yr). In addition, this is the type of work that will advance 'polyculture' research and development efforts. Results reported for the productivity of algal growth on recycled water and digestate, recovery efficiencies of ammonium, and analyses of pretreatment options are all very promising. Still, more work must be done to characterize why growth is stunted when using clarified water recycled from harvesting processes, and to collect long term data supporting the operation of the integrated pilot plant across seasons.
- This project has made progress towards designing a process for algae production using water and nutrient recycling that can be piloted and assessed for viability over the next year. The idea of using anaerobic digestion and water recycling to recover nutrients from algal cultures is not a new idea, and it is time for this idea to be critically evaluated and weighed versus other biomass use options.

PI Response to Reviewer Comments

- For both the Cal Poly Adaptive Sampling and Prediction (ASAP) and Algal Biomass Yield (ABY) projects, the reviewers noted a lack of contextualization and metric development with which to assess the studied algae biofuel processes relative to alternative processes. The techno-economic and lifecycle assessments (TEA and LCA) to be prepared as part of these projects will provide this information. MicroBio Engineering, Inc., will use standardized assessment methodologies (specifically CA-GREET and the BETO Algae Program harmonized TEA/LCA approaches), allowing integration of these project results directly into the BETO evaluation process.
- The reviewers asked how biomass productivity from photoautotrophic algae growth can be differentiated from heterotrophic growth on reduced substrates of wastewater origin. This issue is not important for scaled-up processes where water and nutrients are

extensively recycled and where wastewater would be only a minor input as make-up for evaporation and other losses. It has, however, been a long-standing and unresolved question in the field of algal wastewater treatment, specifically where untreated wastewater is a significant or even the main input for algal production. In this project, the raceways produce an algal biomass that predominantly forms flocs, ranging from hundreds of microns to even several millimeters in size, with bacteria, algae, and detritus intermixed. Thus, it is difficult to differentiate algal from bacterial biomass by microscopic observation, staining, or particle size distribution. "Net productivity," simply calculated as the difference in ash-free dry weight of suspended solids in the effluent minus the influent mass, has been used as the main means of assessing new biomass production separate from the influent flows of organic matter. When growing algae in recycled wastewater media, this is not an issue, as most wastewater organic matter has been already removed. This approach, therefore, allows a more direct assessment of photoautotrophic productivity. A task to develop a practical laboratory analytical method to differentiate and quantify bacterial and algal biomass in the pond effluents was not successful.

- The relative benefit of use of anaerobic digestion as the means of producing biofuel and resolubilizing nutrients was questioned versus other possible, but unspecified, uses of the biomass. Anaerobic digestion of residuals from liquid biofuel production decreases fossil carbon emissions and improves process economics through electricity generation. The digestion used in this project simulates digestion of residuals from production of liquid biofuel or other products. With that understanding, the project is likely compatible with the reviewer's view.
- A comment on strain screening and biomass production for HTL processing was misplaced in this ASAP project and will be addressed in the Cal Poly ABY project response.
- The PIs appreciate the reviewers' helpful comments and critiques.

INTEGRATION OF NUTRIENT AND WATER RECYCLING FOR SUSTAINABLE ALGAL BIOREFINERIES

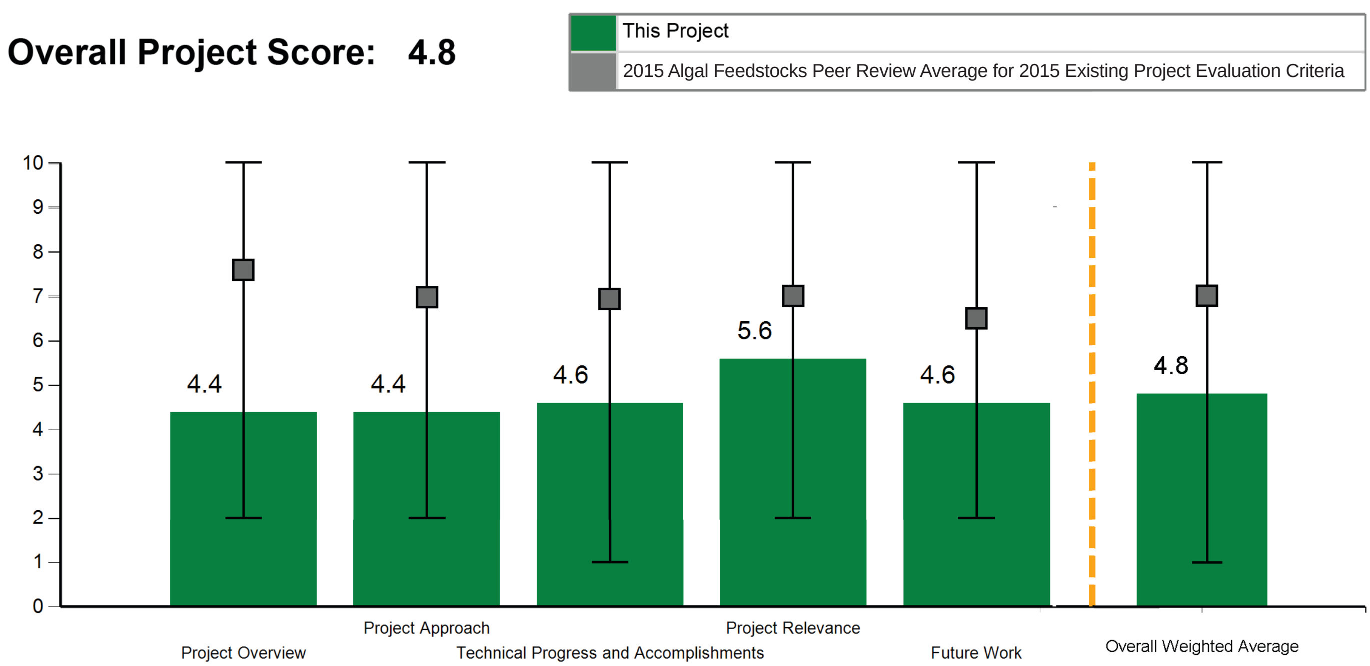
(WBS#: 1.3.2.202_Z)

Recipient:	University of Toledo
Presenter:	Sridhar Viamajala
DOE Funding FY14:	$411,573
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,588,361
Project Dates:	2/1/2013 - 1/1/2015

Project Description

The overall goal of this project is to develop the enabling science and engineering that will result in environmentally sustainable algal biomass and biofuel production with minimal synthetic fertilizer inputs. Nutrient and water recycling is especially critical for overall sustainability of commercial systems. The assembled team has successfully isolated and characterized high lipid-producing native alkaliphilic algae which are less susceptible to detrimental contamination, at least partially due to the higher pH culturing conditions. The project team has also tested novel “smart hydrogel”-based low-energy options for solid-liquid separation that allow for effective water recycle since they do not involve use of contaminating chemicals (e.g., flocculants). This project is evaluating algal growth and lipid production by alkaliphilic organisms using nutrients from waste streams and recycled post-conversion residues and water recovered from our harvesting methods. The specific objectives for this project are to: (1) evaluate the effects of nutrient integration/recycle options on algae growth and lipid production; (2) develop low-cost and low-energy water recovery methods; (3) characterize the development, structure, and stability of microbial communities in algal systems that contribute to stable algal biomass and lipid production; and (4) perform economic and life cycle assessments (LCA) for sustainable algal biorefineries.

Overall Project Score: 4.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The project pieces together some unique research areas to form the basis for a study on sustainable algal biofuel systems. The hypothetical system would utilize adapted native algal strains grown in wastewater, and would be harvested by sequestering water from the biomass in engineered hydrogels. These two aspects have an innovative quality to them, and can perhaps be conceived as an appropriate opportunity for co-localization at wastewater facilities. However, the microbial community analysis presented in the middle of the presentation appeared out of place, and was not appropriately contextualized in way that would ground its relevance to improving algae system design.
- The development of thermosensitive hydrogels could represent an interesting dewatering technology option if the remaining funding is spent on attempting to dewater actual outdoors raceways using the hydrogels and developing best practices about how to deploy and recover the gels at scale. The other aspects of this project need not be continued.
- Three efforts were reviewed. How they were connected to each other and how they contribute to the overall effort were not communicated.
- This is an assortment of independent projects with no clear plan for integration. The bench scale results of Task A are not impactful and are a duplication of current efforts being conducted at relevant process scales by others. The reported productivities for wastewater-grown cultures were not favorable as compared with those grown on control media. As a field, we need to be focused on increasing productivity using alternative nutrient sources over those achievable with laboratory optimized media recipes as a definition for success at any scale. The stimuli-triggered gel separation technology investigated as Task B is interesting, and the achievements made in regard to gel stimuli responses at small scale are satisfactory. However, scalability of this technology to the levels needed for algal biofuel production is questionable. For Tasks C and D, there is no connection between the reported results and relevance to BETO program goals. The TEA model is flawed and redundant in the portfolio because NREL is actively publishing high quality, in-depth design cases.
- This project is conducting bench-scale analysis to evaluate possible strategies for nutrient recycling/utilization and harvesting. The questions being asked about algal utilization of waste water, residual biomass, and novel harvesting technologies are valid, but seem to be occurring in an isolated and disjointed way. To make more of a contribution, this project should pivot toward scale-up, or begin working with another entity performing complimentary work.

PI Response to Reviewer Comments:

- The reviewers appear to have three main concerns: (1) What is the merit and relevance of our project tasks?; (2) How do the tasks integrate?; (3) What are the scale-up plans?

1. Relevance and Merit

Task A (Cultivation) - We have focused on high lipid-producing alkaliphilic algae, which are less susceptible to detrimental contamination due to the higher pH conditions. Higher pH tolerance has also allowed use of bicarbonate for rapid lipid accumulation and high lipid content—between 35-50% weight by weight (w/w) fatty acid methyl esters (FAME), even in wastewater. These lipid values are much higher than those reported in the literature (usually 15-30% FAME) for mesophilic microalgae grown on wastewater. The areal biomass productivity of the strains in our project is also high—up to 30 g/m^2/day.

Task B (Harvesting) - In addition to harvesting, the hydrogel method allows recovery (and reuse) of process water as well as soluble unused nutrients. The energy use and costs of hydrogel harvesting are lower than centrifugation, cross flow filtration or chemical flocculation. In addition, biomass and harvest-water quality are preserved since no soluble chemicals are added (unlike chemical flocculation). We have shown that: (1) concentrations of ~100 g/L can be achieved by cyclic use of hydrogels; (2) residence time of the harvesting process could be <4 hours; and (3) gels are mechanically robust and reusable.

Task C (Ecological Analysis) - Large scale algae cultivations are unlikely to remain pure cultures. Yet, the relationship between system stability and biological diversity is still not understood. Here, on an industrially relevant scale (15 million gallons/day), we have developed and tested the newest molecular techniques to characterize and quantify microbial community dynamics (algae, bacteria, and viruses over space and time). The tools developed can be broadly applied to other equally large, engineered biofuel systems to gain valuable ecological insights for optimal productivity as well as system dysbiosis (e.g., culture crash).

Task D (LCA and TEA) - The TEA and LCA in this work is being developed in close concert with experimentalists, such that results help guide experimental work. This interaction has identified potential improvements/relative impacts of dewatering via hydrogels, and increased biomass yield via bicarbonate manipulation. The quantitative mass and energy balance data in these models are also useful for others (e.g., NREL) for comparative analyses across other DOE-funded technologies.

2. Integration

Many wastewater streams (e.g., from anaerobic digestion) have concentrated nutrients and have to be diluted (20x-40x) using fresh water. So far, we have shown the feasibility of harvest water reuse (e.g., using hydrogels) to achieve dilutions without any measurable impact on biomass productivity.

Characterization of communities that have evolved in robust and in crashed cultures would enable development of targeted strategies to promote positive interactions and control predators. In this project, we have so far developed and calibrated microbial ecology analysis methods that are appropriate for use in these complex communities using a large wastewater system as a test case. During the remainder of this project, we will apply these methods to characterize microbial communities that develop over short- and long-term cultivations and correlate with biomass productivity measurements.

3. Scale-up

In year 3 of our project, we plan to scale-up cultivation and hydrogel harvesting methods (Tasks B and E). We have partnered with Clearas Water, Inc., which has several pilot-scale algae-based wastewater treatment sites currently operational. We will perform >1,000 liter-scale cultivations. We will also scale-up a hydrogel dewatering system prototype and assess continuous harvesting. Microbial ecology analyses will be performed during these tests to quantify the population dynamics during long-term cultivation and the data will be incorporated into LCA and TEA.

HTL MODEL DEVELOPMENT

(WBS#: 1.3.4.100)

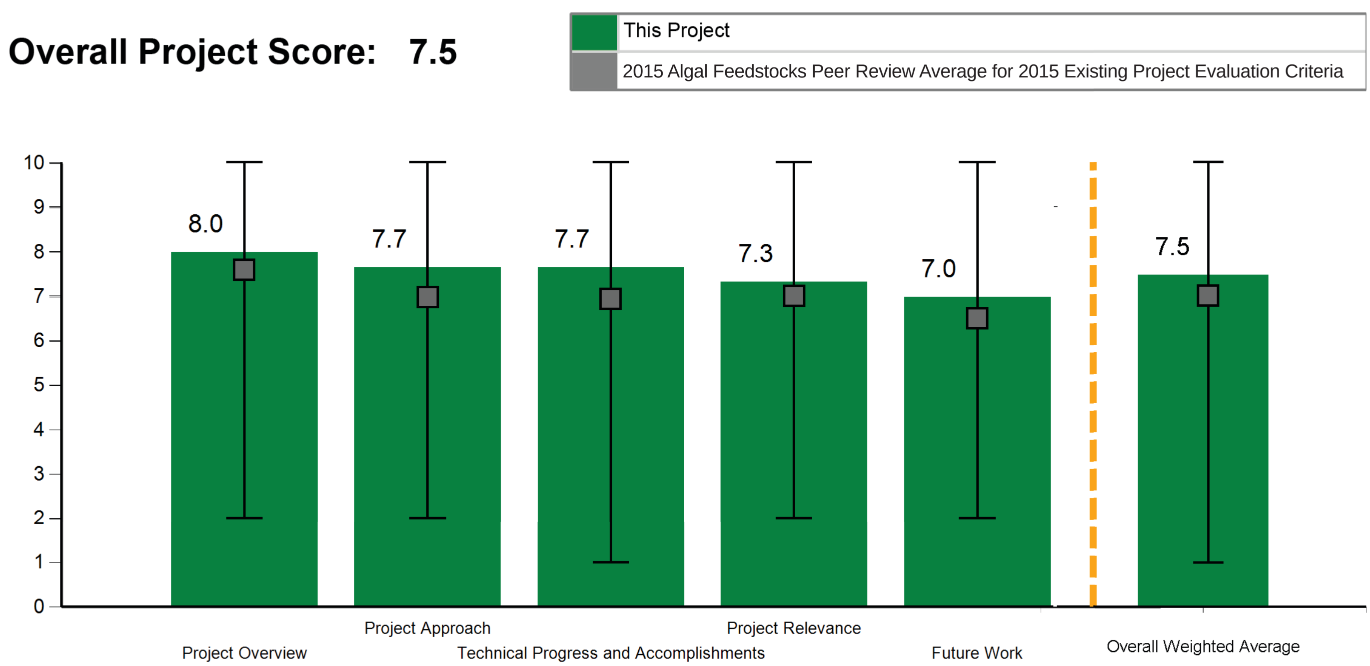
Recipient:	PNNL
Presenter:	Susan Jones
DOE Funding FY14:	$315,609
DOE Funding FY13:	$239,357
DOE Funding FY10-12:	$0
Planned Funding:	$1,888,034
Project Dates:	10/1/2012 - 9/30/2017

Project Description

The project will develop sufficient data to formulate a robust and detailed technoeconomic model of the algae hydrothermal liquefaction (HTL) process. The integrated algae HTL process includes catalytic hydrotreatment (HT) of the HTL bio-oil product catalytic hydrothermal gasification (CHG) applied to the aqueous byproduct. The project is aligned with goals of BETO to achieve annual productivity (equivalent to 1,500 and 5,000 gallons per acre per year by 2014 and 2022, respectively) by significantly increasing the yield of fuel form microalgae biomass. The project has leveraged process data from the National Alliance for Advanced Biofuels and Bioproducts (NAABB) to build process models (HTL, HT, CHG) followed by TEA and LCA sensitivity analyses to understand variances and significant impact areas for further optimization. Targeted R&D will be conducted to improve process performance for HTL, CHG and HT processes. These results will be used to update models and to direct targeted research in FY15-16 to optimize yields and processing conditions. This data is used to further update model and state of technology (SOT) and harmonization modeling efforts within BETO.

Overall Impressions

- This project focuses on the downstream modeling of HTL conversion, and is designed to establish research targets for subsequent oil upgrading, water treatment, and nutrient recycle. The project is contextualized well and, overall, has notable relevance to BETO.
- Some aspects for the potential use of bio-oil for co-processing and integration into existing refining infrastructure was not adequately discussed, but



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

could increase the options for downstream processing and oil utilization and may enhance the overall relevance of this work.

- This project provides the benchmark of downstream processing requiring $1.18/gge out of the total $4.50/gge production cost goal for algal fuels. The major cost determinant of algal fuel, by this project's assessment, is feedstock cost for dewatered wet algae (20% solids). Without further upstream modeling work, the current utility of continuing this project seems low.
- Clearly communicated solid technical program to address key uncertainties and target further developments.
- This project is producing quality peer-reviewed design reports based on experimental data. Rigorous planning and reporting has resulted in quality deliverables (e.g., MYPP additions, baseline reports), and plans for future work are clear with relevant and timely milestones.
- This is an essential project in BETO's portfolio and key to its decision-making, particularly as BETO embarks on this new priority pathway of HTL. The key will be for this model to stimulate new research and inquiry across the entire field, and then have access to and properly utilize all the available information. There may be less institutional knowledge to support this pathway, compared to biochemical or lipid conversion processes.
- Obviously, a central part of the program is offering guidance on different process schemes for algal processing. It would be good to offer further guidance on whether biological treatments, such as fermentations, could compete with brute force thermochemistry as these technologies become more efficient, and especially how nutrient, water, and CO_2 recycling impact potential costs. Also, it would be good to broaden analyses to algal growth.

PI Response to Reviewer Comments

- Thank you for your review. We agree that the current conversion-only focus is limited in its utility; we plan to expand our efforts to include the farm component. The use of existing infrastructure is also an important area for investigation. We have a separate project with NREL, looking specifically at refinery integration for biomass-derived intermediates, the results of which can be used to inform the HTL project. Understanding the relative merits of different processing methods and the impacts of different strains and ash contents are key aspects of this work. The comparative assessment between different processing schemes is formally carried out through presentations to BETO at their annual state of technology meetings, as well as informal discussions throughout the year by the different labs and their partners.

THERMOCHEMICAL INTERFACE

(WBS#: 1.3.4.101)

Photo Courtesy of PNNL

Recipient:	PNNL
Presenter:	Dan Anderson
DOE Funding FY14:	$1,117,336
DOE Funding FY13:	$602,371
DOE Funding FY10-12:	$0
Planned Funding:	$1,680,293
Project Dates:	10/1/2012 - 9/30/2017

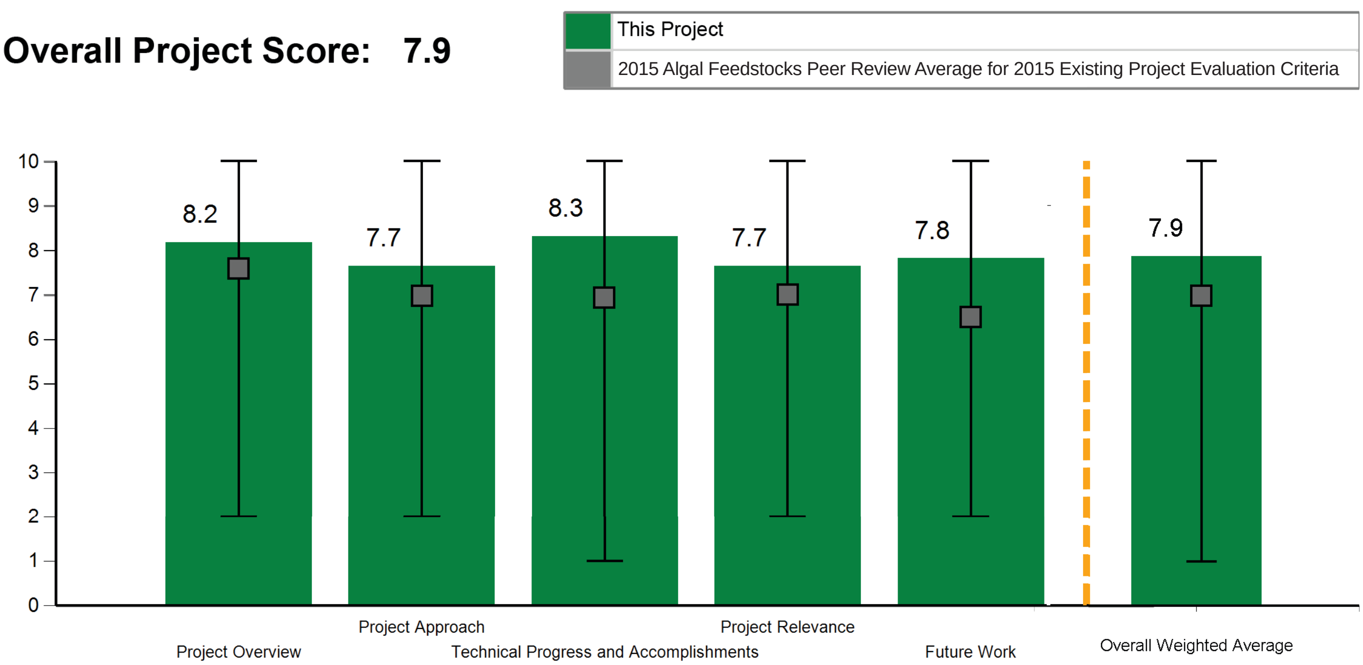
Project Description

This project is focused primarily on developing advanced hydrothermal liquefaction (HTL) processing methods to improve process efficiency, reduce capital and operating costs and improve biocrude quality. In addition, the project will also develop processes to enable nutrient recycle/bioavailability from HTL waste streams and support the design, procurement and operation of an engineering-scale HTL skid. All data from these efforts will directly support the Algae HTL pathway model and the SOT. Scale-up and technology transfer are important components of the project. Other activities in the first two years of the project include efforts to complete key NAABB data sets for HTL processing, cultivation and strain development.

Overall Impressions:

- Initially established as part of the NAABB wrap-up, this project seeks to improve algae HTL process-

Overall Project Score: 7.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ing methods, and allow for more optimal nutrient recycle from HTL waste streams. There is a record of successful cooperation and technology transfer that is improving thermochemical platforms more broadly. This work is relevant to BETO as it would promote whole algae HTL and upgrading. Past success indicates a high likelihood of continued progress based on the specified milestones.

- At commercial scale, pumping costs are likely to be significant for this approach; a fair comparison would be pumping cost for ethanol plants. Feedstock price needs to include drying costs and storage if assuming carrying summer harvest to winter. I would like to better understand the plan to achieve a 50% increase in HTL liquid hourly space velocity as well as the 10% increase in carbon yield of the recovered bio-crude.
- HTL provides an opportunity to normalize variations in algal feedstock quality while providing a respectable yield to liquid fuel.
- This project is highly relevant for advancing the optimization and scalability of the promising HTL pathway. Technology transfer efforts are superior, and pilot performance data from companies (Genifuel/Reliance/Algenol) will assist PNNL with refinement of the HTL model.
- This project provides an essential function of being the R&D base for the HTL TEA model. Increased interactions and feedback with industry will be a must for refining the model, as will highly targeted R&D at PNNL. The proposed skid-scale HTL model should assist the project on all fronts.
- This is very important work for what will likely be the initial commercialization pathway for algal biomass to biofuels. It is being carried out with care and diligence.
- It is an important strength of the BETO portfolio to cover both brute force hydrothermal methods and 'biological' deconstructive methods.

PI Response to Reviewer Comments

- We agree that pumping cost associated with harvesting dilute algal cultures is significant, and that innovative technology improvements to drive down the cost of algal biomass are needed. This is true for all conversion and/or extraction pathways that use algal biomass and was not a focus of this project. Drying costs were included in the TEA and we realize that this is not an energy efficient method for storing excess algal biomass. This was the method chosen in the initial design case. We believe there are better methods to deal with seasonal fluctuations in algal biomass and process throughput by considering the use of mixed feedstocks as an example. Our plans to achieve a 50% increase in HTL liquid hourly space velocity as well as the 10% increase in carbon yield of the recovered bio-crude are focused on understanding the relationship of key process parameters vs. feedstock characteristics on oil yield and quality. We are pursuing plug flow designs with much greater conversion efficiencies and advanced separations methods to recover more carbon as part of the fuel fraction. We thank the reviewers for their thoughtful comments, questions and recommendations.

PROTEIN FERMENTATION

(WBS#: 1.3.4.200)

Recipient:	SNL
Presenter:	Ryan W. Davis
DOE Funding FY14:	$173,397
DOE Funding FY13:	$21,577
DOE Funding FY10-12:	$0
Planned Funding:	$1,105,026
Project Dates:	1/30/2013 - 9/30/2015

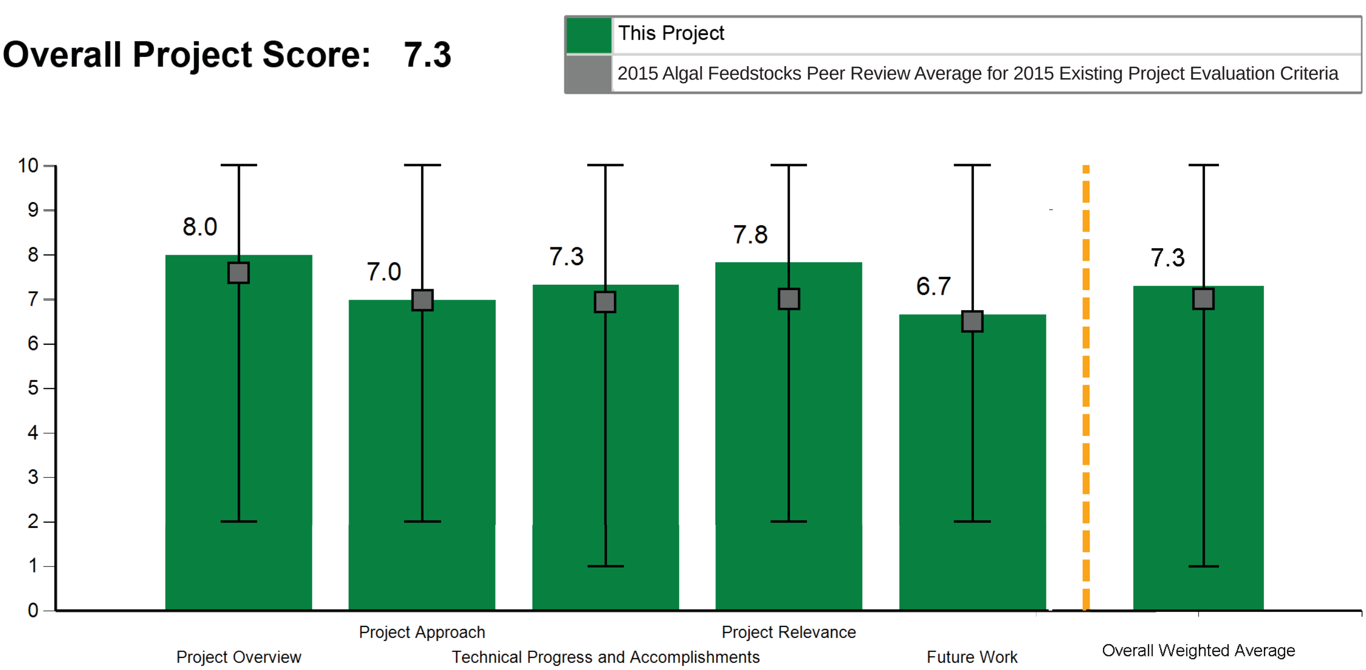
Project Description

The goal of this effort is to enable the production of algae biofuels at 5,200 gallons/acre/year by 2022, in accordance with BETO's Multi-Year Program Plan (MYPP). To achieve this goal, maximal conversion of all of the algae biomass components to liquid fuels is required, not just the lipids that have been the focus of much R&D. The challenge of concurrent high biomass and lipid productivity remains elusive. In fact, proteins comprise 40-50% of the biomass at maximum growth conditions. We are applying fermentation strategies for generation of mixed (>C2) alcohols and ammonium from algal proteins to increase the total yield of liquid fuels and recycle the major nutrients. Although dependent on the amino acid composition, the theoretical yield of protein fermentation can exceed that of ethanol from sugar. Through our efforts, the project team has identified a pretreatment and biochemical conversion process that integrates ethanol production from algal sugars, mixed alcohol production from proteins, and lipid and alcohol co-separation. Maximum protein conversion yields up to 80% of theoretical were obtained at bench scale by minimizing product inhibition and biochemical redox imbalance.

Overall Impressions

- The goal is to improve overall biomass conversion by considering novel conversion routes for proteins which make-up as much as 50% of algal biomass. This will be achieved by optimizing protein fermentation to mixed alcohol liquid fuels.

Overall Project Score: 7.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- From a mass balance standpoint, this seems to be a viable option. Innovative projects like this can be challenging as they require all new system designs (upstream and downstream). New separation systems for unique alcohol products, as well as supply chains, that are not well-established, will need to be considered.
- The concept of protein fermentation is innovative, but we should remain cautious until the TEA results can be scrutinized and the results can be available to contextualize expected prospects for the technology more broadly.
- This project has a potential positive disruptive (i.e., innovative) impact on BETO's portfolio due to its focus on upgrading the total energy content of algal biomass; however, it is still in a fledgling state at its current scale of 100 L and goal of 80% carbon conversion.
- This is an innovative project that addresses the issue of what to do with all the protein in a manner that will directly support biofuel production.
- This project is exploring a novel opportunity for the protein in algal biomass: fermentation into fuels or products. Given that protein can make up a significant portion of the biomass, there is value in considering several options for its fate. Results so far at the lab-scale are promising; however, protein fermentation will likely encounter the same efficiency and titer issues as sugar fermentation. The next steps of the project, scale-up and combined sugar and protein fermentation, should reveal more about the potential of this approach.
- Recognizing the prevalence of proteins in algal biomass challenges our thinking to capture value for the protein. Many options need to be considered before launching into further lab developments.
- This is very nice work at the frontier of microbial fermentation, working with a pathway that is not widely appreciated. It has expert collaborators at UCLA. The LCA benefits of returning nutrients, especially N as ammonium, to the growth ponds may be substantial, but the debits of so much manipulation of the biomass (compared to brute force liquefaction) may outweigh them. But that is beside the point at this stage. Demonstrating the feasibility of this approach will allow such calculations to be developed on a real data basis, and allow appropriate decision making in the future. That is the benefit of the portfolio approach BETO is using, not focusing too early on a single pathway to fuel. This is an outstanding part of the program.

PI Response to Reviewer Comment

- The alcohol products are readily separated from the fermentation liquor with solvents that are commonly used for lipid extraction. Subsequent purification of the lipids and alcohols from the consolidated product stream should avoid costly downstream separations (e.g., azeotropic distillation).
- We agree with the potential challenges with the titers and efficiencies, but we also believe that we have standard processing and operational strategies that can be employed as necessary.
- We agree with the need for a robust, scenario-based TEA to help identify the opportunities and challenges associated with this activity within a systems-level framework. As noted previously, this work will be carried out by Patricia Pacheco (SNL). We feel that the results obtained to date by this project highlight that this technology platform is a viable conversion route that deserves serious consideration for potential inclusion in the MYPP, based on the results obtained from the TEA.

ALGAL BIOMASS CONVERSION

(WBS#: 1.3.4.201

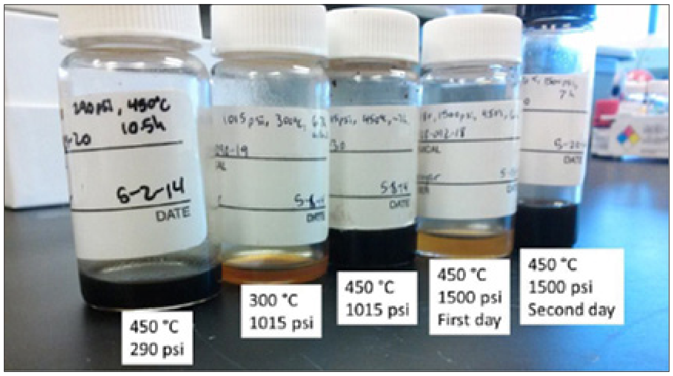


Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Philip Pienkos
DOE Funding FY14:	$626,735
DOE Funding FY13:	$17,597
DOE Funding FY10-12:	$0
Planned Funding:	$2,454,891
Project Dates:	1/30/2013 - 9/30/2015

Project Description

The Algal Biomass Conversion Project was initiated in FY13 to develop biofuel production processes with an overall goal of reducing production costs through advanced process options for the conversion of lipids, carbohydrates, and proteins to biofuels and bioproducts. We have partnered with Arizona State University for biomass production and Sandia National Laboratories for protein valorization. The project plan has four components: (1) development of pretreatment processes for hydrolysis of algal carbohydrates; (2) demonstration of fermentation processes for valorization of algal sugars; (3) development of extraction processes for efficient recovery of fuel-grade lipids; and (4) development of lipid upgrading processes for evaluation of lipid quality. The project has demonstrated these conversion processes up to the 100 kg scale, with algal sugars converted to ethanol and succinate and fatty acids converted to hydrocarbons. The process is applicable to biomass

Overall Project Score: 7.0

Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

from both freshwater and marine strains and is not absolutely dependent on high lipid biomass. The current process configuration has become the framework for the Algal Lipid Upgrading Design Case with a modeled cost reduction of 40% compared to the harmonization basecase. The main challenges are to develop the basis for a low cost scalable extraction process, recover high sugar yields with minimal degradation products, and to establish and achieve the product specifications for the modeled final product, a renewable diesel blendstock.

Overall Impressions

- This project seeks to improve overall algal biomass conversion by integrating multiple unit processes to better utilize available resources including both carbohydrates and lipids. The performers argue that the proposed pre-processing, hydrolysis and fermentation of carbohydrates to ethanol, may allow for more effective utilization of algal biomass. One perceived problem with this approach is that producing ethanol from terrestrial feedstock is very inexpensive, and the additional overall costs for processing algal biomass to generate relatively small amounts of ethanol may void any advantages of recovering ethanol from algal carbohydrates in the first place. It may be more useful to study ways to increase the lipid profile of algae, as well as the lipid extraction processes, than to study ways of generating product from the carbohydrates.
- Consistent quality of feedstock for the algal lipid upgrading (ALU) pathway will continue to be a challenge until productivity kinetics are optimized. However, bottlenecks exist in this project concerning the scale of biomass intake (i.e., how to process 10 st at a time). It seems nearly impossible to deliver such a quantity of microalgae to this group so that the work can progress. It may be necessary to optimize scale-dependent processes using an alternate feedstock for the time being.
- Developin higher fuel yield from fixed algal biomass is an interesting option. The strategy needs careful comparison to alternative down stream approaches. The added complexity may limit adoption.
- An approach to valorizing all individual cellular components has been previously neglected. The project's focus on characterization and valorization of algal sugars is particularly relevant, since the range of available sugar types would be a flexible feedstock for fuels and co-products. The impacts of this pathway on the minimum fuel selling price (MFSP) are promising. In addition, this project has leveraged the BETO-funded testbed program through collaborations with the ATP3 site at ASU for biomass production.
- This project is incrementally improving and identifying issues with the downstream operations that have been built into the NREL ALU design case for DOE. Improvements do need to be made in this area, but the design case indicates that these operations are not the main cost drivers, and will be very specific to the industrial scenario. Research in this space should be focused and working to identify best value for the field as a whole. That being said, there is always room for innovations that take a major leap ahead of the well documented issues with downstream operations in the entire biofuels field.
- This is a very important part of the program, being carried out in a well-coordinated way. As they point out, the issue is the cost of algal production, so this work will only be truly useful if that is reduced. It is very appropriate that this "deconstruction" approach be done in parallel with the brute force thermochemical route; both have potential advantages and disadvantages that need to be considered and addressed.

PI Response to Reviewer Comments

- It is not clear what the reviewer means by an alternate feedstock for algae, but I would argue that any such material would introduce much more uncertainty than continued operation with actual algal biomass at the kg scale. Our process, consisting of well known and modeled unit operations pretreatment, fermentation, distillation and liquid/liquid extraction, reduces much of the uncertainty for scale up and modeling.

- We believe that the TEA analysis for valorization of algal carbohydrates to ethanol makes a compelling case for the validity of this concept (a reduction in cost of 40% compared with the basecase of lipid-only process) and also believe that our knowledge of scaling of ethanol fermentation and recovery helps to mitigate risks in modeling this approach. We are not advocating a 'sugar-only' process, but taking advantage of the sugars that are available and are not valorized sufficiently by conversion to biogas in the basecase process. It is likely that higher value coproducts from sugars (especially based on processes where sugar concentration is not a critical parameter, e.g., continuous processes with immobilized cells) will be able to drive the MFSP down still further than ethanol. This was touched on briefly in the description of the succinic acid fermentation.

  Even assuming progress in developing higher lipid content biomass in a cost effective manner, we believe that our wet extraction process based on pretreated biomass is already robust enough to stand on its own in a lipid-only system. But it is not clear that increased lipid productivity will necessarily eliminate the opportunity for carbohydrate-based coproducts, and further exploration of the patterns of metabolic rearrangement that occur during nitrogen starvation using a broader range of algal strains (both natural and improved) will help to understand the breadth of opportunity with this process.

- Ultimately, we believe that the successful deployment of algal biofuel technology will require the same principles brought to bear in the oil industry: finding a use for every fraction of crude oil.

- We began this project by evaluating the major components, lipids and carbohydrates, with SNL focusing on the proteins, and in this way, we have identified a real opportunity for biofuel production cost reduction. We will continue to improve this process and establish incremental improvements by seeking to improve yields. We believe, however, that significant additional improvements in MFSP will come from exploiting the minor (though still significant) components, working in partnership with the NREL Algal Biomass Valorization project, and building a portfolio of coproducts that can scale with fuels.

- One of the things we hope to come out of the work in the near future is a better standard for process metrics. We have attempted to be very rigorous in our adherence to the use of gasoline gallon equivalent (gge) as a metric rather than simply gallons of product. This is a straightforward calculation when the products are fatty acids and ethanol, but much less so with HTL oil. Ultimately, an "apples-to-apples" comparison will allow for a better evaluation of the pros and cons of each approach.

- Ideally, an economic process for a single product would be the starting point, and identification and production of coproducts would come later and increase the overall profit margin. That's the way the petroleum industry started and its initial success depended on abundant cheap feedstock and readily available technology. Currently, neither of these situations exists for algae, and so complexity may be a necessary evil.

ALGAL BIOMASS VALORIZATION

(WBS#: 1.3.4.300)

Recipient:	NREL
Presenter:	Lieve Laurens
DOE Funding FY14:	$872,821
DOE Funding FY13:	$637,803
DOE Funding FY10-12:	$0
Planned Funding:	$2,789,376
Project Dates:	10/1/2012 - 9/30/2017

Project Description

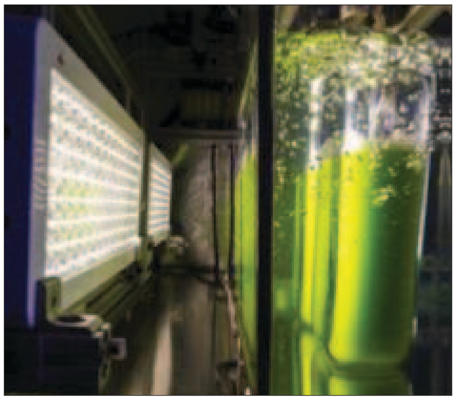
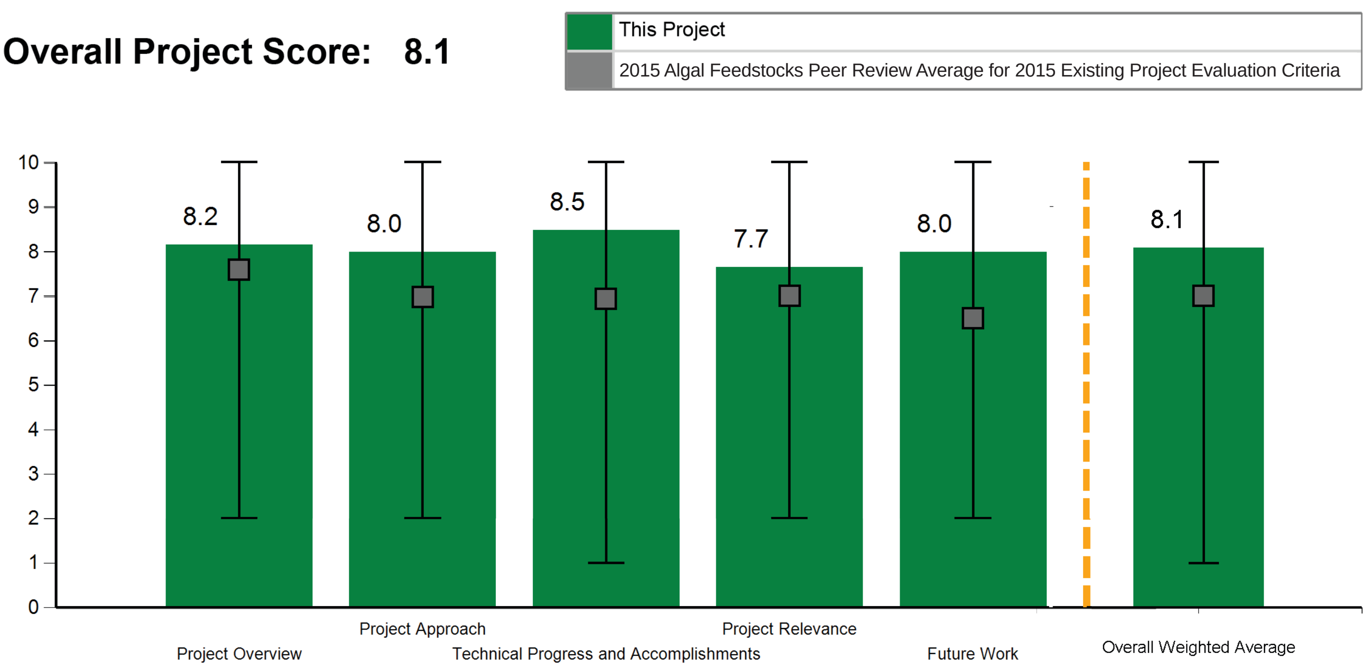


Photo Courtesy of NREL

With the progression of algal biofuels and co-products from research to commercialization scale, the demands increase for rigorous experimentation and validation to provide the requisite data on biomass products. To reduce the cost of fuels to $3/gge in 2022, this task will focus on increasing the inherent value of the biomass through the identification of key targets that provide value to algae beyond lipid-based fuels. To reduce uncertainties around current harmonized models and productivity assessments, and analytical procedures, this project will support the generation of verified data to underpin the economic base-case and set realistic process and cost targets for future strain improvements. Similarly, robust data are needed to assess progress toward the targets using standardized measurements. The approach taken in this task is to establish compositional analysis for mass balance closure around algal biomass and to validate process chemistry and yields in production and conversion scenarios. This project will provide experimentally validated procedures that can advance the field of algal biofuels by providing validated standard analytical methods, data for techno-economic modeling and analysis, and quantitative metrics for process and strain improvement strategies.

Overall Project Score: 8.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project seems to be a well though-out and relevant with detailed objectives, milestones, and methods to achieve the stated goals. The results are forthcoming and the technical findings and recommendations are being incorporated by researchers in real time. Good progress has been made so far, and the future output seems promising.
- This project has done the critical work of standardizing the metrics and methods by which BETO compares the upstream progress of all projects. There are multiple areas of the portfolio that could benefit from increasing synergy with NREL, most notably polyculture work and measuring realtime variability in maximum energy content of biomass.
- Mass balances and improved analytical methods will benefit the overall efforts by providing credible data for comparing alternatives. Specific composition analysis may provide insights to algal physiology changes due to processing conditions.
- The technical progress on this project has been substantial and has been disseminated through publications in peer-reviewed journals and the published NREL methods, which are easily accessible online. This project represents a much needed harmonization of methods for the valorization of biomass across the field. All BETO funded projects should be required to use these methods.
- This project addresses a key but underemphasized problem with algal biomass, the ability to accurately and robustly characterize the biomass composition. This is particularly relevant with so much interest in the field on lipid upgrading, biochemical conversion of different fractions and co-product development. The project is making strides in these areas, and the important factor will be the wide adoption of the practices by the field.
- This is very beautiful work that should certainly be part of the algal biofuels portfolio, and be at a national lab. As it matures, it should aim to give clear guidance to other programs of when such exquisite analyses are appropriate. Simple reliable tests are also required, and will probably remain the bedrock for most experiments.

PI Response to Reviewer Comments

- We thank the reviewers for the comments on our work. As this work is progressing, we will certainly keep the reviewers' comments into account to make sure we help develop simple and reliable tests that can be implemented across laboratories for routine monitoring of major constituents, as well as continue the development towards maximum valorization, purification and development of coproducts in algal biomass from different sources based on advanced molecular analytics.

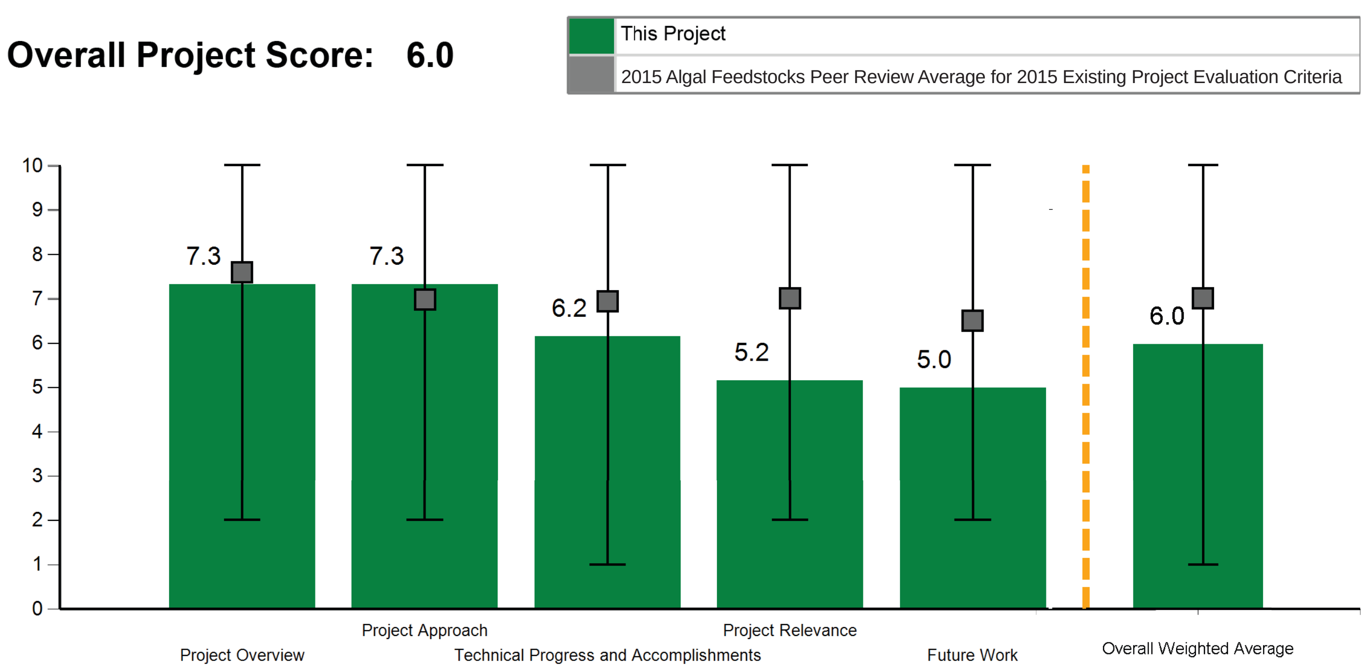
PRODUCING TRANSPORTATION FUELS VIA PHOTOSYNTHETICALLY-DERIVED ETHYLENE

(WBS#: 1.3.4.301)

Recipient:	NREL
Presenter:	Jianping Yu
DOE Funding FY14:	$250,130
DOE Funding FY13:	$155,090
DOE Funding FY10-12:	$345,168
Planned Funding:	$399,612
Project Dates:	10/1/2013 - 9/30/2015

Project Description

The objective of this task is to develop a novel photosynthetic CO_2-to-ethylene conversion system using genetically modified cyanobacterium. Ethylene is the most versatile building block for the production of diverse fuels and chemicals. Direct photosynthetic conversion of CO_2 to ethylene has the potential to reduce the nation's reliance on fossil fuels, and to lower GHG emission. Started as a seed project in FY11, the project has demonstrated sustained CO_2-to-ethylene conversion in transgenic *Synechocystis* 6803 expressing the *efe* gene encoding ethylene forming enzyme from the bacterium *Pseudomonas syringae*. A number of bottlenecks were identified and overcome. The current peak productivity is 30 mg/L/hr. Ethylene is a gas, therefore it can be harvested from head space, avoiding cell harvesting and associated challenges. It was also demonstrated that sea water (with additional N and P nutrients) can support photosynthetic ethylene production. In addition, long-term ethylene production in day/night cycles demonstrated ethylene production over several weeks. Analysis of carbon metabolism and photosynthesis shows that ethylene production is supported by metabolic network plasticity and by stimulation of photosynthesis. A conceptual photosynthetic ethylene to fuel production process is established, along with an initial cost model.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This technology appears to be innovative in its approach, and could serve as the basis for a very unique process to generate high value ethelyne based products and biofuel co-products. However, more work needs to be done to characterize what this system may look like at scale, and research efforts should be tailored to best promote the establishment of a viable system.

  Additionally, the project performers need to more adequately contextualize the relevance of this project, and they need to consider appropriate rationalizations for this research and possible system configurations, products, and environmental advantages.
- The relevancy of this work seems three-fold: (1) green ethylene production would support a market need in packaging and consumer products industries; (2) plastic milk jugs made from this raw ethylene are an example of carbon sequestration (buy green plastic, sequester CO_2); and (3) the spent biomass would support HTL. Dr. Yu would do well in his final report to contextualize his research in these three areas.
- This is interesting science at an early stage. The applications are unclear.
- The progress toward increasing ethylene production using molecular approaches is substantial, and it was discovered that there is a cooperative metabolic interaction with ethylene production and photosynthesis. Future work should be focused on the minimum amount of science required to de-risk the technology to the point that it will attract external funding support. Results of this academic project are Nature publication worthy. Although it is currently at a low TRL level, this is a high-risk, high-reward project that will be impactful if scalable.
- This is an early stage R&D project that targets ethylene improvement in one strain. Therefore, it is well-defined and sequential. There is some question as to how a project this small and R&D-focused will quicken the pace to meet DOE's out-year production goals, but there is some merit to having niche projects in a portfolio. However, this project will need continued investment to advance the R&D to the point where real testing for commercialization can be considered. It was positive to see some industry interest in the project, or at least in bio-ethylene as a product. As soon as possible, a robust TEA analysis should reveal if this is a viable path.
- This is very elegant molecular biology, but of very doubtful commercial relevance. Ethylene is one of the world's commodity chemicals, and it is very unlikely the work here could compete at any scale or any price.

PI Response to Reviewer Comments:

- Thank you to reviewers for pointing out some potential uses of this new technology. Ethylene is a versatile feedstock for both fuels and chemicals, and spent biomass would support HTL. Thus, this technology has potential to help realize the vision of "replacing the whole barrel."
- It is agreed that more work needs to be done to characterize what this system may look like at scale.
- Thank you for the generous comments on the progress and the science. The discovery of stimulation of photosynthesis by ethylene production is indeed very interesting and we plan to study the molecular trigger behind it in order to develop novel strategies for increasing biomass productivity. A Nature Plants paper based on this work is now published.
- Process development and TEA are important areas for future study that will help determine if there is a credible route to economic ethylene production.

ALGAE TESTBED PUBLIC-PRIVATE PARTNERSHIP (ATP3) - A RAFT PARTNERSHIP

(WBS#: 1.3.5.100)

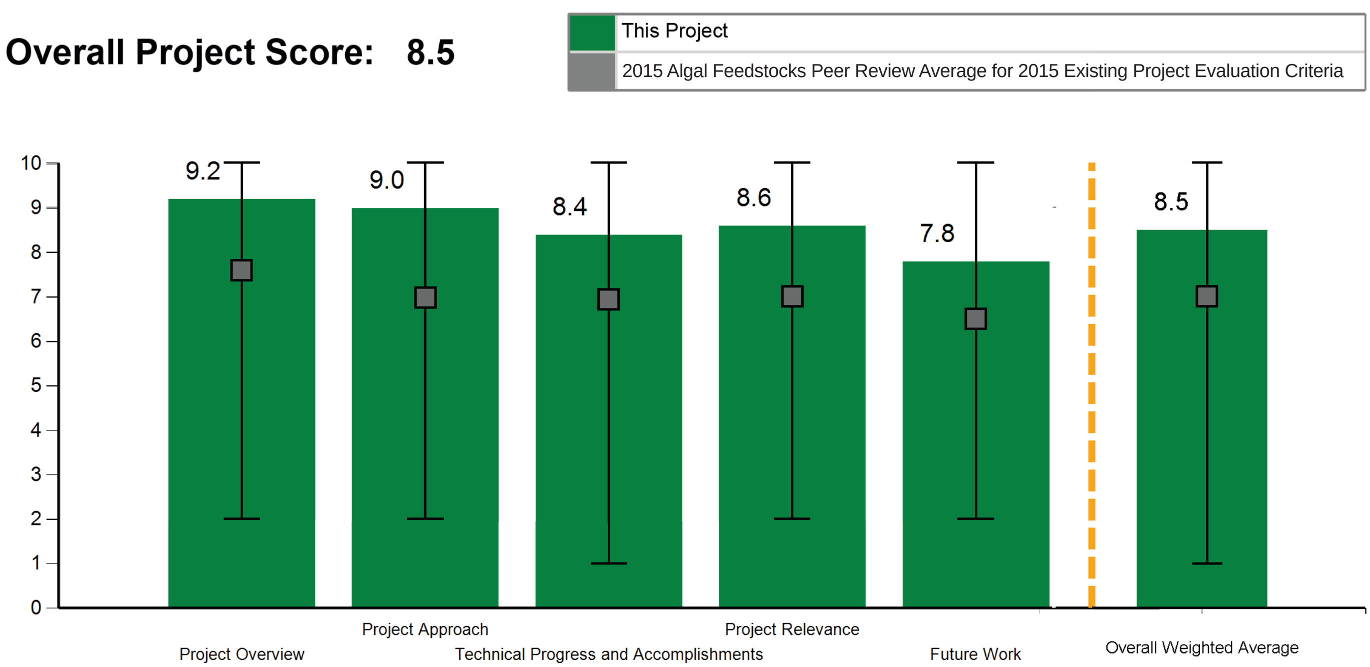
Recipient:	Arizona State University
Presenter:	Gary Dirks
DOE Funding FY14:	$1,989,265
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$8,767,935
Project Dates:	1/31/2013 - 1/31/2018

Photo Courtesy of Arizona State University

Project Description

The Algae Testbed Public-Private Partnership (ATP3) goal is to establish a sustainable network of regional testbeds that empowers knowledge creation and dissemination within the algal research community, accelerates innovation, and supports growth of the nascent algal fuels industry. ATP3 increases stakeholder access to high quality facilities (Function 1) by making an unparalleled array of outdoor cultivation, downstream process equipment, and laboratory facilities available along with world renowned expertise from a tightly managed multi-institutional and transdisciplinary team. ATP3 utilizes a powerful combination of facilities, technical expertise, and proactive management structure to support the DOE's techno-economic, sustainability, and resource modeling and analysis activities, helping to close critical knowledge gaps and inform robust analyses of the state of technology by conducting coordinated long term

Overall Project Score: 8.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

cultivation feedstock trials at Arizona State University's geographically diverse sites to provide a unique data set regarding reproducibility, scalability, seasonal, and environmental variability (Function 2). These data are critically important to support techno-economic analysis (TEA) and life-cycle assessment (LCA) activities that will guide research and development towards the transformative goal of cost-competitive algal biofuels by 2022.

Overall Impressions

- This project pulls together several operating algae facilities and establishes unique metrics to compare all projects and various parameters equivalently. Overall, this approach offers unique testing capabilities to early stage projects and provides expertise and technical assistance for enhancing project outcomes. Coordinated research can be compared based on local environmental conditions as inherent design differences and other variations are minimized by standard systems and metrics. Success of this project will benefit the state of technology and improve the viability of commercial bioenergy applications throughout many regions and climates.
- ATP3 represents the backbone of the DOE portfolio and represents a singular achievement in standardizing the metrics and methods with which to measure progress. But the growing capacity of the consortia is underutilized at a time when downstream processing experiments struggle to obtain sufficient quantities of biomass. Could Sapphire ponds be added to increase mainland ATP3 capacity?
- ATP3 has established a solid foundation for future work in this area. The round robin testing and unified protocals and equipment provide an improved view of environmental factors. Future work is agressive in introducing many new parameters. Continued collaboration will maintain a solid scientific view of the critical issues.
- The test bed aspect of this project is attracting users with different needs, and seems to be fulfilling the intended community function through internally supported projects, education and training, and provided access to a range of facilities and equipment. Though the project needs to find a viable path to support itself should DOE funding run out, so far it appears to be a success. The long-term cultivation trials are also providing a community service by working to standardize protocols and provide robust realistic data sets to the field to assist R&D and modeling efforts. Both of these thrusts help address gaps and needs cited by several other projects in the portfolio.
- This is a most welcome addition to the program. I expect it to be worth the investment as it is used by more and more people. I look forward to seeing genetically modified organisms being used, with the accompanying regulatory requirements. BETO should fund this project for several years to give time for academia and small companies to develop strains and species that are worthy of the reproducibility that this project can deliver.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

REGIONAL ALGAL FEEDSTOCK TESTBED PARTNERSHIP

(WBS#: 1.3.5.111)

Recipient:	University of Arizona
Presenter:	Kimberly Ogden
DOE Funding FY14:	$1,033,237
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,766,763
Project Dates:	9/1/2013 - 9/30/2015

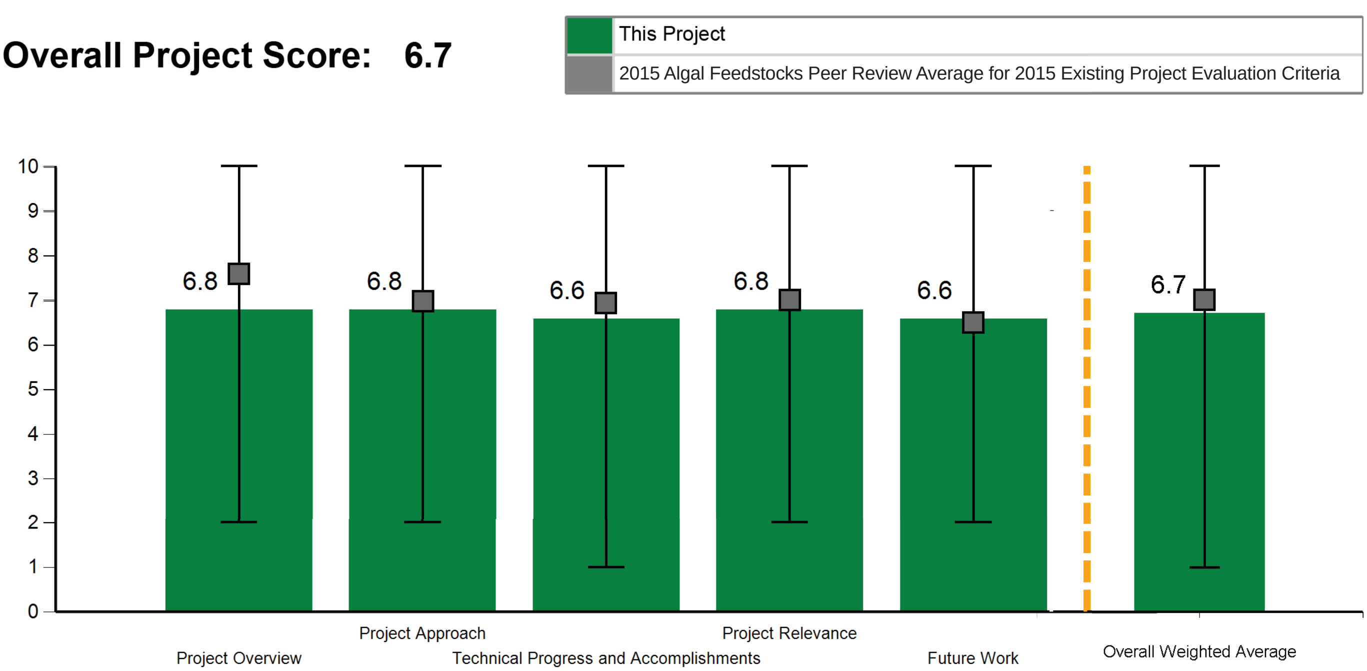
Project Description

Regional Algal Feedstock Testbed (RAFT) creates a network of facilities supporting the biofuels industry. RAFT partners strive to overcome critical barriers of cost, water resources, and nutrient recycle to obtain long-term sustained domestic algal biomass production. The project team offers a variety of sophisticated, monitored, and controlled cultivation systems for large-scale algal production in testbeds located in strategically chosen regions of the U.S. This effort will primarily address the long-term algal cultivation trials; however all facilities can accommodate users. The project strategies are to: (1) determine growth rate and productivity in the laboratory to evaluate the best strains for seasonal growth; (2) optimize media to reduce cost; (3) transfer information and stains to testbeds for outside growth; (4) cultivate strains semi-continuously, monitoring pH, T, water, nutrients, dissolved oxygen (DO), etc.; (5) develop new molecular techniques and sensors to monitor cultivation; (6) make data available to modelers who update their models and provide feedback to testbeds; and (7) begin cycle again in the next season and also investigate use of impaired waters for cultivation. Data for the summer/fall/winter of 2014-2015 will be presented as well as preliminary modeling results. The data management system will be highlighted.

Overall Impressions:

- RAFT is working to establish a collaborative network of algae testing facilities. Critical algae biofuel

Overall Project Score: 6.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

system barriers such as cost, water requirements, nutrient cycling, contamination, and test bed crashes are studied. The project employs sophisticated monitoring (developed novel DO testing system in house), and controlled cultivation systems at test facilities. The project contributes to meeting BETO program objectives, and the presenters aptly contextualize this work within that frame.

- This project is a good example of one which struggled to report doubling time required for its biomass. It is possible, even when temperature and photoperiod vary, to bracket a range over different temporal resolutions, including days, weeks, months, and the year. It would be wise to wrap this location(s) into the ATP3 project in order to standardize the way results are obtained, and thus be able to compare productivities cross-portfolio.
- This nicely complements the ATP3 effort with longer term cultivation studies. Understanding the origin of crashes is critical to long term developments.
- This project appears to be less of a test-bed and more a project that has the facilities for long-term outdoor cultivation studies. Other than feeding data into models, there was little apparent community interaction, though other projects in the portfolio mentioned working with this project. The cultivation studies are important, but should be selected and designed to meet the needs of the larger community.
- Reliable prolonged outdoor growth is achieved by several commercial companies, but few have achieved long term growth of highly productive strains. This project addresses several areas where improvements must be made if program goals are to be met. As such, it is a vital part of the BETO program – a part not being carried out at the National Labs.

PI Response to Reviewer Comments

- We thank the reviewers for the constructive feedback for the project. The majority of the comments are positive. However, there is some disagreement amongst reviewers about the synergy of this project and ATP3. The University of Arizona-led RAFT was set up from the beginning to focus on long-term cultivation trials with the most promising production strains that were identified in NAABB with very little emphasis on functioning as user facilities. We are working with ATP3 to standardize the data that is collected in both programs; ATP3 will be adapting our data management system. We believe our work is synergistic and complementary and our research plan is well-developed.
- Some specific areas we are focusing on, that ATP3 is not, include the following: (1) detailed strain characterization to measure key parameters to predict strain performance using environmental simulated cultures for developing a crop rotation strategy to optimize year round productivity in outdoor systems; (2) comparing and contrasting different cultivation systems (traditional raceways, arid temperature management cultivation system, photobioreactor) instead of using just one traditional system; (3) monitoring and optimizing nutrients (C, N, and P primarily, as well as some trace elements) for each algal species to reduce costs; (4) understanding cultivation of algae in impaired waters; (5) developing on-line sensors and control strategies; (6) using both PNNL's growth model and climate simulate cultures to predict the performance of strains prior to getting them out into test beds; and (7) integration of biomass access tool (BAT) modeling for regional/national production assessments comprehensive trade-off analyses based on testbed data.

LARGE-SCALE PRODUCTION OF FUELS AND FEED FROM MARINE MICROALGAE

(WBS#: 1.3.5.120)

Recipient:	Cornell University
Presenter:	Mark Huntley
DOE Funding FY14:	$4,240,322
DOE Funding FY13:	$947,782
DOE Funding FY10-12:	$1,802,522
Planned Funding:	$2,957,156
Project Dates:	9/1/2010 - 2/28/2015

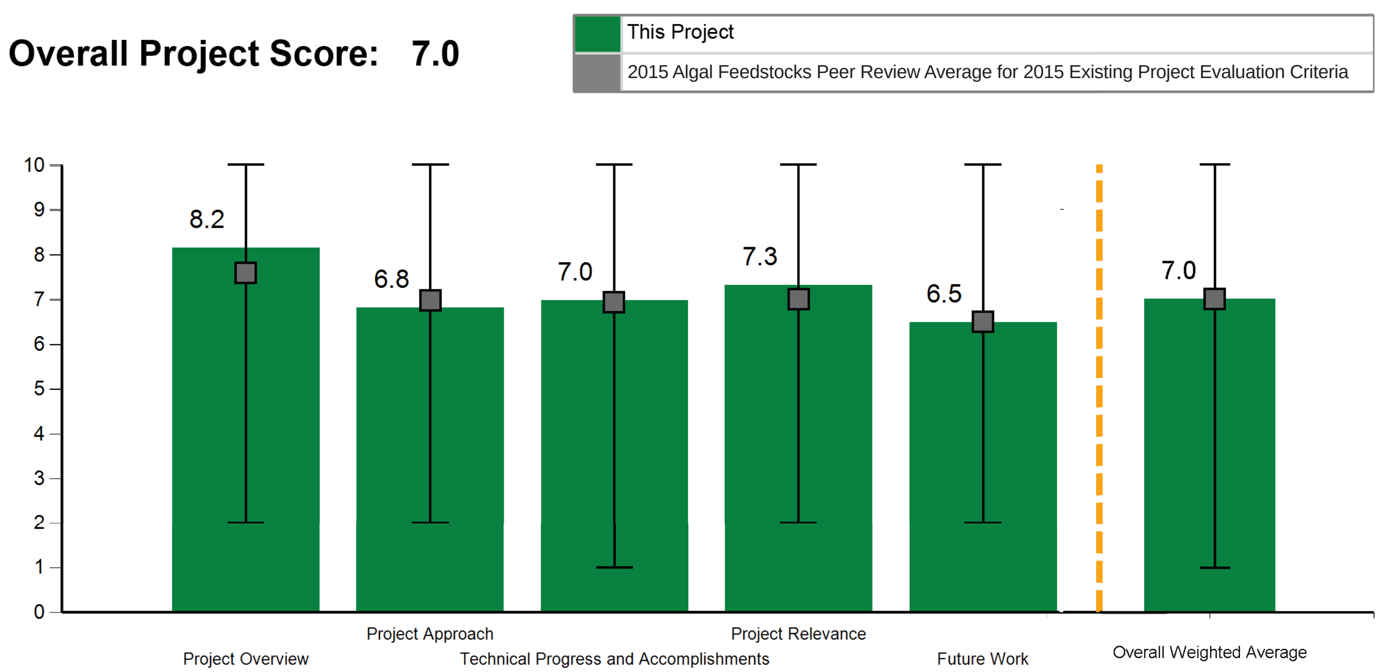
Project Description

The Cornell Consortium has demonstrated a fully integrated process for the production of biofuels and high-value nutritional bioproducts from marine microalgae at pre-commercial scale. The project has achieved unprecedented yields of algal oil, and converted the oil to viable fuels. It also has demonstrated the potential value of the residual co-product as a viable feed ingredient for important animals in the global food supply. Comprehensive TEA/LCA studies of 20 comparative technology pathways, based on actual production at demonstration scale, deliver a fuel price of $2.76 to $8.96 per gasoline gallon equivalent (gge) and an energy return on investment (EROI) of >1.4 for a fuel that meets the Renewable Fuel Standard for advanced biofuels. The project has met or significantly exceeded three BETO MYPP goals: 1. Performance against clear cost goals and technical targets (Q4 2013); MET, Q4 2013. 2. Productivity of 1,500 gal/acre/yr algal oil (Q4 2014); EXCEEDED: 3,800 gal/acre/yr, Q4 2014. 3. Productivity of 2,500 gal/acre/yr algal oil (Q4 2018); EXCEEDED: 3,800 gal/acre/yr, Q4 2014. The Consortium's growing body of 27 peer-reviewed publications provides a comprehensive and detailed analysis of the commercialization potential for algal biofuels and its national and global impact.

Overall Impressions

- This project, as with other consortium projects, has a broad scope including aspects up and down

Overall Project Score: 7.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

the algae biofuel supply chain from strain development to system design, integration, optimization, and sustainability analysis. A general weakness of these broad projects, as discussed by the other reviewers and myself, is that the apparent area requiring the greatest additional research effort is feedstock productivity and characteristics thereof. Downstream conversion and general process integration advances are redundant as they are similar to those downstream processes for terrestrial feedstock conversion. I have no reason to doubt that this consortium is meeting the platform objectives and exceeding them in some areas, and the animal feed co-product discussed is indeed a high-value and useful product. This is a good area to discuss environmental trade-offs, sustainability, and mitigation of climate emissions due to land use change.

- How is it possible that this consortia reported productivities at levels so much higher than the rest of the portfolio?
- The design of a full-scale facility was underwhelmingly supported. While the feed trial results were impressive and represent a significant achievement, the presentation lacked substantive quantitative information regarding production costs and quality of the generated biomass (e.g., protein, lipid, ash levels).
- The extensive development of coproduct potential as feed additive occurred. This is an interesting strategy to potentially achieve high productivity. The peer review will confirm productivity demonstration and vet TEA assumptions recommended.
- The Cornell Consortium has been highly productive. The availability of six months of outdoor cultivation data for each of the two strains tested (a diatom and a chlorophyte with average 38% lipid content) is robust and supports the calculated production of >3,800 g/acre/yr algal oil. If validated, this represents a significant achievement as it surpasses both the 2014 and 2018 MYPP goals. The hybrid photobioreactor (PBR) pond system is novel and likely contributed significantly to productivity achievements. The efficacy of both fuel and feed products was clearly demonstrated. I appreciate the investigation of evolutionarily diverse species; however, the practicality of silica supplementation for growing diatoms at commercial scale needs to be addressed in terms of sustainability issues, negative impacts on farmer's health, and the impacts on overall economics of a high ash content biomass.
- This project appeared to have met its goals, and was able to demonstrate a fairly-integrated algae product production system long-term. Projects like these can be reality checks and are integral, alongside projects that provide incremental improvements and develop new technologies, in assessing and improving the SOT in algae biofuels. Though without a more rigorous assessment and detailed presentation on the economics assumptions and experiment results, it is challenging to assess the viability and scalability of this particular process. It would have been beneficial to have heard lessons-learned from this project, in order to inform future decisions about investments in the field.
- This provides an outstanding demonstration that algal biofuels might realistically be combined with animal feeds. Unfortunately, it confirms that this cannot be commercially viable in the near future without a substantial increase in productivity. However, as long as the work is carefully documented, the project will make a very useful contribution to the eventual commercialization of algal fuels.

PI Response to Reviewer Comments

- NOTE: Comprehensive Consortium results on productivity, algal feedstock biochemistry, facility design and operation, techno-economics and life cycle assessment were published in May 2015. The two following articles appear in Algal Research, online and in print:

1. Demonstrated Large-Scale Production of Marine Microalgae for Fuels and Feed; Huntley, et al (2015). http://dx.doi.org/10.1016/j.algal.2015.04.016
2. Algal Biofuel Production for Fuels and Feed in a 100-ha Facility: A Comprehensive Techno-Economic Analysis and Life-Cycle Assessment; Beal, et al (2015). http://dx.doi.org/10.1016/j.algal.2015.04.017

- Constraints of time and required content in the rules of presentation for the Peer Review process allowed no more than 10 minutes for presentation of the Results of 31 Technical Reports and 27 peer-reviewed publications from this seven-year project. The two most recent papers, by Huntley and Beal (above), provide detailed information requested by reviewers on the following topics that could not adequately be covered in the presentation:
    1. “The design of a full-scale facility...”
    2. “.... production of >3,800 g/acre/yr algal oil, if validated... is significant.”
    3. “..substantive quantitative information regarding production costs and quality of the generated biomass (e.g., protein, lipid, ash levels).”
    4. “...the practicality of silica supplementation for growing diatoms at commercial scale.”
    5. “...a more rigorous assessment and detailed presentation on the economics assumptions and experiment results.”
    6. “Peer review to confirm productivity demonstration and vet TEA assumptions recommended.”

Response to Additional Reviewer Comments:

- *“How is it possible...?”* – This Consortium achieved ‘productivities at levels so much higher than the rest of the portfolio’ because of three main factors: (1) screening >1,000 strains to find top candidates; (2) using a novel hybrid system to avoid system crashes that are common in open pond systems; and (3) rigorously managing culture conditions, including turbulence, nutrient concentration, and residence time in ponds. The “rest of the portfolio” has relied mostly on easily available but often poorly performing strains and then cultivated those in traditional open pond systems. Radically different approaches to cultivation strategy (e.g., Huntley, 2015) may be crucial to dramatic improvements in yield.
- *“This project has a broad scope...up and down the algae biofuel supply chain. A general weakness of these broad projects... is that... greatest additional research is [needed in] feedstock productivity... [not] downstream conversion...”* – The algae biofuel supply chain inherently has a broad scope. To be realistically appraised, the integrated process needs to be deployed—from strain development to cultivation, processing, and product assessment. Some areas of operation need more attention than others. This project focused on feedstock productivity and co-product development. A fully integrated supply chain was deployed and evaluated, but no effort was made or supported by BETO for advances in downstream conversion.
- *“...the animal feed co-product is... high-value and useful - good area to discuss ... environmental trade-offs [etc]...”* – Several forthcoming (2015) publications from this Consortium are precisely focused on results that may quantifiably inform policy discussions on environment, sustainability, and land-use change.
- *“..algal biofuels might realistically be combined with animal feeds. Unfortunately it confirms that this cannot be commercially viable in the near future without a substantial increase in productivity.”* – One approach to commercial viability, as the reviewer suggests, is a substantial increase in productivity. Another approach is to increase revenues via co-product value. Both can be effective. Commercial viability appears attainable via co-product value in the near future. Results and conclusions are fully discussed in papers by Huntley, et al (2015) and Beal, et al (2015).

CONSORTIUM FOR ALGAL BIOFUELS COMMERCIALIZATION

(WBS#: 1.3.5.130)

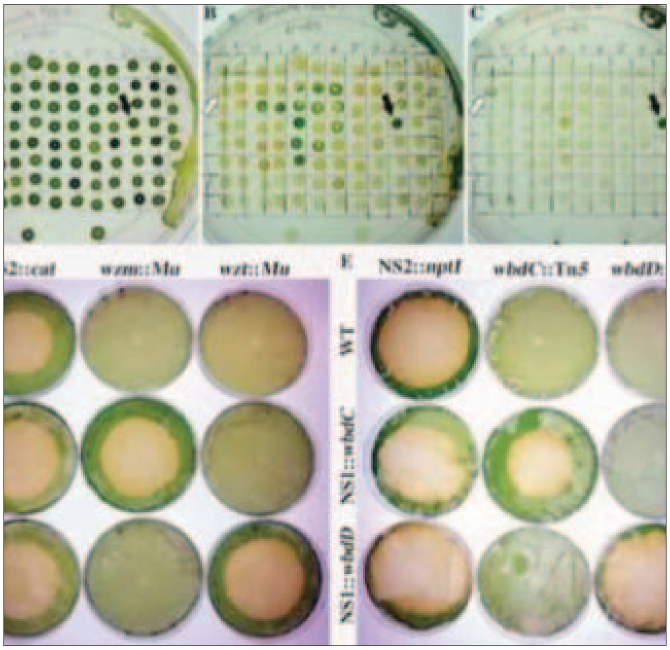


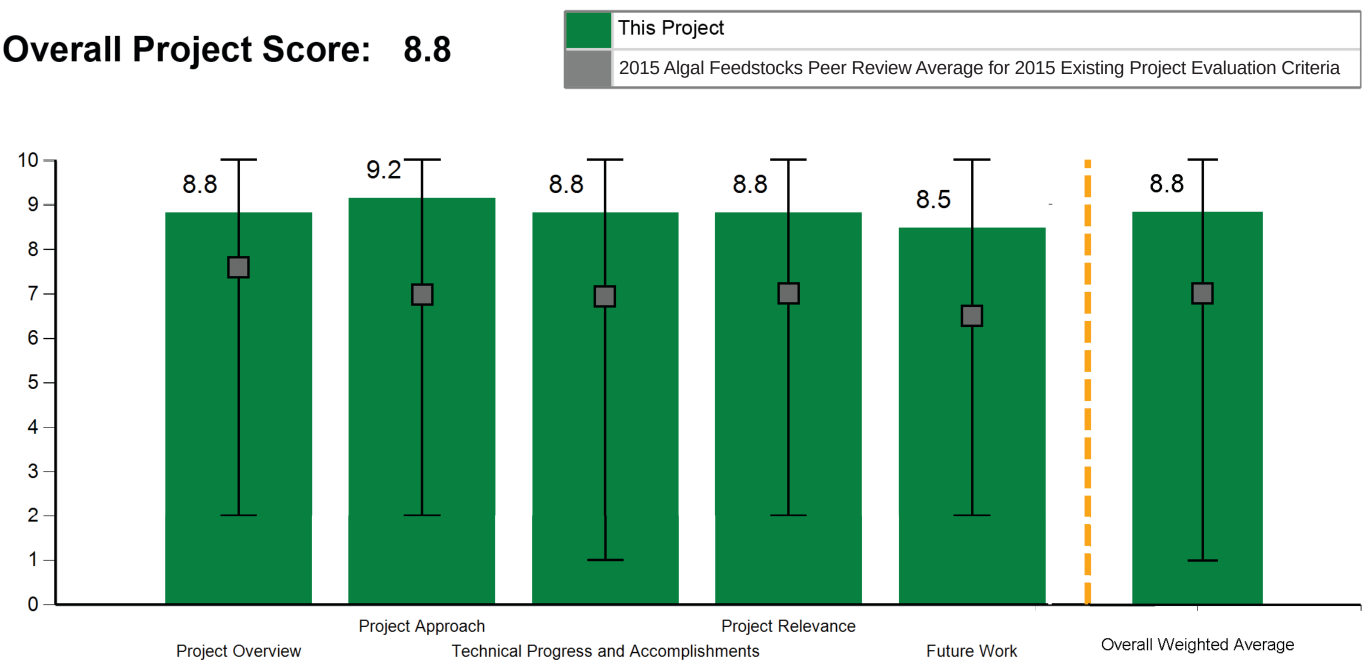
Photo Courtesy of University of California at San Diego

Recipient:	University of California at San Diego
Presenter:	Stephen Mayfield
DOE Funding FY14:	$2,366,677
DOE Funding FY13:	$3,565,048
DOE Funding FY10-12:	$3,596,862
Planned Funding:	$2,031,459
Project Dates:	9/1/2010 - 9/30/2015

Project Description

Since 2011, the Consortium for Algal Biofuel Commercialization has conducted research to enable commercially viable algal fuel in three key areas: crop protection, nutrient utilization and recycling, and genetic tool development. Two commercial partners, Sapphire Energy and Life Technologies, participated as collaborators. These research areas address some of the main challenges with algae biofuel and will increase biomass productivity, decrease production costs and introduce genetic tools to enable algae industries. In crop protection, the project team characterized and identified algal genetic resistance to fungi and amoebae, developed

Overall Project Score: 8.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

anti-viral technologies, developed methods for finding or constructing grazer resistant genes, and found that algae polycultures fare better against predators than monocultures. In nutrient utilization and recycling, the project identified improved commercially relevant strains that use recycled nutrients after hydrothermal liquefaction and oil separation with Sapphire Energy. In genetic tools, the project developed over 150 algae genetic products now publicly available through Life Technologies, including gene expression devices, broad-host-range plasmids, selection markers, promoters, targeting vectors, and more. Also, the project conducted the first EPA approved genetically modified algae outdoor trial to test genetic stability, and strain dispersal and invasion. It was found that the genetically modified organisms (GMO) dispersed, but did not displace native species, and that the genetically modified (GM) traits are likely to be stable in commercial settings.

Overall Impressions

- A valuable aspect of this consortium's work is the narrowed scope of the research and the consistent research approach employed to address barriers. Specifically, focusing on the feedstock production and yield (crop protection, nutrient utilization, and genetic manipulation) are ultimately the things that are limiting the overall viability of algae-based biofuels and products more broadly.
- It is clear from this presentation that the research funded thus far has provided a route for algae biotech to be established and for it to be profitable. Although the noted successes thus far have relied on products of far greater value than fuel, continued commercialization will drive down overall process costs and provide additional means to improve the prospects for algal biofuel technologies to come online at commercial scale.
- Dr. Mayfield has proven himself and his cohort to be the pioneers of GM algae production. The rest of the field would do well to remember two of their takeaways: (1) Consortia need to excel outdoors when exposed to local algae populations. Volunteer strains abound in the wild. (2) The product defines the production cycle. Find a product you can uniquely make. That is your path forward.
- The project is right on target. Making value adding products at commercial scale is critical to technology transfer from lab to real world conditions. First demonstration of GM algal in an open system is a critical first step to future developments.
- Dr. Mayfield's ability to pivot the project to align with the rapidly evolving needs of the industry is refreshing. The large body of published work and development of successful commercial partnerships reflect the project's significant contribution to advancing the state of the art. In particular, the acquisition of a TERA permit and successful completion of GMO trials is highly impactful and will open doors for other researchers working with GMO.
- Overall, this project was highly productive in terms of basic research publications and developing genetic tools for the research community. The consortium also made a large commercially applicable contribution to the field by conducting the first outdoor GMO algae trial. This project supports the notion that robust academic labs can make large contributions to the knowledge pool for a commercial industry if willing to co-develop and manage projects with commercial partners.
- The clear outcomes and partial success of this program amply justify its substantial cost. The TERA permit is an important milestone, especially as it passed uneventfully. This was a very successful consortium that delivered some first class science with a team of outstanding researchers who are publicizing the field, training new professionals for the nascent algal industry, and publishing in world-class journals. This is an outstanding investment in this exciting new field.

PI Response to Reviewer Comments:

- We thank the review panel for these very kind words, and for the recognition that we took risks, especially on the TERA GM trials, and that these paid enormous benefits for the entire community.
- We would also like to point out that since the time of this review, we have managed to make the world's first algae-based surfboard. This was done as a collaboration between CAB-Comm, Solazyme, and Arctic Foam. The first algae-based surfboard was presented to the Mayor of San Diego on Earth Day, and we have received world wide acclaim for this demonstration of a product that can be made of sustainable replacements of petroleum. This is yet another example of CAB-Comm's ability to work with commercial partners to deliver unique and highly valuable products to the market.

BIOMASS PRODUCTIVITY TECHNOLOGY ADVANCEMENT TOWARDS A COMMERCIALLY VIABLE, INTEGRATED ALGAL BIOMASS PRODUCTION UNIT

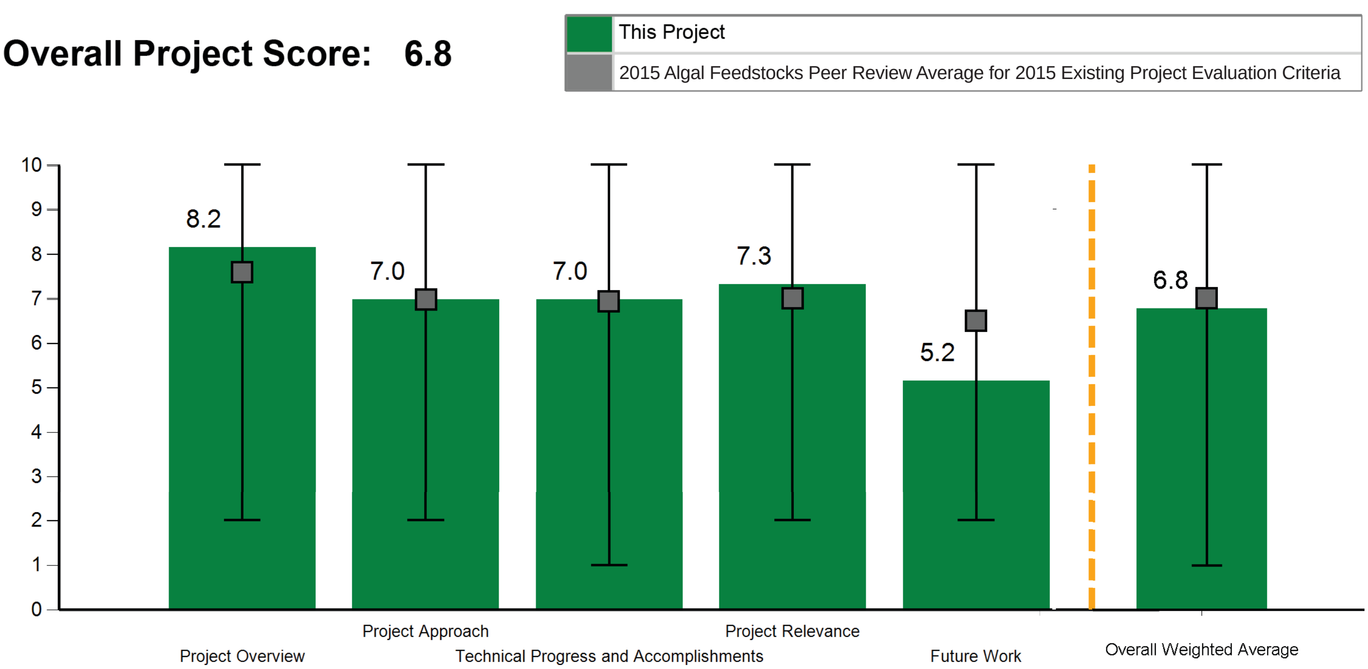
(WBS#: 1.3.5.220)

Recipient:	Sapphire Energy, LLC
Presenter:	Yan Poon
DOE Funding FY14:	$19,167
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,680,833
Project Dates:	9/30/2013 - 9/30/2016

Project Description

Sapphire Energy, Inc., is developing an end-to-end process to produce renewable, algae-based fuel that is fungible with existing refinery streams. The project aims to address three priority areas: (1) improve algal biomass productivity in outdoor cultivation environments relevant to commercial scales; (2) improve pre-processing technologies that can be integrated at scale with biomass production; and (3) successfully integrate priority areas 1 and 2 to ensure that target yields are met at a scale that enables production of cost-competitive fuels and products. In meeting each of these objectives, Sapphire aims to demonstrate sufficient improvements in algal biomass yield at lab and outdoor pilot scales to provide a positive indication towards success of a 1-acre demonstration of 2,500 gallons/acre/year oil productivity by 2018. In a highly integrated process, Sapphire aims to increase intrinsic algal biomass productivity by both employing evolution-based strain engineering as well as developing a systems biology approach to identify the regulatory networks associated with controlling both biomass productivity and oil content. In order to improve its cultivation process, Sapphire is constructing ecologies to minimize yield loss in the ponds by increasing robustness across biotic and abiotic stresses. Improvements are also developed in nutrient recycle,

Overall Project Score: 6.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

harvest and extraction, and hydrothermal treatment and extraction methodologies, by increasing efficiency and decreasing cost.

Overall Impressions

- Sapphire Energy operates fully integrated algae biofuel processes, and ongoing research is directed at improving performance up and down the production chain. Research objectives address three priority areas, including improving biomass productivity, establishing relevant pre-processing technologies, and overall integration of technologies from each end of the process. The research targets are ambitious, and perhaps too broad. It is assumed that the scope of the project is being reevaluated and it is suggested that the focus be placed on improving biomass productivity. Sapphire's unique strain engineering approaches and noted expertise in this area will likely offer the greatest dividends from investment in fundamental strain engineering and evolution.
- Because a private company like Sapphire treats its findings as competitive IP, what quantitative tangibles can be delivered to DOE to advance the Peer Review process? It remains to be resolved what structure would best serve BETO at the Peer Review. Certain underutilized synergies were apparent here and Sapphire is encouraged to work synergistically with other BETO projects.
- The themes in the presentation are aligned with the overall objectives, but insufficient details shared to render an opinion.
- Technical progress has been substantial for all priority areas of this project. Progress made in improving algal biomass productivity through synthetic biology approaches is particularly encouraging. The approach taken to investigate consortia for "polyculture" was scientifically sound, and the fact that no consortia were found that could outperform the best single strain cultures is a significant finding.
- This project is attempting to develop and optimize a specific production system for increased productivity that can be successfully piloted in Phase 2. The project seems to be making some progress; however, the project is being re-scoped by DOE so the path forward and technology choices are subject to change. Sapphire has capabilities and experience in piloting, so hopefully sound decisions can be made and the piloting effort will still occur with the right suite of technologies.
- A substantial project by one of the few commercial concerns still focusing on algal biofuels rather than other algal products. It is an integral and very promising part of the overall BETO Program.

PI Response to Reviewer Comments

- Sapphire values the continued partnership with the DOE and appreciates the reviewers' comments. Sapphire welcomes new opportunities to work synergistically with other BETO projects. The size of the project and the limited amount of time during the peer review unfortunately made it challenging to share much detail.

REALIZATION OF ALGAE POTENTIAL (REAP)

(WBS#: 1.3.5.230)

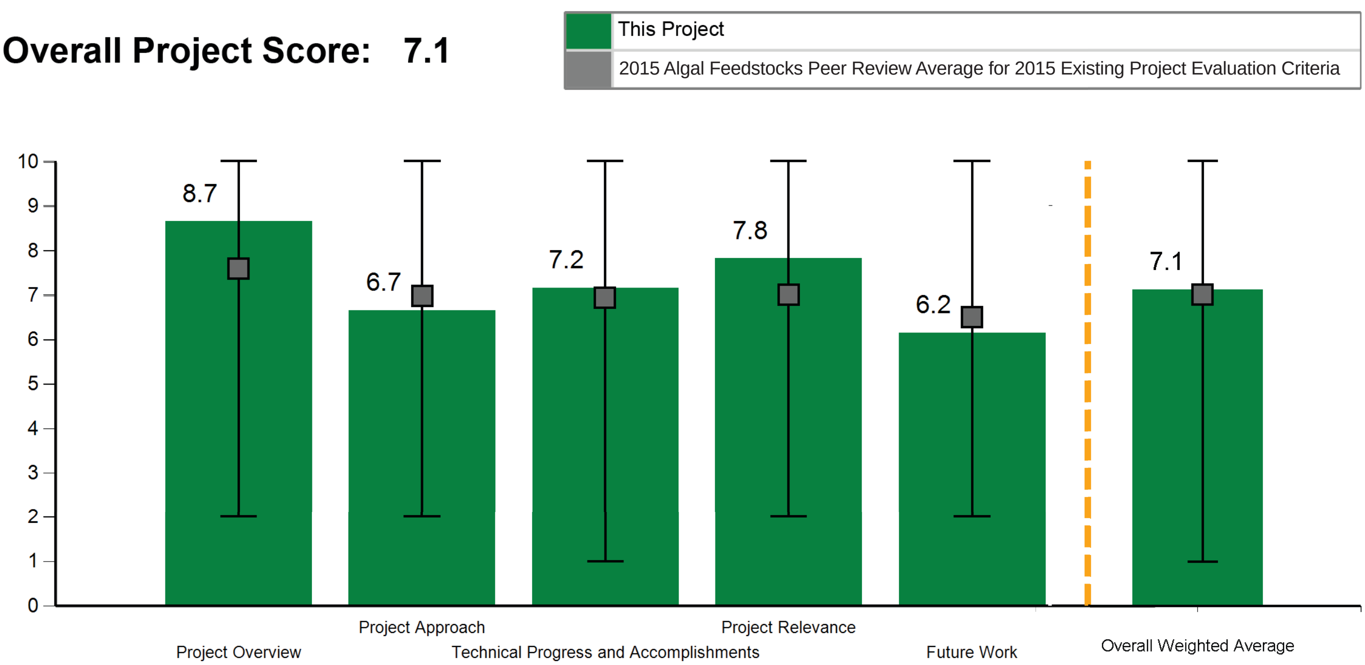
Photo Courtesy of New Mexico State University

Recipient:	New Mexico State University
Presenter:	Peter Lammers
DOE Funding FY14:	$25,873
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,719,126
Project Dates:	9/30/2013 - 3/31/2016

Project Description

The goal of the REAP R&D program is to develop an integrated process for producing 2,500 gallons of bio-fuel intermediate per acre per year. This outcome will advance the DOE goal of demonstrating 5,000 gallons per acre per year by 2022. Objectives include: (1) genetic enhancement of yield traits in a robust microalgae; (2) outdoor testing of enhanced strains in scalable, inexpensive plastic photobioreactors; (3) strain-optimized flocculation-based harvesting strategies; (4) wet biomass extraction using a novel sequential hydrothermal liquefaction approach; (5) recycling of nitrogen and phosphorus to limit nutrient costs and associated LCA footprint; (6) use of biochar co-product from liquefaction to provide heat energy; and (7) data from end-to-end process optimization performed at a single site to inform LCA and TEA. This work will produce engineering data for system modeling so that those data will be coherent and integrable at New Mexico State University. Work at Washington State University will explore improvements

Overall Project Score: 7.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

to oil production by sequential hydrothermal liquefaction. Work at LANL/New Mexico Consortium will improve strains. Work at PNNL will validate quantitative growth models required for resource assessment modeling. Work at Pan Pacific Technology and Argonne National Lab will produce energy and material balanced system models in Aspen based on the REAP process data. Work at Algenol Biofuels will support cultivation studies and evaluate techno-economic readiness.

Overall Impressions

- This project seeks to develop strategies to improve the commercial viability of algae biofuel systems including: engineering strains with unique characteristics, such as high heat tolerance, scaled outdoor testing of model strains, and wet biomass extraction using sequential hydrothermal liquefaction (among other objectives). The work supports associated TEA and LCA work and will produce engineering data for these modeling efforts. Overall, this is a solid project with a unique and innovative high temperature configuration that may, as a function of its design, improve overall efficiency and avoid typical problems (such as contamination) encountered by other technologies and configurations.
- Few projects at this year's Peer Review showed better than incremental progress. Dr. Lammers' group is one of the innovative ones. Testing the design case of extremophiles grown in PBRs in hot, arid areas is a novel approach that may yield significant ROI and lessons learned. This project points at the gap between modelers saying, "grow in marginal lands," and the engineering required to do so.
- Some key technical foundation work is being developed. More specific research strategy development may accelerate learnings.
- The use of novel extremophile species that tolerate high temperature and low pH in this project is innovative. If successful, this project will contribute to the development of cultivation systems suitable for growing algae in highly arid regions with limited water availability, where the use of pond systems is prohibited by high evaporative water losses. Additionally, recycling carbon (as water extractable sugars) from biomass before HTL processing would provide a feedstock for fermentation processes or a supplemental source of carbon for growth of heterotrophic organisms. Preliminary TEA/LCA analysis of the proposed pathway is promising and indicates areas that need further improvement to meet GHG emissions requirements for advanced biofuels.
- This project is attempting to optimize a potential production system for productivity, using a particular set of strains for rotation, a photobioreactor (PBR) system and sequential HTL (SEQHTL) processing. Though more work has yet to be performed, so far the improvements have been minimal. To ultimately reach the productivity goal of the FOA, the project needs to remain flexible and choose the most appropriate and high-impact targets for improvement.
- This project combines novel organisms with the only project under review that addresses the light harvesting issues associated with inefficient algal productivity. This latter is a difficult task if we examine the very disparate results available in the literature. Success has not yet been achieved, but the project should be included in the BETO portfolio.

PI Response to Reviewer Comments

- The REAP team appreciates the positive comments of the panel. The goal of 2,500 gal/acre/year is highly non-trivial. Data from the next 12 months of planned research will be critical in determining the vision for an ABY-Phase 2 proposal from the REAP team. The team will remain flexible in the context suggested, allowing the data and modeling efforts to determine the next steps. For example, the value of the SEQHTL system must be rigorously compared to single-stage HTL system with respect to techno-economics and carbon emissions.

POLYCULTURE ANALYSIS

(WBS#: 1.3.2.401)

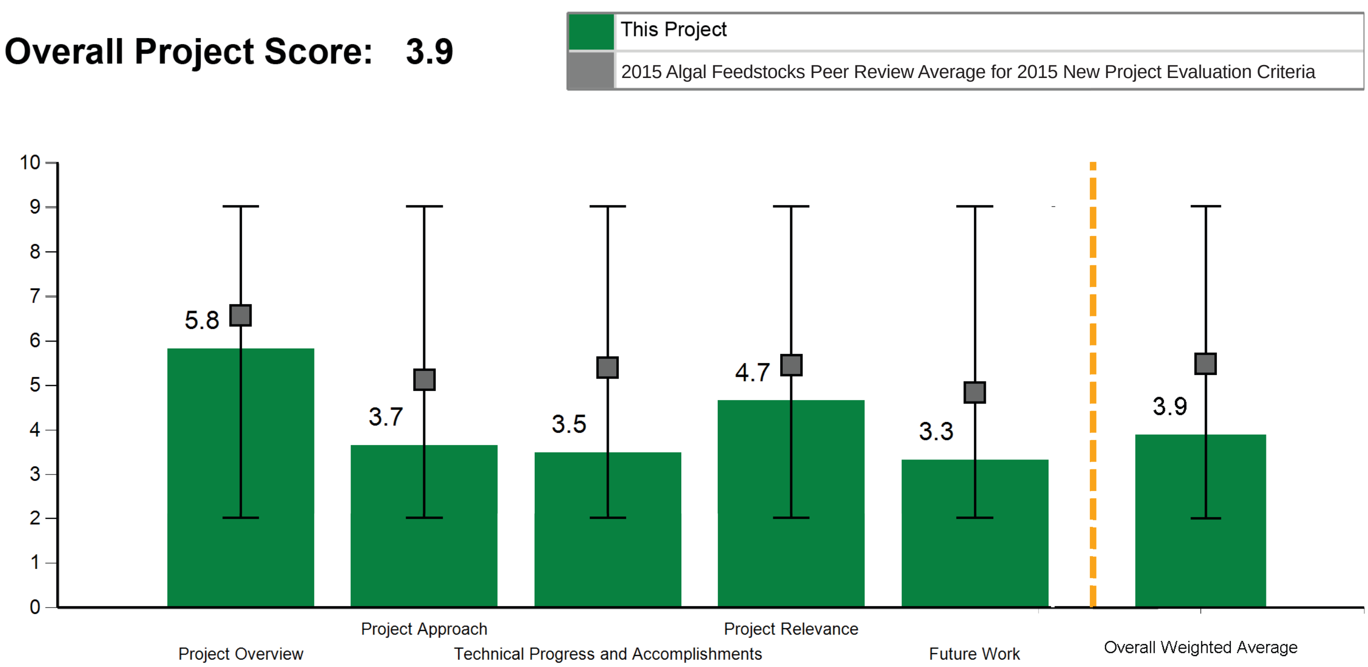
Photo Courtesy of INL

Recipient:	INL
Presenter:	Deborah Newby
DOE Funding FY14:	$432,688
DOE Funding FY13:	$12,792
DOE Funding FY10-12:	$0
Planned Funding:	$1,853,682
Project Dates:	10/1/2014 - 9/30/2016

Project Description

The overarching goal is to develop polyculture-based cultivation approaches, via naturally occurring or rationally assembled consortia, to gain improvements in annual productivity, culture stability through crop protection, and reduction of the overall costs associated with algal cultivation. Polycultures have the potential to rapidly adapt to fluctuating environmental conditions, resist predation, and better utilize resources (e.g., light, nutrients), resulting in greater productivity than mono-culture. A review manuscript developed by the Hub team will establish a baseline for the state of the art for algal polyculture overyielding and resilience and will inform Hub activities. At a high level, the lab-specific research foci are as follows: improved off-season productivity (INL), stability (ORNL), naturally occurring benthic populations and conversion (SNL); and scaling (PNNL). Implementation of the polyculture approach will be carried out in incrementally increasing scales culminating in field-scale demonstrations using facilities

Overall Project Score: 3.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

established within the BETO-funded algae test beds (ATP3 or RAFT) in 2017. The goal is to significantly improve on the Harmonized Algal Biofuels Baseline Study performance of 13.2 g/m^2/day (annual average) through coordination of AOP activities among the four national labs and extended Hub collaborators. The integrated target is to demonstrate annual yields in the 20-30 g/m^2/day needed for 5,200 gal/acre/year target in the MYPP.

Overall Impressions

- The three-member partnership seeks to establish and characterize robust algal consortia that have higher yields and greater stability than typical monocultures.
- There was little to no reference to existing literature regarding algal polyculture engineering that would serve as a guide for these efforts. Establishing a greater lineage from past work to this work may help to assuage concerns about experimental design.
- There is real interest in establishing robust polycultures as a means to improve algal culture stability in outdoor commercial systems. However, noting this interest and putting forward a comprehensive strategy to engineer such polyculture systems are two very different things. Ultimately, while the subject of polyculture engineering is topical, it is difficult to assess how relevant this work will be or if the minimal plans put forth can actually serve as a platform for designing and characterizing algal consortia. The presenter did not make an effective case that this particular project is going to have substantially more relevance than any other similar endeavor.
- This project has multiple personnel issues which are likely to limit success. Algal ecology experts need to be added to the team. The team needs to test polyculture viability outdoors at ATP3 within the first three months and then frequently thereafter. The PNNL test raceways are an inappropriate intermediate step for polyculture, as they do not allow for the potential of contamination by volunteer strains.
- This is an interesting concept with potential to improve resistance. Extending production with a range of organisms has great potential. We need to learn from existing systems, as well as conduct extensive experiments in open systems.
- This project is attempting to address a long-standing problem in the industry about culture productivity and stability at scale. A polyculture approach is one potential solution that is definitely worthy of exploration. This project proposes a step-wise scale-up process and multi-pronged approach to ultimately select a polyculture that will have high productivity outdoors. These are appropriate steps to take. What would enhance this project is sound initial community selection based on preliminary outdoor competition studies and ecological analysis of the strains of interest. Practically, outdoor testing cannot start immediately, but should be started as early on in the process as possible. Identifying a robust mixed community that will perform in a given location will require testing of many combinations of strains, or new ideas/strains could arise from nature.
- This a new hub that has yet to achieve any cohesion. The program has a scientific leadership vacuum, and needs to include an expert in algal ecology to help develop a sensible research plan.

PI Response to Reviewer Comments

- The structure of this research hub was established by the BETO Algae Program Manager, and includes four national labs with very different core capabilities. Projects within the different labs are at different levels of maturity. The project was subjected to a merit review prior to funding. The roles of individual labs were delineated in the organization chart with INL focused on off-season work, SNL on benthic populations, ORNL on stability, and PNNL by providing access to climate controlled ponds. The Hub is not a single project, but an extended collaboration with shared targets and high level milestones meant to facilitate communication and synergy between diverse approaches to meet a common goal. It was clearly stated that each lab operates under its own funding and AOP, but at the request of BETO, shared milestones where included. Achievement of joint milestones could be through combined or individual efforts. The INL PI is responsible for coordination, but the structure and funding of the Hub as defined by BETO does not provide authority for decisions outside of the INL workscope. Each member is expected to contribute to the common goal, managing decisions within each aspect. We agree that this funding structure creates challenges that will need to be managed through frequent internal communications as shown in our proposal's communication plan.

- We agree with the review comment regarding the need to address a long-standing problem in the industry related to culture productivity and stability at scale. We agree that the polyculture approach is one potential solution that is definitely worthy of exploration. Hub members possess diverse expertise including significant experience in algal ecology. Algal ecology expertise is integrated through collaborations and subcontracts (e.g., Val Smith, University of Kansas; Jonathan Shurin, UCSD). Large scale demonstrations are planned at ATP3 sites (under separate funding) and discussions with potential industry partners have been initiated.
- The INL focus is to establish consortia capable of increased productivity during the off-season, specifically spring and fall, addressing a key barrier to annualized productivity targets. The design strategy is a trait-based design, with temperature being a key attribute. Few studies have used synthetic polycultures to improve yields, none specifically targeting the off-season. We are targeting specific fluctuating conditions that are based on yearly averages that cannot be guaranteed to occur in a given year. We would agree that it is optimum to begin with outdoor studies. However, we cannot count on naturally occurring weather to provide reproducible conditions. Thus, we began this project in the laboratory where we can reproducibly model these critical off seasonal conditions with large variations in temperature and lighting.
- INL has a long history in examining microbial diversity and population dynamics in both soil and water, as well as expertise in algal cultivation at a variety of scales. Initial synthetic consortium will be based on a production strain. Other strains will be selected from the prevalent freshwater algal classes (bacillariophyceae, cyanophyceae, chlorophyceae, xanthophyceae, eustigmatophyceae) with the goal of maximizing functional diversity. Literature suggests that greater functional diversity is more important than species diversity to algal productivity. Because it is impossible to know a priori how each strain will interact with one another, a screening strategy has been adopted. Overyielding consortia will be rigorously tested under fluctuating temperature conditions using environmental photobioreactors (ePBRs). We recognize their limitations, but feel that they are the best available and appropriate tool for screening relative productivities of our synthetic communities under simulated spring and fall conditions. Outdoor testing is resource intensive and our screening approach is intended to narrow the candidate polycultures.

SCALE-UP OF ALGAL BIOFUEL PRODUCTION USING WASTE NUTRIENTS

(WBS#: 1.3.5.240)

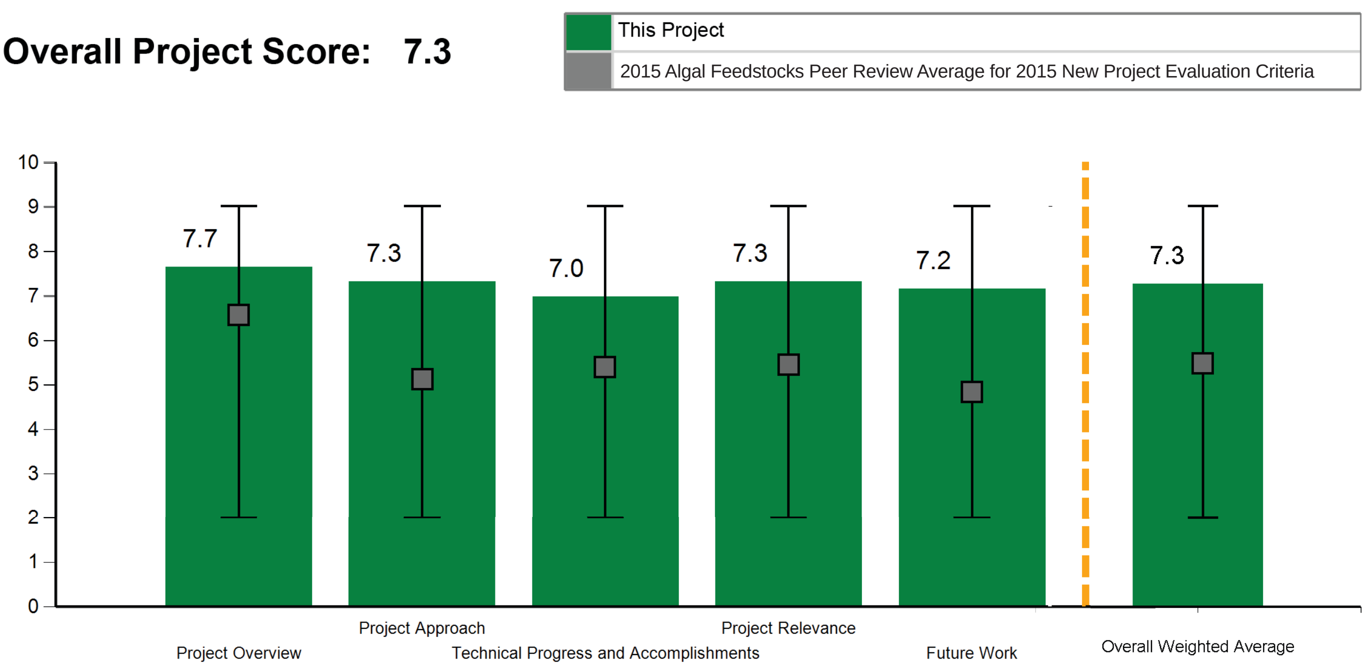
Photo Courtesy of California Polytechnic State University

Recipient:	California Polytechnic State University
Presenter:	Tryg Lundquist
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$930,883
Project Dates:	9/30/2014 - 9/30/2016

Project Description

The project objective is to develop the capability to produce biofuel intermediates from microalgae grown at a wastewater treatment facility with 6 acres of raceway ponds, located in California's Central Valley, targeting production of 2,500 gallons of biofuel intermediate per acre per year by 2018. Compared to the typical results of algae producers, the productivity of algae must be increased to achieve this goal. This improvement will be accomplished by optimizing the growth and survival of selected high-productivity algal strains through laboratory and field experiments. The project is investigating the optimal conditions for growth in each season, and monitoring and investigating control methods for grazers and other deleterious organisms. The project is also demonstrating bioflocculation and settling of algae biomass—a low cost, low energy intensity method of algae harvesting. Algae biomass is converted to biofuel intermediates by two methods for comparison: hydrothermal liquefaction and lipid separation using microfilters. Both methods have the potential to make biofuel interme-

Overall Project Score: 7.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

diates that can be converted to biofuels. The project benefits DOE by providing a large raceway facility at a site with access to wastewater, plus improved understanding of algae mass culturing. The growth model output will also become input to an engineering model, which will be used for study of lifecycle assessment, capital and operating costs, and facility design, including scale-up design.

Overall Impressions

- This project seeks to scale-up an algae biofuel pathway that uses wastewater nutrients. The plan is to characterize CO_2 cycling and identify critical parameters to perform associated TEA and LCA for this system configuration. Sustainable algae systems will not be able to rely on large amounts of water that could be used alternatively for agriculture (this is especially true in California's Central Valley), and thus the prospects for co-localization and integration of such systems at wastewater treatment facilities is of interest. The results presented are not appropriately contextualized in a manner that would allow the reported results to serve as a metric for placing this work among the current state of these technologies. Thus, the overall relevance cannot be assessed. Falling back on the intuitive relevance of such systems in general is contrived.

- While algae grown on wastewater will likely end up being a marginal contributor to production of algae biofuel feedstocks, currently this project produces the most biomass out of any project in BETO's portfolio. Success of this project is currently limited by its inability to close the carbon mass balance. Is the main source of carbon in the algae allochthonous (fixed CO_2) or autocthonous dissolved organic carbon?

- This is solid data-driven work to address some key issues. Understanding contributions of the dissolved organic carbon to overall productivity will strengthen results. Resolving differences between pilot systems and larger units is very useful.

- Results indicate that the HTL aqueous phase is completely inhibitory to algal growth and is not suitable to be recycled for use in subsequent cultivation rounds. This will negatively impact the proposed process and the PIs should evaluate how this will impact the TEA/LCA feasibility of this process early on in the project. That being said, the biofuel intermediate goal of 2,500 gal/acre/year, requiring a productivity of 20 $g/m^2/day$ in this case, appears feasible based on data collected thus far, but will depend largely on results throughout the upcoming summer season. Looking toward future work, the PIs should make it a priority to close the mass balance on biomass characterization, since 33% is currently unaccounted for. Finally, the inclusion of Chlorella sorokiniana DOE 1412 is not relevant to the overall objectives of this project. Similarly, focusing on lab scale activities for strain development is not relevant to or supportive of the goals of this project. It would be more efficient to reallocate resources from these tasks to address with the issues with recycling the HTL aqueous phase.

- This project is attempting to develop and optimize an algae production system that leverages wastewater treatment for increased productivity. The project is addressing the areas of optimized cultivation conditions, strain assessments, and improved harvesting and conversion into biofuel intermediates. Incremental improvements have been made on all fronts and hopefully will continue, though the system will have to overcome production variability from many factors, and a mixed algal community that may be hard to force productivity increases upon (there may be a "limit"). Planned piloting and modeling efforts should reveal the system's weaknesses and advantages.

- This is an outstanding project working at very large scale with a municipal wastewater treatment plant that is already growing tons of algae. This provides a testbed for developing approaches to meeting BETO goals, and the work is proceeding apace.

PI Response to Reviewer Comments

- The reviewers noted a lack of contextualization and metrics with which to assess algae biofuel production using wastewater relative to alternative processes. The techno-economic and lifecycle assessments (TEA and LCA) to be prepared using the data generated during this project, along with projecting further necessary advances, will provide this information. MicroBio Engineering Inc., will use standardized assessment methodologies (CA-GREET and the BETO Algae Program harmonized TEA/LCA approaches) allowing integration of these project results directly into the BETO evaluation process.
- HTL wastewater has been noted to be very inhibitory to algae growth by the Cal Poly research group and by others. The reviewers rightly commented that overcoming HTL wastewater inhibition will add to the TEA/LCA costs/emissions. This topic will be explored further in laboratory experiments and then in the final TEA and LCA studies using the latest in-house and external information available.
- The task on algae growth model development was criticized as irrelevant or not well connected with the main effort under this project. The major goal of the ABY program is to demonstrate and increase areal productivity. The pilot plant work is meant to measure productivities of native polycultures for use in planning the near-term Phase 2 scale-up. Combining these experiments with the growth modeling work of Dr. Huesemann's lab at PNNL will provide a stronger basis for projecting the field results to a larger-scale production. He is working to increase the throughput of the strain evaluation process with innovative lab culturing hardware to determine the parameters needed in his Algae Growth Model (AGM), to more quickly predict the monthly productivity of new algae strains in most any climate. In our ABY project, we are helping to validate the AGM with pilot plant production data, which will have general applicability to other locations nationwide. Chlorella DOE 1412 was selected for the initial studies because of the considerable knowledge accumulated by Dr. Huesemann and others on its growth characteristics. In Phase 2, Dr. Huesemann would evaluate wastewater strains, with the intent to deploy a suite of high productivity strains at pilot scale. As in the Cal Poly ASAP project comments, the reviewers asked how biomass productivity from photoautotrophic algae growth can be differentiated from heterotrophic growth on reduced substrates of wastewater origin. The ASAP response is repeated here: This issue is not important for scaled-up processes where water and nutrients are extensively recycled and where wastewater would be only a minor input as make-up for evaporation and other losses. However, it has been a long-standing and unresolved question in the field of algal wastewater treatment, specifically where untreated wastewater is a significant or even the main input for algal production. In this project, the raceways produce an algal biomass that predominantly forms flocs, ranging from hundreds of microns to even several millimeters in size, with bacteria, algae, and detritus intermixed. Thus, it is difficult to differentiate algal from bacterial biomass by microscopic observation, staining, or particle size distribution. "Net productivity," simply calculated as the difference in ash-free dry weight of suspended solids in the effluent minus the influent mass, has been used as the main means of assessing new biomass production separate from the influent flows of organic matter. When growing algae in recycled wastewater media (which has already had most wastewater organic matter removed) this is not an issue. Further, the process allows a more direct assessment of photoautotrophic productivity. An ASAP project task to develop a practical laboratory analytical method to differentiate and quantify bacterial and algal biomass in the pond effluents was not successful.
- The PI appreciates the reviewers' helpful comments and critiques.

ADVANCING COMMERCIALIZATION OF ALGAL BIOFUELS THROUGH INCREASED BIOMASS PRODUCTIVITY AND TECHNICAL INTEGRATION

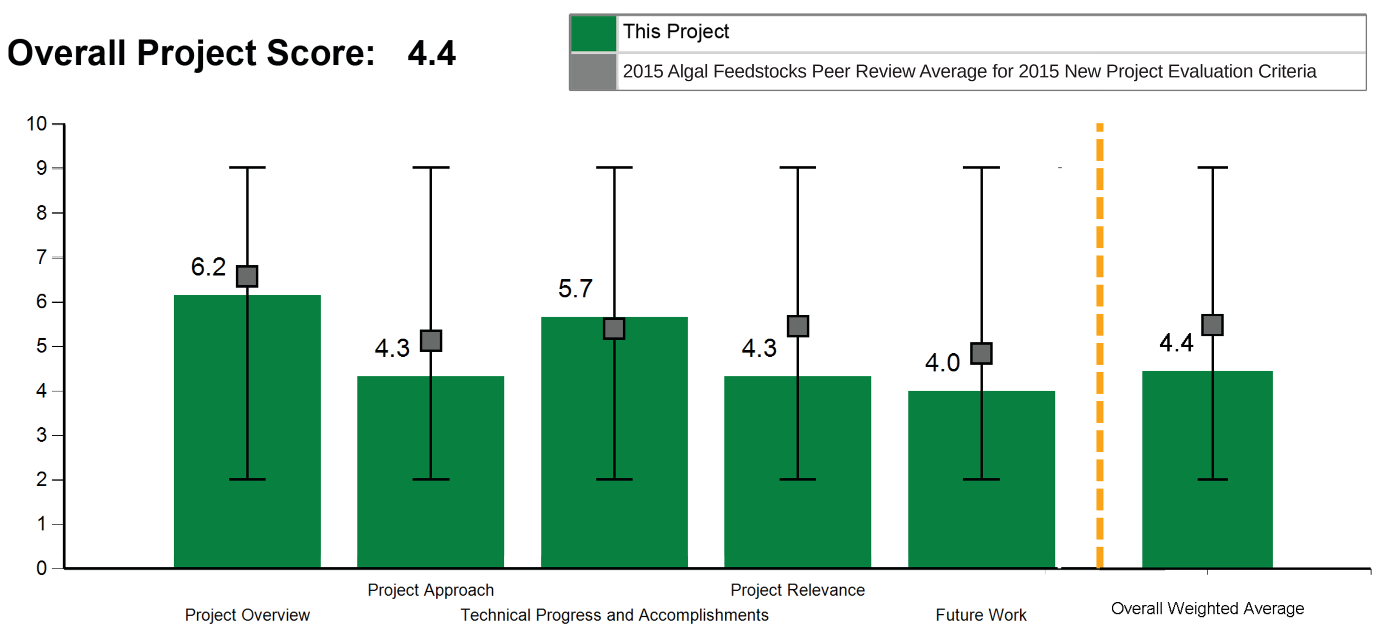
(WBS#: 1.3.5.250)

Recipient:	Cellana
Presenter:	David Anton
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,706,000
Project Dates:	9/1/2014 - 9/30/2016

Photo Courtesy of Cellana

Project Description

Our project goal is to achieve a fully-integrated, high-yield Algae Feedstock Logistic operation system using the most advanced strain improvement, cultivation, and processing technologies in the proven algae cultivation operations at Cellana's Kona Demonstration Facility (KDF). Cellana's experience producing algae at a demonstration scale will be leveraged to identify two strains with potential to achieve the goals of the Algal Biomass Yield (ABY) funding opportunity. Novel strains will be identified using a variety of techniques and tested and cultivated at lab-, mid-, and demonstration-scale for their potential to increase biomass and lipid productivity and lower operational costs. Improved pre-processing technologies will then be evaluated using these strains along with a techno-economic analysis (TEA) model, which will quantify all key variables in the manufacturing process, not only the specific lipid



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

and biomass productivity experimental parameters. This model has been developed and is being verified. Initial process integration will be developed at lab scale as a guide for scale up. All technologies will be integrated at demonstration scale for verification of an improvement in lipid and biomass productivity and further validation of production cost. Cellana's goal is to develop a commercially viable algae production process using a combination of research and techno-economic analysis with the ultimate goal of building profitable algae production facilities.

Overall Impressions

- This project seeks to optimize and integrate algae biofuel processes leveraging new strain development and other fundamental research, but largely relying on an in-place demonstration facility for research support. Most components of the research, including looking at strain development, and integration modeling as well as TEA and LCA are typical, and the presentation did not adequately distinguish a unique niche for this work.
- This grant contributes to Cellana's ability to purchase supercritical fluid extraction capacity; what is unclear is what return BETO will see on such an investment. The grant feels too large in scope for what tangibles are promised. The presentation was opaque and lacked sufficient detail on research methods, metrics, and deliverables.
- The limited information shared prevents systematic review of status and plans. Participation in the ATP3 effort was very useful.
- An adequate review of the scientific integrity of this project was not possible due to the lack of information presented to reviewers.
- Cellana's integrated demonstration-scale facility has been utilized for years and should be a source of cultivation know-how for the entire field. They are serving this function as a partner of the ATP3 test-bed facility. This project involves their additional work to identify more productive strains and improve existing harvesting and extraction technologies, and ultimately demonstrate the best suite of technologies at their facility. These are good objectives, but the existing research plan and goals appear to lack the structure, detail, milestones and external engagement they will require to succeed.
- It is too early to judge this program.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

HYDROCYCLONE SEPARATION OF TARGETED ALGAL INTERMEDIATES AND PRODUCTS

(WBS#: 1.3.3.100)

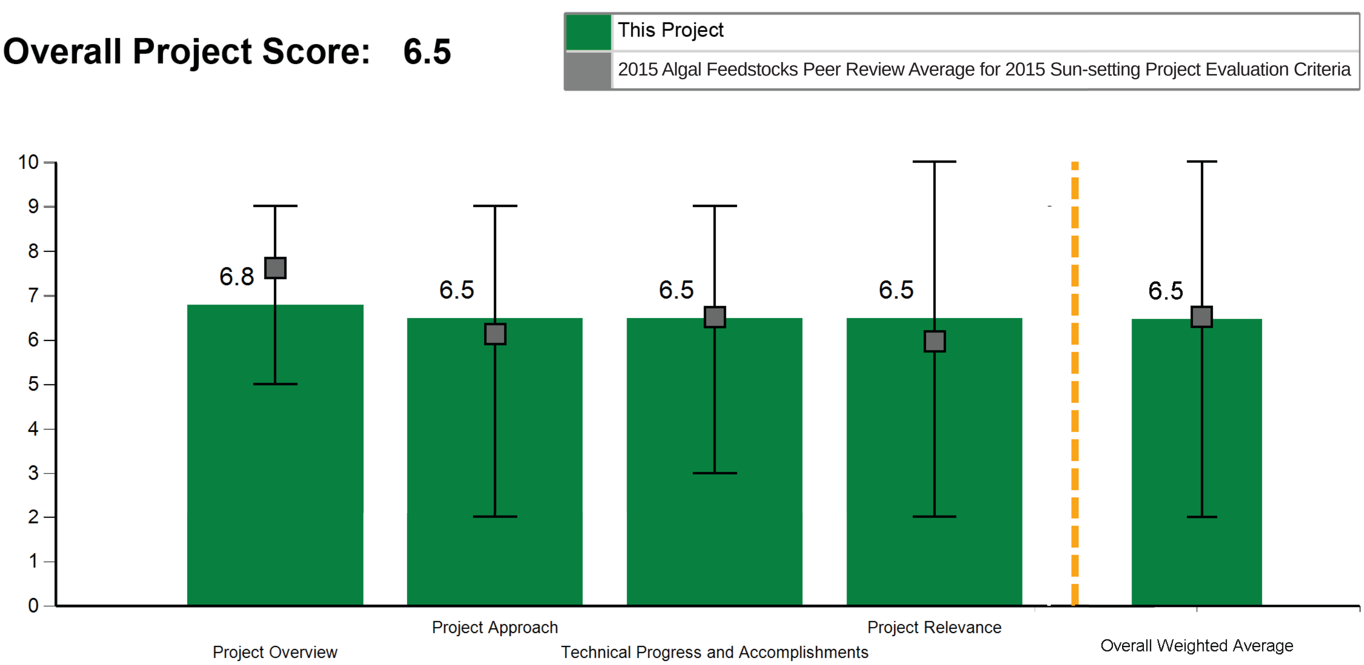
Recipient:	ANL
Presenter:	Philip Laible
DOE Funding FY14:	$332,310
DOE Funding FY13:	$258,679
DOE Funding FY10-12:	$0
Planned Funding:	$9,011
Project Dates:	10/1/2012 - 9/30/2014

Photo Courtesy of ANL

Project Description

A continuous-flow dewatering process utilizing hydrocyclones has been demonstrated to recover algae from the culture medium. Being low-cost and energy-efficient (nearly passive), this technology has the potential to replace current centrifugation and/or filtration operations. Hydrocyclones can be used in-line with other dewatering methods, reducing equipment use and staff workloads. These devices are comprised of a conical body where liquid is fed tangentially near the center. Separated components exit at two opposite axial ports. Rapid centrifugal flow forces dense/coarse material out through the bottom (underflow) while light/fine materials follow the majority of the liquid and exit the top (overflow). Use of hydrocyclones of different sizes and varied operational parameters identified conditions that yield high recoveries of algal biomass—especially in multistage, recirculating pathways. On the 20-L scale, greater than 90% biomass could be harvested with concentration factors of >15X within 20 minutes – using a

Overall Project Score: 6.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

power input less than that of a standard light bulb. This success was duplicated at the REAP algal production facility at New Mexico State University. The general utility could be expanded with application to a variety of species spanning a range of cell sizes and densities (varied lipid content). Costs of unit operations based upon this technology are at or below conventional approaches with far less capital requirements and the endless ability to scale.

Overall Impressions

- Isolation and dewatering of algal biomass remains a substantial obstacle to the commercialization of algal biofuel systems. Hydrocyclone technology was shown to be very efficient at concentrating algal biomass often operating near theoretical limits—this would be significant for minimizing overall energy demands for this unit process.
- The technical accomplishments reported are in line with the level of investment and will be valuable for continued research into this technology as it applies to algal systems.
- Carry this work forward by giving a hydrocyclone to a Master's student at ATP3 and allowing them to test it in the field at raceways operating at full algae productivity. After the DOE investment of half a million dollars on this device, it seems disappointing to shelve it without testing it on different cell morphologies, densities, and cell sizes. It would also be interesting to test this with a polyculture, which would subject the device to a range of different cell parameters. This being said, any future work on this device needs to be done on an extremely thin budget. Running out its potential at full production scale is ahead of what the biology can produce.
- In the future, when DOE BETO funds two competing approaches (e.g., hydrocyclone and RAE's harvester), the project manager would do well to standardize the metrics of success, including testing with DOE model strains, an energy cost assessment done on the same TEA model, and if at all possible, experiments conducted with the same volume/density of algal culture.
- This is a useful option for partial thickening dilute raceway suspensions at modest investment. It needs to be linked to a specific production strategy to be useful.
- The hydrocyclone did not achieve high dewatering yields without multiple passes through the system. Since the cost and energy associated with pumping water around was not discussed, it is difficult to assess the impact of this system on advancing the state of the art.
- This project met its objectives of building a prototype hydrocyclone unit for algae biomass harvesting, and optimizing and modeling operations for that unit. It was also tested in the field at a test-bed pond. The technology performs similarly to competing technologies, but has potential due to decreased CAPEX. At this stage, the technology will need to be further tested for broad applicability in the field, and can later be optimized by the industry if adapted, since other large-scale hydrocyclones exist in other industries. There are many similar technologies available for this stage in the algae supply chain. Which technologies industry will adapt and optimize has yet to be seen.
- Interesting work that needs to be compared (on paper at this stage; no need for more experiments) with the air froth technology described by Jeffrey Kanel of Renewable Algal Energy (RAE).

PI Response to Reviewer Comments

- The tests that the reviewer suggested could be tackled by a Master's student seem appropriate. The application of hydrocyclones to the dewatering of polycultures is most interesting and something that we have talked about attempting, but lacked access to mixed cultures. Production capacities and the scaling of dewatering efforts will be critical factors as input into future TEAs. For efficiency, the sizing of hydrocyclone systems will be coordinated with the production capacity of each individual installation.

- As stated in earlier responses, we agree that better coordination would result in better side-by-side comparisons at the end of projects.
- The operating energy expended was measured directly in every experiment. Capital expenditures will be installation specific and will be elaborated upon at scale if hydrocyclone efforts are funded in the future. Operational energy was quantified and included in more detail in the quarterly reports. Energy expended was within the same order of magnitude for our small-scale efforts as would have been used for separating the same amount of algal biomass, but using competing operations of settling, dissolved air floatation, and centrifugation run with scaled equipment. Thus, we described a qualitative comparison in the slideshow with the expectation that future efforts could accurately compare technologies at the same scale. We agree that this could have been improved and that capital expenditures would be the key to making hydrocyclone technology an economically viable solution.
- We appreciate the thoughtful comments from the reviewer and agree that time will tell whether or not hydrocyclones will be adopted and will prove energy-saving in the field.
- As stated before, we completely agree that better coordination among ongoing projects within the Algal R&D portfolio would result in better side-by-side comparisons at the end of projects. Comparable TEAs (at appropriate scale) will drive technology implementation and scaled testing going forward.
- We agree with the reviewer that the correct sizing of hydrocyclone systems will be important for each installation and operational parameters that work best with production strains need to be coordinated at each site. The scale-up and link to larger algal production facilities were outside of scope of this small, proof-of-principle, seed-project effort.

MANAGING THE MICROBIAL ECOLOGY OF A CYANOBACTERIA-BASED PHOTOSYNTHETIC FACTORY DIRECT!

(WBS#: 1.3.3.900)

Recipient:	Arizona State University
Presenter:	Bruce Rittman
DOE Funding FY14:	$321,335
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$115,441
Project Dates:	12/1/2012 - 11/30/2014

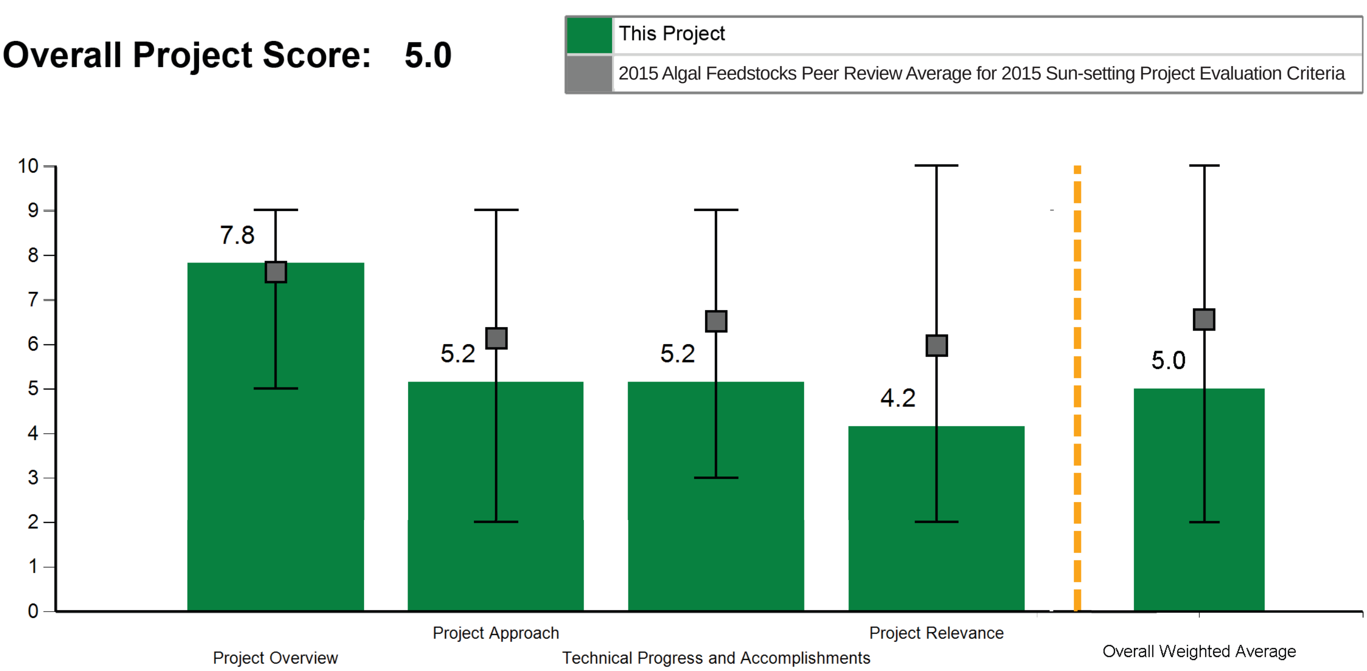
Project Description

This project evaluated the factors controlling the productivity of Photosynthetic Factory Direct!, in which genetically modified Synechocystis excretes laurate, a jet-fuel precursor. It was found that the modified strain releases less than 10% of its fixed C as laurate, but much more to soluble microbial products (SMP) that grow heterotrophic bacteria. High light intensity and P depletion accentuate SMP release. The N source controls the availability of inorganic C. Synechocystis-based photobioreactors (PBR) develop microbial communities with diverse heterotrophic bacteria that are able to biodegrade laurate. A very high specific growth rate and moderate light intensity help to suppress heterotrophs and laurate biodegradation. The project developed a novel harvest system that recovers laurate by ion exchange and removes SMP by adsorption. The project team were able to extend the time in which laurate recovery takes place using the harvest system.

Overall Impressions

- The project investigates the production and secretion of laurate from cyanobacteria (Synechocystis). Although the utility of establishing consolidated bioprocesses for biofuels or biofuel precursors, this presentation did not adequately establish a project overview that clearly indicated a broader impact for the research.

Overall Project Score: 5.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- Research into consolidated biomass and biofuel accumulation systems is valuable, but the outcomes from this specific project appear to be limited in both technical output, and broad applicability.
- The overall limited relevance and impact of this work may have been a function of inadequate investment, poor model system and model product selection, and poor intermediate planning.
- Production of 4.5 mg/L laurate is suboptimal; the goal of 100 mg/L may also be too low, as laurate is common to many production pathways. This project's most significant contributions are at low technology readiness levels. It would be a strong contribution to BETO's portfolio for Dr. Rittman to share his molecular methods for determining heterotrophic presence in seemingly pure Synechocystis inocula.
- This is an interesting scientific demonstration. The commercialization strategy is unclear.
- An interesting project that still needs a substantial amount of fundamental work before commercial relevance can truly be assessed.
- This is a one-lab project focused on production of a one-fuel precursor product. Their technical approach to answer the proposed questions was sound. Small projects like this have exploratory value and could result in scale-up and commercial opportunities, but for DOE, at this stage, it is challenging to assess the long-term viability or impact of this technology. Clearly, it will have scale-up challenges as the technology potentially requires a complicated but non-sterile PBR system and because many bacteria appear to have an appetite for the product.
- This is interesting science, but unrelated to the goals of the overall program.

PI Response to Reviewer Comments

- At the time this project began, laurate production by Synechocystis was the focus of a large ARPA-E-funded effort. Heterotrophic consumption of laurate clearly was a bottleneck to success. Thus, our project was a fundamental study directed toward a critical success factor of that large effort.
- While some outcomes of our work are specific to Synechocystis and laurate production, the project's results also provide fundamental information about the microbial ecology of PBRs (e.g., it can be quite diverse with heterotrophs growing on the products of autotrophs); how to control C and electron flow in PBRs (e.g., minimize soluble nicrobial products (SMP) formation); and how to control key PBR conditions, such as the inorganic carbon concentration and speciation. These principles can be applied to other phototrophs and products.
- Furthermore, our team is following up directly on the most promising paths, e.g., reducing SMP release by modifying Synechocystis to produce less extracellular polymeric substances and by preventing nutrient depletion, operating special membrane biofilm reactor (MBfR) systems to obtain very high specific growth rates, and exploiting the NH_4NO_3 N source to allow superior pH control.

NATIONAL ALLIANCE OF ADVANCED BIOFUELS AND BIOPRODUCTS (NAABB)

(WBS#: 9.5.1.1)

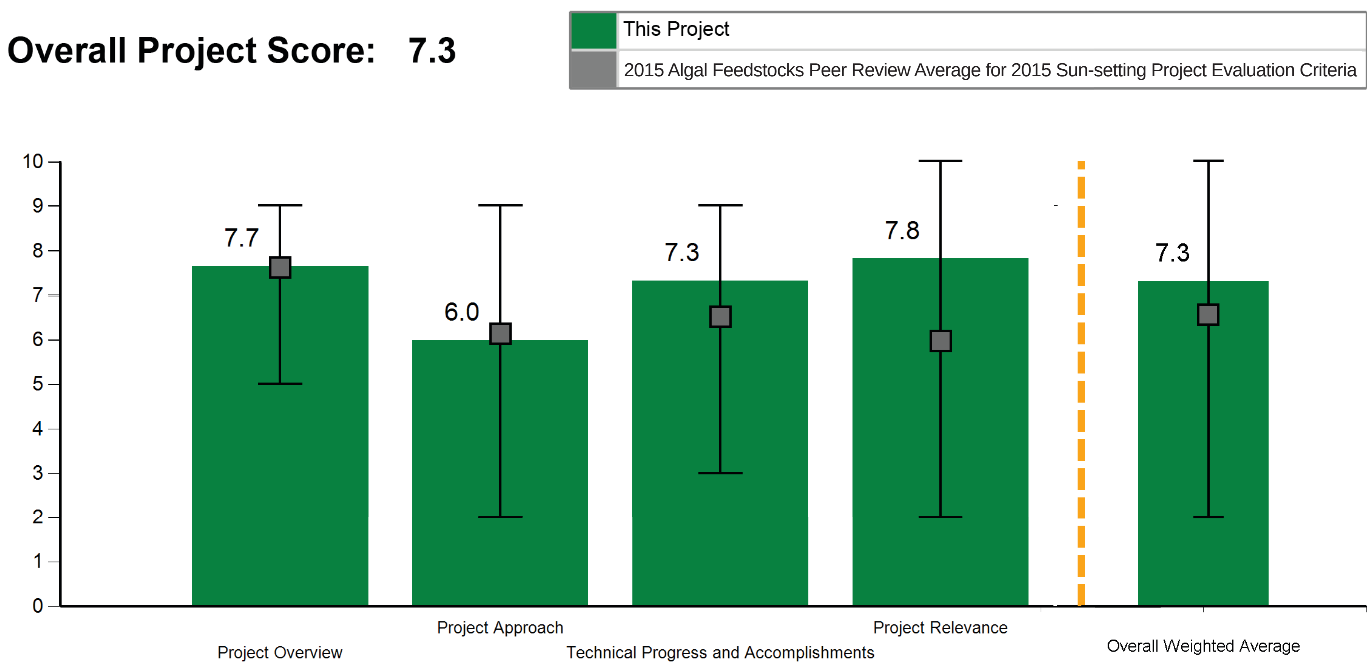
Photo Courtesy of Donald Danforth Plant Science Center

Recipient:	Donald Danforth Plant Science Center
Presenter:	Jose Olivares
DOE Funding FY14:	$1,458,476
DOE Funding FY13:	$9,250,649
DOE Funding FY10-12:	$21,347,692
Planned Funding:	$142,549
Project Dates:	1/28/2010 - 9/30/2014

Project Description

The National Alliance for Advanced Biofuels and Bioproducts (NAABB) is a consortium of 39 institutions developed to capture and integrate intellectual property, expertise, equipment, and facilities from a diverse set of companies, universities, and national laboratories in order to develop a systems approach to innovation for sustainable commercialization of biofuels and coproducts. This group ended operations in 2013 and the NAABB Algal Biofuels Consortium was formed to address key barriers across the full value chain of algal biofuels pro-

Overall Project Score: 7.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

duction. As such, it is an integrated program developing tools that facilitate deployment through science and technology. The NAABB is bringing innovation across the technology development platforms with core economics and sustainability goals, as well as a cohesive picture to all efforts. Several key technical challenges are addressed by the NAABB Algal Biofuels Consortium, including: (1) algal strains that can be cultivated in real-world conditions and harvested with minimal energy; (2) technologies that are scalable and provide energy return on investment; (3) technology integration with needed nutrient, water, and other recycles; and (4) sustainable technologies with respect to environment, cost and permitting.

Overall Impressions

- NAABB's success is reflected by its large volume of high impact publications in this area. Moreover, its technology has served as a seed for many subsequent research projects.
- I am concerned by NAABB's statement that strain selection work needs to continue. The hope of discovering one natural super-strain has already exhausted a large amount of dollars without achieving success. I would like to better understand what NAABB considers to be its top three achievements, which move BETO's portfolio forward. The presentation given would have benefited from some reshaping to better communicate the highlights and lowlights of the last few years.
- The broad scope and complexity of interactions are difficult to follow. Inclusion in numerous publications, a conference, and a journal provide an opportunity for further dialogue. It would have been nice to hear about key learnings and recommendations for continued work.
- The technical achievements have been detailed in the formal NAABB synopsis report and an analysis of the impact of NAABB deliverables on advancing the state of the art was thorough. Although the strain screening project ultimately turned out to be unsuccessful (as the Chlorella sp. DOE1412 strain has since been shown to be highly problematic for outdoor cultivation), the investment of 25% of the budget into algal biology R&D did yield significant deliverables in the area of algal molecular biology. The sequence and assembly of eight commercially relevant algal genomes, transcriptomics-based metabolic networks, and development of a molecular toolbox for multiple species have provided a solid platform to be leveraged by the algal biology R&D community. The whole algae HTL pathway that resulted from this project may prove to be its most impactful legacy. It is clear from this presentation that results from this program are being used as a foundation for expanded research in BETO's portfolio. Since the objective of the algal biofuel consortia FOA was to develop a framework for sustainable algae production as a first step toward reaching commercialization, I would consider the breadth of foundational R&D deliverables demonstrated across the value chain by NAABB to be a success. Additionally, the establishment and continued support of the ABBB conference and the Algal Research peer-reviewed journal are of immense value to the field.
- The NAABB consortium was an ambitious effort aimed at bringing together members of academia, the DOE national lab system, and industry to address all areas of the algal supply chain and not only make basic discoveries and process improvements, but also help bring those improvements to the private sector. Inevitably, there was more or less success in different areas, and the speaker was able to demonstrate where NAABB had made some significant contributions to the field. Several presentations over the three-day review referenced strains or technology that were being leveraged from the NAABB.

- The conventional wisdom in algal biofuels is that the success of cultivation (or productivity of the biomass) will be the critical element that advances or slows down the field. Given the investment and amount of work in the NAABB that focused in these areas, additional discussion on key improvement targets, significant barriers and related lessons-learned would have been useful to the audience.
- This enormous program has brought together an outstanding team that has performed some interesting academic work, and successfully rejuvenated academic interest in algae.

PI Response to Reviewer Comments

- We thank the reviewers for recognizing the efforts, challenges, and outcomes of the consortium within the short presentation. We refer the reviewers and the public to the NAABB Final Report and over one hundred publications in the peer reviewed literature for many of the details of the NAABB work that were not included in the presentation. The impact of the three-year effort has now extended to many of the projects within the BETO portfolio. This, along with the development of a revived community around algae research, which includes a major journal and international conference series, provides an underpinning for much future work in this area.

ALGAL BIODIESEL VIA INNOVATIVE HARVESTING AND AQUACULTURE SYSTEMS

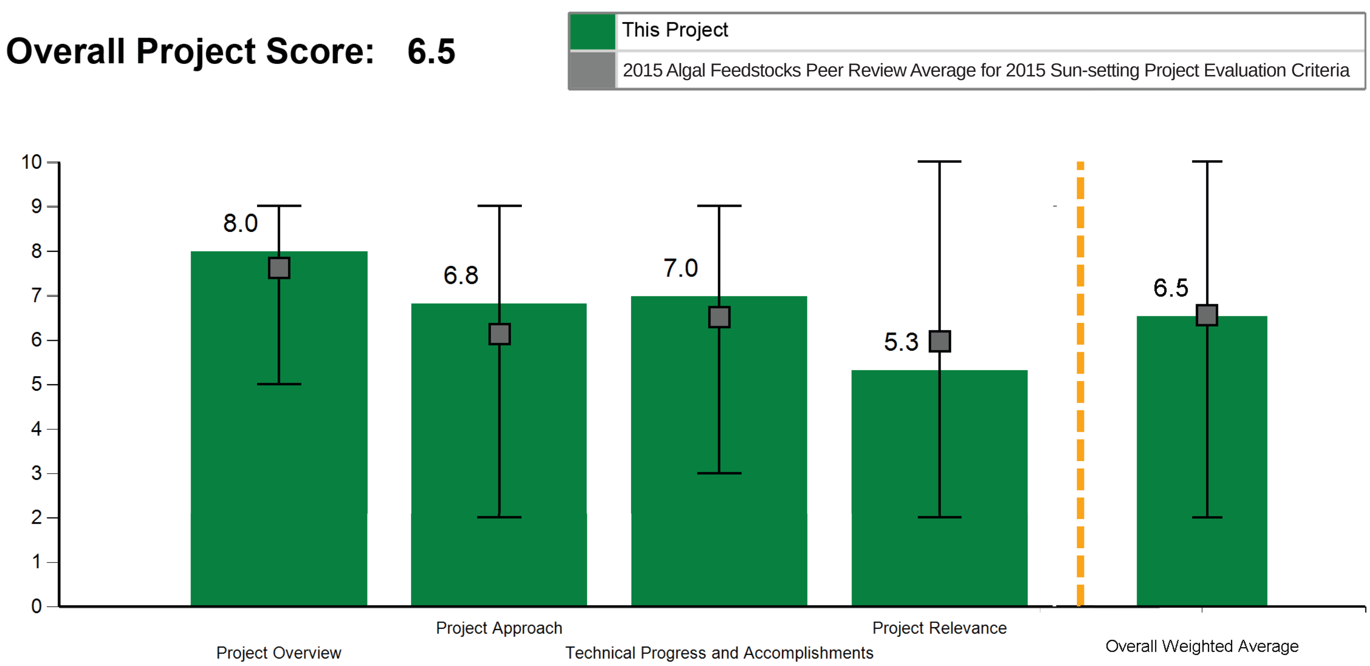
(WBS#: EE0004536)

Recipient:	Renewable Algal Energy
Presenter:	Jeff Kanel
DOE Funding FY14:	$963,295
DOE Funding FY13:	$607,893
DOE Funding FY10-12:	$1,508,197
Planned Funding:	$28,162
Project Dates:	10/1/2010 - 9/30/2014

Photo Courtesy of Renewable Algal Energy

Project Description

This project was in support of the BETO MYPP goal of demonstrating technologies to produce sustainable algal biofuel intermediate feedstocks for the renewable diesel effort. It focused on harvesting (dewatering and concentrating), and successfully met the primary goals of: (1) demonstrating a prototype algal harvesting process capable of automatically controlled continuous operation at >300,000 gallons per day (1.14 million liters per day); and (2) the energy consumption by the process did not exceed 10% of the energy content of the algal biomass being processed. Historically, Renewable Algal Energy, LLC (RAE) successfully demonstrated DOE Phase I & II Small Business Innovation Grants scaling-up (engineering, building and operating) to a 10 gallon per minute (gal/min) unit. The data from the 10 gal/min unit was used to design and engineer the 208 gal/min harvester in this Phase III Xlerator project. Full automatic process controls were implemented in the 208 gal/min harvester so that the automation technology is directly transferable to a 2,000 gal/min commodity harvester. The process control offered continuous measurement of



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

energy usage and algal biomass recovery was quantified. As a consequence of this project, an off-take agreement with Neste Oil and a strategic partnership with ABB, Inc., provided validation of the quality of oil and support for this technical approach, both facilitating its global deployment.

Overall Impressions

- Harvesting algal biomass remains a substantial obstacle to the commercialization of algal biofuel systems. This project seeks to develop and demonstrate an algal oil harvesting system. This project is sun-setting, and has ultimately produced a functioning demonstration scale unit process for concentrating algal biomass. The system can process up to 300 gal/min for extended periods of time.

- The researchers demonstrated a prototype for the developed technology and achieved a substantial goal. The results presented further showed that the energy demand for operating this system was not greater than 10% of the energy content of the algae, and the presentation offered good supporting evidence for claims made.

- The technology's industrial relevance is being demonstrated with an off-take agreement with Neste Oil, and this suggests that the technology is capable of collecting algae oil at commercially viable prices.

- This project is an example of impressive technological achievement underdelivering due to missing contextualization within a BETO energy production pathway. Algae strains tested did not include one of the benchmark strains, making it difficult to compare this technology's effectiveness or model its cost and efficiency within ALU-TEA or HTL-TEA.

- Specific performance parameters were defined and met. It is uncertain how broadly the approach may apply. Confirmation of application to other strains at larger scale is desirable.

- Why were such low culture densities used for experimental validation of the harvesting equipment? By rough calculation, the targets of 400K cells/mL and 700K cells/mL needed for less than 10% energy expenditure would be equivalent to approximately 0.1 - 0.2 g/L dry weight (based on an estimated 200-300 pg/cell weight for a 12 micron cell). This is not at all relevant to the densities that would be seen for biofuel production strains which would be closer to 0.7 - 1 g/L for pond harvest and 2 - 3 g/L for PBR harvest. Higher culture densities would probably impact processing speeds. The maximum cell density that was experimentally tested with this equipment was not clear from the presentation.

- This project had a simple, well-defined objective to design, build and operate a novel algae harvester, while assuring that the energy consumed by the harvester did not exceed 10% of the energy within the algae. They were also able to show that the resulting algae biomass was still suitable for fuel upgrading. The project indeed met these objectives. It seemed, however, isolated from the balance of the DOE portfolio in that no other project seemed to be leveraging or testing this new technology. It was also unclear, though they met their energy use, what the CAPEX investment would be for this technology and how it fits into the larger DOE TEA efforts.

- This was an important but relatively small part of the portfolio, carried out carefully, successfully, and within budget.

PI Response to Reviewer Comments

- We agree that demonstration of this technology with other algal strains of interest could be of value, and we are open to collaborations.

- As presented, the target cell concentrations for the 200 gpm and 330 gpm harvester flow rates were 625K cells per ml (cpm) and 325 cpm, respectively.

Assuming a spherical cell with neutral buoyancy with an average diameter of 11.7 microns in a culture medium of 1.148 grams/cc sp. gr., the target cell counts convert to 0.27 g/L and 0.53 g/L. As discussed in the Q&A of the presentation, the harvester is robust in the range of cell concentrations that have been concentrated to a 0.5 - 5% slurry. In the previous Phase II SBIR, cell concentrations ranged from 0.05 g/L to 1.05 g/L (10 micron diameter cells). Past development studies used concentrations as low as 0.01 g/L (20,000 cpm).

CONVERSION R&D

TECHNOLOGY AREA

CONVERSION R&D

INTRODUCTION

Conversion research and development (R&D) is focused on producing commercially viable technologies to convert terrestrial and algal feedstocks into liquid fuels, bioproducts, and biopower. To advance conversion R&D, BETO's Conversion Technology Area is working to deconstruct feedstock into intermediate streams (sugars, intermediate chemical building blocks, bio-oils, and gaseous mixtures) and then upgrade intermediates into fuels and chemicals.

Moving forward, the traditional division between biochemical and thermochemical conversion technologies will become less evident as the focus shifts to a simpler process flow where the polymeric feedstock is deconstructed into intermediates, which are then upgraded into products. With this in mind, the Biochemical and Thermochemical Conversion Technology areas were combined into a single entity under Conversion R&D for BETO's March 2015 Multi-Year Program Plan (MYPP) update. Because the 2015 Peer Review considered project activities from FY2013-FY2015, the review operated under the structure set forth in the November 2014 MYPP update.

For the purpose of the
2015 Project Peer Review:

- Biochemical conversion projects and technologies involve pathways that use sugars and lignin intermediates.
- Thermochemical conversion projects and technologies involve pathways that use bio-oil and gaseous intermediates.

CONVERSION R&D SUPPORT OF OFFICE STRATEGIC GOALS

The Conversion R&D area has partnered with a wide range of institutions to conduct R&D that supports BETO's strategic goals. The purpose of this R&D is to develop, validate, and deploy sustainable, commercially viable biomass conversion technologies to produce biofuels that help meet the Energy Independence and Security Act of 2007 Renewable Fuel Standard (RFS) targets.

The Conversion project portfolio directly addresses and supports development of technologies necessary for producing fuels and bioproducts from high impact feedstocks, including herbaceous, woody, algal, and some waste factions, such as municipal solid waste.

The Conversion Technology Area's strategic goal is to:

Develop commercially viable technologies for converting biomass feedstocks via biological and chemical routes into energy-dense, fungible, finished liquid transportation fuels, such as renewable gasoline, diesel, and jet fuel, as well as bioproducts or chemical intermediates and biopower.

CONVERSION R&D SUPPORT OF OFFICE PERFORMANCE GOALS

The overall performance goal of Conversion R&D is to reduce the projected mature technology processing costs for converting algae or lignocellulosic biomass to hydrocarbon fuels via a thermochemical pathway. There are many different combinations of unit operations that could result in a successful conversion strategy.

To evaluate the maturity of these processes, as well as the R&D hurdles for each, there are several design cases with cost targets and technical goals that outline how these performance goals might be achieved via continued research, development, and deployment (RD&D) over the near-, mid-, and long-term. To benchmark the progress of a few representative pathways that link conversion technologies, BETO funds R&D to overcome barriers to support the following cost targets:

- By 2017, validate an nth plant modeled minimum fuel selling price (MFSP) of $3/gasoline gallon equivalent (gge) ($2011) via a conversion pathway to hydrocarbon biofuel with greenhouse gas (GHG) emissions reduction of 50% or more compared to petroleum-derived fuel.
- By 2022, validate an Nth plant modeled MFSP of $3/gge ($2011) for two additional conversion pathways to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Conversion R&D area:

APPROACH FOR OVERCOMING CHALLENGES

The progress and future direction of BETO R&D is regularly monitored and evaluated to determine the annual R&D priorities necessary to overcome existing technical barriers. Prioritization of R&D is based on periodic evaluation of the Conversion R&D portfolio, as well as information on technologies being developed without government involvement. These technology assessments help prioritize which conversion pathways could support BETO's 2022 $3/gge price goal. From now through 2022, Conversion R&D activities will focus on developing and validating additional feedstock and conversion processes that can help meet a $3/gge price goal to maximize biofuels production in conjunction with value-added chemicals.

For more information on Conversion R&D, please review BETO's Multi-Year Program Plan at: *http://www.energy.gov/eere/bioenergy.*

Conversion R&D Barriers	Barriers Specific to Thermochemical Conversion	Barriers Specific to Biochemical Conversion
• Feedstock Variability • Reactor Feed Introduction • Efficient Preprocessing and Pretreatment • Aqueous Phase Utilization and Wastewater Treatment • Materials Compatibility and Reactor Design and Optimization • Product Finishing Acceptability and Performance • Process Integration • Petroleum Refinery Integration of Intermediates • Cost-Effective Hydrogen Production and Utilization	• Efficient High-Temperature Deconstruction to Gaseous Intermediates • Efficient High-Temperature Deconstruction to Bio-Oil Intermediates • Efficient Gaseous Intermediate Cleanup and Conditioning • Efficient Bio-Oil Intermediate Stabilization and Vapor Cleanup • Efficient Catalytic Upgrading of Gaseous Intermediates to Fuels and Chemicals • Efficient Catalytic Upgrading of Bio-Oil Intermediates to Fuels and Chemicals	• Efficient Low-Temperature Deconstruction • Efficient Sugar and Aromatic Intermediate Cleanup and Separations • Efficient Catalytic Upgrading of Sugars and Aromatics to Fuels and Chemicals

BIOCHEMICAL CONVERSION

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Biochemical Conversion Technology Area is one of seven key technology areas reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of 39 projects were reviewed by five external experts from industry and academia. These projects represent a total U.S. Department of Energy (DOE) investment of approximately $65 million (FY2013-FY2014), which equates to around 16% of the BETO portfolio covered at the review. During the review, the Principal Investigator (PI) for each project was given approximately 30 to 45 minutes to deliver a presentation and respond to questions from the Review Panel. Projects were evaluated and scored on the following criteria: project approach, technical progress and accomplishments over two years, relevance to BETO goals, and future plans.[1]

BETO designated Bryna Guriel as the Biochemical Conversion Technology Area Review Lead. In this capacity, Ms. Guriel was responsible for all aspects of review planning and implementation. Overview information on the Biochemical Conversion Technology Area, along with full project scoring results, summary comments, analysis, PI response, Review Panel Summary Report, and the BETO Programmatic Response are found in the following sections.

BIOCHEMICAL CONVERSION

OVERVIEW

The Biochemical Conversion Technology Area focuses on the research, development, and demonstration of biological processes that convert biomass to biofuels, chemicals, and power. Biochemical processes also complement thermochemical conversion by providing residual materials for further processing.

In a traditional biochemical conversion process, biomass is chemically pretreated and fed to enzymes that liberate the biomass-derived sugars. The resulting sugar-rich stream (hydrolyzate) is then fed to organisms that ferment the sugars to fuel precursor molecules. The biochemical conversion platform also has a large stake in low-temperature, non-enzymatic, and non-biological processing routes. Such technology pathways use catalytic and mechanical systems to produce sugars (and/or other intermediates from biomass) and upgrade those sugars and intermediates to create finished fuel blendstocks.

One of BETO's priorities is to make the biochemical conversion process more cost effective. The process breaks down the cell wall of plant matter through the introduction of enzymes or acid to extract the sugars, which are then converted to biofuels using microorganisms. The process is costly due to the complex nature of the cell wall. Lignocellulose (mainly lignin, cellulose and hemicellulose) is the primary component of plant residues, woody materials, and grasses, and the cell wall structure of this plant matter is partially comprised of long chain sugars (carbohydrates), which can be converted to biofuels. Due to its complex structure, lignocellulose is more difficult to break down into sugars, making this material more expensive to convert to biofuels.

A key to developing cost-competitive cellulosic biofuels is reducing the processing and capital cost and improv-

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the Final Report.

ing the efficiency of separating and converting cellulosic biomass into fermentable sugars. Current research and development (R&D) focuses on high-yield feedstocks, more efficient enzymes, and more robust microorganisms to advance biochemical conversion processes. The resulting advanced biochemical conversion technologies will increase fuel yields in integrated biorefineries—facilities that combine conversion capabilities with heat and power efficiencies to produce fuel and products.

BIOCHEMICAL CONVERSION TECHNOLOGY AREA REVIEW PANEL

The following external experts served as reviewers for the Biochemical Conversion Technology Area during the 2015 Project Peer Review.

BIOCHEMICAL CONVERSION	
REVIEWERS	
Carol Babb (Lead Reviewer)	Leidos
Kevin Gray	Intrexon
Daniel Lane	Saille Consulting, LLC
Justin Stege	Independent Consultant
Bob Wooley	Biomass Ad Infinitum, LLC

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data, as provided by the PI for each project.

Project Scoring Information: The final score charts depict the overall weighted score for each project in each technology area. Titles for each project and the performers are also provided in the scoring charts.

Project Reports:

- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space allotted.
- **Project budget and timeline information** is based on self-reported data, as provided by the PI for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and whiskers charts depict

the range of scores for each evaluation criteria across all projects reviewed within each technology area.

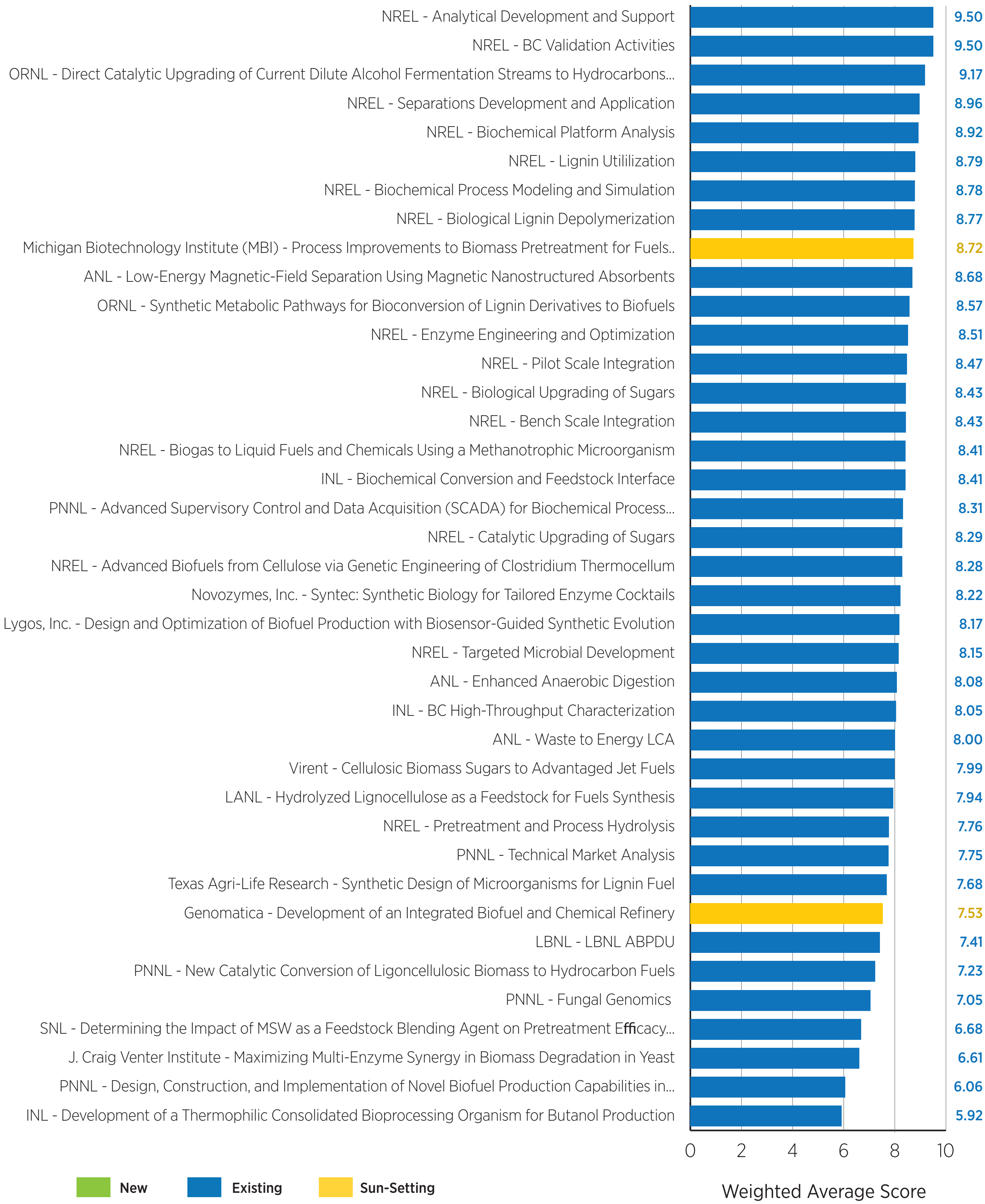
- **Reviewer comments** are presented as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.
- **PI responses** represent the response provided by the PI to reviewer comments, as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by reviewers, and in other cases, provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the Review Panel.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Biochemical Conversion Technology Area.

BIOCHEMICAL CONVERSION TECHNOLOGY AREA SCORING



REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

Strengths

Project Management: DOE insists that key project management processes be implemented and followed. Strong project management has helped the completed projects succeed, and coordination between the projects and BETO is evident. It is apparent that milestones/criteria and project management are emphasized by the PI's. The BETO technology managers are well-informed regarding the office/technology area and proficient in project management.

Coordination of Project Portfolio: The projects selected and reviewed represent a fairly diverse portfolio, containing different types of technologies and projects at various development stages. Project managers show exceptional focus and coordination in their drive to meet BETO process goals for 2017 and 2022. At least half of the portfolio's projects are focused on the challenges and process concepts found in the BETO 2017 and 2022 Process Diagrams. One example was research on the split stream concept, with a focus on higher value coproducts from C5 sugars, hydrocarbon fuels from C6 sugars, and value added products from lignin. The current emphasis and acceptance of the necessity to couple value added coproducts with hydrocarbon fuels to facilitate favorable economics is critical. The key to success, and ultimate commercialization, lies in the technologies' economic viability, market relevance, and demand for products. The projects are relevant to the technical area, are focused on improving economics, and are concentrated on parts of the process that promise to have the largest impact.

Analytical Support: The analytical support and development provided by the National Renewable Energy Laboratory (NREL) team is viewed as a key contributor to the progress and success of the program, and a key enabler for the nascent biofuels and bioproducts industry. The methods and procedures developed to analyze material for the PIs, coupled with the standardization and publication of the protocols, is commendable. These have not only benefited projects funded within the program, but also other private and academic entities pursuing research and commercialization in the area of advanced biofuels and bioproducts.

Coordination among the National Laboratories: Active coordination and data sharing among the national laboratories has been strong across the portfolio, and this is especially true for the research on lignin utilization. For the portfolio as a whole, regular communication and ongoing discussions among the PIs is evident and should facilitate advancement of R&D to the next stage of technology readiness.

Validation: DOE continues to require that a third party, NREL, conducts a technical validation of each project upon award. This validation provides DOE with information on the status of the project and also provides valuable feedback to the PIs themselves. The Peer Review Panel unanimously supported the importance of the validation process and considers it to be a program strength. The Panel recommends that the process continue and the overall procedure is accurately documented.

Techno-Economic Analyses (TEA): The use of TEA was widely implemented throughout the portfolio (>80%). The importance of understanding the economic viability of a technology early on in the research, or qualifying the possible solutions to a process challenge, cannot be overstated. The use of TEA is important and encouraged—either via NREL's Aspen model, or the project's own in-house process. This should be conducted on a consistent basis throughout the project lifecycle, including its early stages.

Weaknesses

Justification for the Process Concept for 2017/2022: The Panel understands that BETO is establishing certain pathways and process concepts as part of the program's more recent focus on hydrocarbons versus ethanol. They are not clear on the justification for the fermentation end products (i.e., lipids) versus platform chemicals (i.e., fermentation products that are subsequently converted to diverse fuels and chemicals via simple, established chemical routes—examples might be lactic acid, succinic acid, isobutanol).

Lack of Industry Projects: The majority of the projects in the current portfolio are associated with the national laboratories and their partners. There is a lack of external, competitively awarded projects, as well as some redundancy across projects. Encouraging diversification, involvement, and funding of private sector research is recommended.

Go/No-Go TEA: Although listed as a strength, there are funded projects that have still not utilized the TEA process, either initially or throughout the course of their research. As discussed in the Strengths section, the importance of understanding the economic viability of a technology early in the research is imperative, and using TEA to evaluate different process options, or make go/no-go decisions, is good project management. It appears that use of TEA has been focused on the extensive "Design Report," however, a lesser, but still rigorous, material balance and economic analysis might suffice early in the project. The Panel recommends that BETO convene a group, consisting of practicing engineers and individuals from NREL, to help develop a template or procedure for implementing TEAs through different project stages.

Lack of Project/Process Diversity: The focus on near-cost targets/processes, as outlined in the 2017 and 2022 Process Diagrams, may lead to a lack of project diversity. The risk of this approach is that potentially viable processes or pathways may not be funded and researched.

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

The current biochemical portfolio contains diverse projects and technologies at relatively early stages of R&D. There were no projects ready to be licensed or moved into deployment; however, this is to be expected considering the program's move from ethanol to hydrocarbons only two years ago. Based on the Review Panel's ratings, the impact and significance of the biochemical portfolio resulted in a strong portfolio overall with the majority of projects rated fairly high, and even the lower rated projects evaluated as good overall. In general, the project portfolio is on track to achieve the goal of the Biochemical Technology Platform—to advance cellulosic hydrocarbons and chemicals—and several projects have the potential to make particularly large impacts.

BETO's challenge is to fully understand the knowledge gained through cellulosic ethanol platform projects and leverage these lessons to promote the goals and objectives of the hydrocarbon platform. BETO has achieved this goal and must maintain its role as problem solver. In addition, the program needs to remain in front or on the leading edge of these new technologies, while not competing with industry. DOE plays a critical role in assisting and funding research, investing in relevant technologies, and de-risking technology, which ultimately facilitates investment from the private sector, and enhances the state of U.S. industry and world leadership. An ongoing challenge for the platform's technical managers is to facilitate increased coordination between deployment projects and R&D to help the platform focus on barriers that need to be addressed.

The projects identified by the Review Panel as strong, relevant, and high impact are:

- Direct Catalytic Upgrading, Ethanol to Jet/Diesel/Gas – Oak Ridge National laboratory (ORNL)/Vertimass
- Depot Concept/AFEX Pretreatment – MBI
- Biochemical Conversion-Feedstock Interface – NREL/Idaho National Laboratory (INL)
- Lignin Conversion Research Projects – Multiple
- Biochemical Platform Analysis – NREL
- Separations – NREL
- Waste to Energy TEA and Lifecycle Cost Analysis – Argonne National Laboratory (ANL)/NREL

The Panel identified the following projects as not as strong:

- Fungal Genomics – Multiple
- Thermophilic bioprocessing for BuOH – INL
- Maximizing Enzyme Synergy in Yeast – J. Craig Venter Institute

It should be noted that the weaker project ratings do not reflect concerns with the level or quality of research, or the PI, but rather the applicability to the program goals going forward.

RELEVANCE

3 Are the projects in this program relevant to achieving BETO's broader goals? Are the projects well aligned with what is needed by industry for successful commercialization of an advanced bioenergy industry? How can the impact of BETO on the emerging industry be amplified?

The overall Project Portfolio is viewed as largely relevant to achieving BETO's goals, i.e., moving the industry forward from R&D to commercialization. The Panel felt that all of the projects were meeting the relevance criterion. The hydrocarbon focus is still relatively new to the R&D arena and, therefore, the Technology Readiness Level (TRL) of the projects is generally low, with most projects in the early stages of development. However, the focus of the portfolio projects is fairly diverse and covers several areas/technologies/pathways that could be instrumental to the successful commercialization of the industry.

A few of the projects did stand out and were considered highly relevant and critical to advancing the industry. These projects include:

- Biochemical Conversion-Feedstock Interface – NREL/INL
- Analytical Development and Support – NREL
- Lignin research *could be* highly relevant to industry (should make sure lignin from operating processes is included where possible) – Multiple
- SCADA Research – Pacific Northwest National Laboratory (PNNL)

INNOVATION

4 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

Most of the projects dealing with the development of cellulosic biofuels are innovative, and focused on overcoming barriers and improving economics. The projects target different areas in the process from feedstock-in to product-out. They address many of the genetic, chemical, biological, and process and/or equipment challenges that have been identified as problems, from either a technical or an economic vantage point. The transition to the hydrocarbon platform appears successful, and selected projects, most of which are in the early stages of development, seem to be relevant and on track. In general, the projects presented were found to be innovative, interesting, worthwhile, and deserving of continued funding.

Projects that the Panel identified as addressing technical area problems with innovative approaches are:

- Hydrolyzed Lignocellulose for Fuels – Los Alamos National Laboratory (LANL)
- Lignin Research – Multiple
- Enhance AD – ANL
- Synthetic Biology with Biosensor for Malonic Acid – Lygos, Inc.
- Nanostructure Absorbents – ANL

5 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation? Why?

Most projects are in the early stages of the pipeline, which is to be expected at this point in the platform's development. The hydrocarbon platform is still relatively new, especially when one considers the years of R&D that went into the cellulosic ethanol platform. The current platform's project funding is primarily directed at national laboratory projects. The Panel expects that more funding will be awarded to the private sector in the next wave of grants and that more industry players will team on laboratory projects. This type of teaming has historically been productive and resulted in commercialization of various technologies.

Examples of projects that the Panel feels were funded at optimal/suboptimal technology pipeline include the multiple Lignin Research projects, and the ORNL Ethanol Upgrading project. A significant result from the cellulosic ethanol research was that finding a value for lignin, other than burning it, is imperative to the successful commercialization of the industry. The basis for the lignin research projects, and the cooperation and sharing of data and learnings among the national laboratory participants, is commendable and encouraged. The ORNL research represents an opportunity to build on the ethanol platform and move on to hydrocarbons.

Further, the Panel recommends new approaches to addressing technology area problems. For example, funding projects that use ethanol as a platform chemical. There is an overabundance of ethanol available, and while the Panel recognizes that it may not be the optimal platform chemical, it is still a viable platform to springboard research into other, value-added chemicals that could enhance the economics of the industry. Use of ethanol as a platform chemical can also help overcome the "blend wall" issue, and even advance first generation ethanol.

GAPS

6 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

The projects reviewed by the Panel encompassed mechanical and chemical pre-treatment and deconstruction of lignocellulosic biomass, higher value lignin research, development of aerobic fermentation organisms, and upgrading of sugar intermediates to hydrocarbons and fuel-blend oxygenates. Projects spanned the biochemical conversion pathway, including feedstock supply, improvement of enzyme efficiencies, as well as product recovery and downstream processing. To some extent, the projects covered all of the process concepts put forth in the 2017 and 2022 Process Diagrams.

With the program's shift to a hydrocarbon focus, there continues to be a need to leverage knowledge from the cellulosic ethanol projects. Further, there should be a program-orchestrated effort to integrate lessons and accomplishments from other platforms.

Both the biological pathway and the catalytic pathway funding should include Funding Opportunity Announcements (FOAs) for higher value products that will enhance the economic viability of the hydrocarbon platform. Lignin utilization is a key coproduct that needs continued research. Also, building on issues identified in the ethanol program, hydrolyzate clean-up and all aspects of separation remain barriers that need solutions.

Specifically, the Panel identified two technical areas that should receive attention and funding in the future:

- Reactor design should be aligned with enzyme research. Optimum reactor designs could enhance the progress and functionality of the enzymes.
- Aeration design for fermenters at scale is an area that presents significant challenges going forward. Anaerobic fermentation in excess of one million gallons is commercialized, but the need for large aerobic fermenters is a reality considering the hydrocarbon pathways being researched.

The Panel concluded that one portfolio area required less emphasis - the screening/discovery of carbohydrate degrading enzymes. Much of this work has already been conducted as part of the cellulosic ethanol platform over the last 20 years, and therefore, additional research is not expected to result in significant discoveries. Also, multiple industrial companies have the capability to further this development in an effort to foster commercialization. To some extent, this ability resulted from DOE support.

The Panel concluded that the portfolio area that could benefit from greater emphasis was lignolytic enzyme research.

SYNERGIES

7 What synergies exist between the projects in this technology area? Is there more that BETO could do to take advantage of these synergies?

Significant synergies exist among the national laboratory projects focused on lignin and higher value lignin products. Laboratory-to-laboratory interaction and data sharing are beneficial and productive and should continue to be encouraged. Where possible, we encourage dissemination of lessons learned and transferrable technology designs—analogous to the popular NREL laboratory analytical procedures (LAPs). Continued collaboration across the R&D portfolio is important.

Synergies also exist in the project management structure that DOE requests from all PIs. This includes the TEA evaluations, which facilitate decision making and promote progress in the most economical manner possible. The project management structure helps evaluators to rank the projects and determine their status with regard to the program's goals and objectives.

Synergies exist among several projects that adhered to process steps and unit operations from the 2017 and 2022 Process Diagrams. Findings from these projects should be shared collectively to leverage these synergies.

The Panel encourages interaction with research organizations involved with the U.S. Department of Agriculture's feedstock development activities, e.g., National Institute of Food and Agriculture (NIFA), INL, and other national laboratories and agencies to capitalize on synergies.

8 Does this program appear to be appropriately leveraging breakthroughs from the DOE Office of Science, ARPA-E, National Science Foundation, and/or other DOE Offices or federal agencies?

There is some evidence that the program has leveraged breakthroughs from other federal agencies. One example is the innovative nanoparticles cost reduction project, which is leveraging work conducted for DOE's ARPA-E.

The Panel recommends and encourages more consistent and transparent collaboration with other offices, such as ARPA-E and the Office of Science. Collaboration exposes researchers to additional research concepts that may not have been identified by the platform. Coordination and cooperation with other offices is viewed as a viable approach to introduce these new and unique technologies to the program. Co-evaluation of FOA applications would allow projects to transition through different offices at different stages of TRL.

RECOMMENDATIONS

9 What are the top three recommendations to strengthen the portfolio in the near to medium term?

The Panel offers the following recommendations to strengthen the portfolio in the near/medium term:

1. BETO should provide a TEA template at the project outset or as part of the application process for all projects. This would include seed projects and national laboratory projects. TEA is seen as a vital and critical tool to quantify metrics and guide decisions, even in the infancy of the research. The overall use of metrics as a management tool has been consistent throughout the Platform. The Panel recommends use of a graded level of metrics and milestones tailored to the TRL status of each project, which may ensure that the "Smart" milestones are more realistic to the projects in the early TRL stage.
2. The Technical Area Validation process/model should be captured for posterity. The Panel is concerned that as key process managers change, the process itself could be lost.
3. Projects should be required to show historic progress towards goals/targets over the project lifetime and provide a specific lessons learned summary covering that history. The summary should include original goals achieved, including actual metrics,

modification to goals or targets, and reasons for the modification; TEA results and conclusions; and any other relevant information.

Overall, the current portfolio is appropriately varied and Platform Technology Managers' oversight of the validation, stage gates, and best project management practices are very good. The program's continued insistence on use of effective project management principles, coupled with validation, increases the odds of project success and are highly encouraged.

Further, it appears that most of the 2013 Peer Review Panel's recommendations have been incorporated into the goals and make-up of the projects in the portfolio.

BETO PROGRAMMATIC RESPONSE

IMPACTS

The Biochemical Conversion area would like to thank all five reviewers for their time, and appreciates the dialogue that resulted from the review process. The following section addresses the Panel's points regarding project impacts.

Justification for the Process Concept for 2017/2022: Extensive analysis has gone into the process concepts for 2017 and 2022 based on design cases and ongoing research. These process concepts undergo constant revision to capture the latest advances in technology. Further, BETO as a whole is exploring additional work on bioproducts and hopes to provide significantly updated analysis for the coproduct section of the concept for the 2017 review. The Biological Upgrading design case shows a need for coproducts produced from lignin to meet the $3/gge cost target and significant research is ongoing in this area.

Lack of Competitive Projects: BETO is currently (at the time of publication) engaged in the negotiation process for a number of new competitive projects and hopes to use these to augment the national laboratory projects already in the portfolio. In addition, the awardees of the Biological and Chemical Upgrading for Advanced Biofuels and Products (BCU) and Renewable Carbon Fibers FOAs did not present at this review due to their recent award status, but represent additional opportunities to engage industry. Partners include Natureworks, Vertimass, and American Process, Inc.

Strong Focus on 2017/2022 Goals: The Review Panel expressed some concern that, because of the strong focus on the 2017 and 2022 verification efforts and cost targets, other potential areas of research may be neglected in the interim. Recognizing that $3/GGE biofuels will be difficult to produce without coproducts from lignin, the 2017 process concept will not undergo formal verification. This will allow more research into areas of the portfolio that are not currently emphasized, as the reviewers suggest. This includes research into the utilization of lignin, aerobic reactor design, and synthetic biology.

As of March 2015, the office published design case models detailing eight potential pathways to biofuel production (four focused on thermochemical pathways, two on biochemical pathways, and two on algae pathways). While the design cases focus on specific conversion technologies, the ultimate goal is to develop technologies along several pathways to address the broad range of physical and chemical characteristics of various feedstocks and to reduce the risk that any specific technology could fail to reach commercial viability. This is referred to as the pathways approach. The pathways approach aims to diversify R&D in recognition that industry will ultimately decide which pathways are the most viable. It enables progress in one technology so that it can have effects across multiple different pathways.

The specific design case pathways allow BETO to focus R&D on the areas that contribute most to production cost, and to show progress from year to year in a relevant metric (Minimum Fuel Selling price or MFSP). These pathways are meant to be representative pathways utilizing modular pieces that may be combined in various ways to reach finished fuels and products. As the pathways approach becomes more developed, the Thermochemical Conversion area hopes it will become more apparent how different projects fit into the portfolio as a whole and overall reliance on using the 2017 and 2022 cost goals as primary measures of project success will be reduced.

More information on the pathways approach can be found in the Multi-Year Program Plan at: *http://www.energy.gov/eere/bioenergy*.

INNOVATION

BETO responses to the Panel's comments on innovation are summarized below.

Use of Ethanol as a Platform Chemical: BETO agrees that finding alternative uses for ethanol represents an area of significant opportunity. Technology developed at ORNL to upgrade ethanol into fuels and chemicals has been licensed to Vertimass and will continue to be developed with BETO support.

Acid-Pretreated Lignin: The Review Panel expressed an interest in seeing more work on acid-pretreated lignin as a response to the "improved understanding of the composition and physical nature of this new raw material." At the time of this report's publication, a project that would address this suggestion is still under negotiation. In addition, heightened emphasis on lignin utilization as per the 2022 process concept will allow for more projects in this area in the coming years.

GAPS

Two specific gaps were identified by the Review Panel as the highest concern:

- **Reactor design should be aligned with enzyme research. Optimum reactor designs could enhance the progress and functionality of the enzymes:** BETO is funding several projects to address the design of aerobic reactors to better accommodate organisms and enzymes with oxygen requirements. In addition, new reactor designs for organisms that form biofilms are under development as part of the Biological Upgrading of Sugars Annual Operating Plan.
- **Aeration design for fermenters at scale is an area that presents significant challenges going forward. Anaerobic fermentation in excess of one million gallons is commercialized, but the need for large aerobic fermenters is a reality considering the hydrocarbon pathways being researched:** Several projects are being undertaken to address this challenge. Extensive modeling efforts are also underway to better understand oxygen transfer in aerated reactors. Despite the extensive challenges remaining, industrial-scale fermentation in aerobic reactors currently occurs at the 200,000 L scale at companies like Amyris.

SYNERGIES

The Review Panel suggested that the Biochemical Conversion area continue to work closely with both internal and external groups, such as the Feedstocks area and ARPA-E. Feedstocks Interface continues to be a focus of the lab projects funded by Biochemical Conversion and that coordination should continue to develop. In addition to the nanoparticles project identified by the Review Panel (2.5.5.100 – Low-Energy Magnetic-Field Separation using Magnetic Nanostructured Absorbents), BETO communicates regularly with ARPA-E by sharing information on relevant projects, especially those from the ARPA-E PETRO (Plants Engineered to Replace Oil) biomass-based fuels and Electrofuels Programs. BETO also shares upcoming announcements, communications, and talking points about related initiatives, such as the REMOTE (Reducing Emissions using Methanotrophic Organisms for Transportation Energy) Program. The intent of these communications is to help both programs operate in such a way that they complement one another and increase the relevance of related projects. In addition, BETO works closely with the Office of Science Bioenergy Research Centers.

RECOMMENDATIONS

There were three major recommendations set forth by the Review Panel:

- **DOE-BETO could look to provide a TEA template at the project outset or as part of the FOA application process**: The Biochemical Conversion area agrees that TEAs are fundamental for project decision making and many projects could benefit from a process like this. They are currently working with the Analysis and Sustainability area to develop a workable template for a "lite" TEA that can be used in FOA applications and for new projects.
- **The technical area validation process/model should be captured for posterity**: The Biochemical Conversion area plans to work with the validation task to ensure the methodology is captured to preserve institutional memory.
- **Projects should be required to show historic progress towards goals/targets over the project lifetime and a specific lessons learned summary should be developed**: This suggestion will be incorporated into planning for the 2017 Peer Review, and will be especially important as the Biochemical and Thermochemical Conversion Areas begin to combine relevant projects starting in FY2016 to comply with the EERE-wide guidance for "fewer, larger projects."

BIOCHEMICAL PLATFORM ANALYSIS

(WBS#: 2.1.0.100)

Project Description

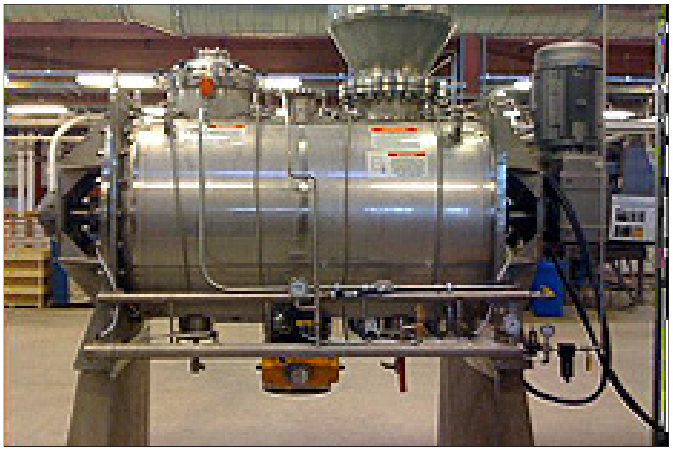
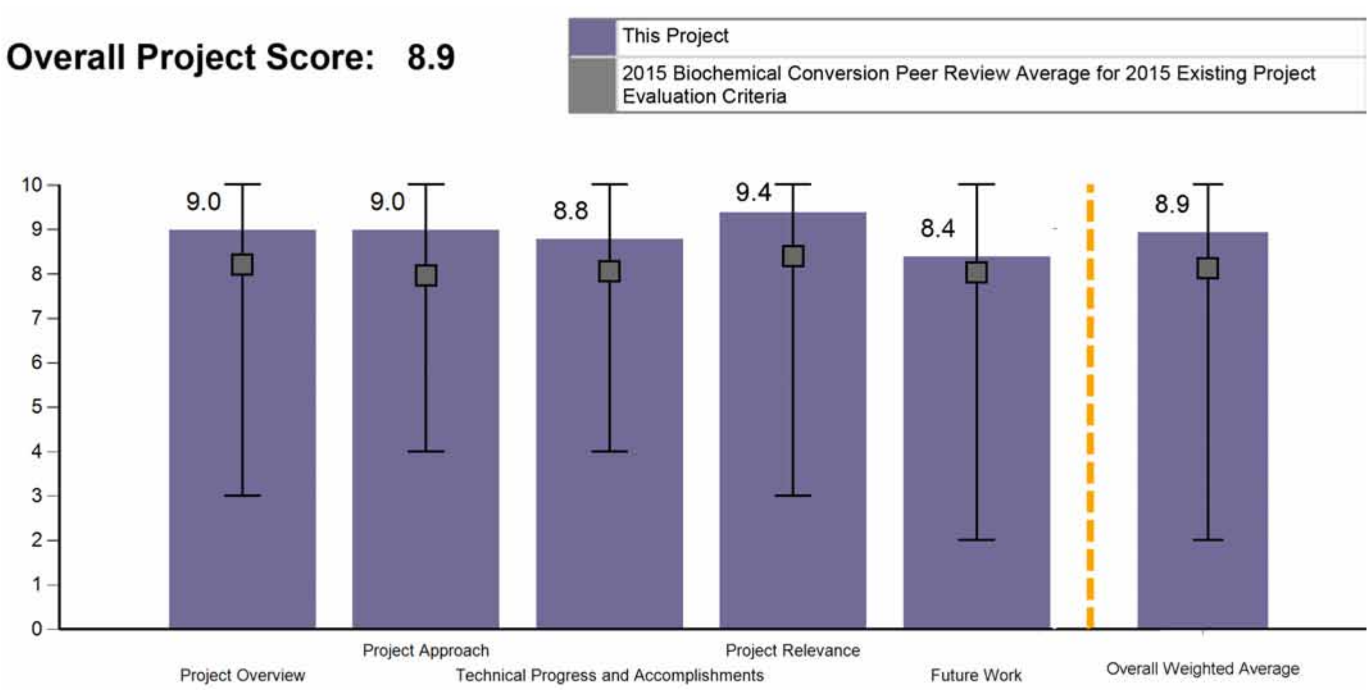


Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Ryan Davis
DOE Funding FY14:	$858,075
DOE Funding FY13:	$1,113,039
DOE Funding FY10-12:	$1,803,813
Planned Funding:	$2,689,844
Project Dates:	10/1/2010 - 9/30/2017

Biochemical Platform Analysis investigates process economics that can be used to assess cost viability for a given conversion technology pathway. Platform Analysis also helps to direct research by maintaining benchmark models describing the current conceptual state of technology, against which proposed research and anticipated results can be compared based on modeled costs. This process helps to indicate the impact of core research toward meeting competitive cost targets. This project is highly relevant to supporting BETO Program objectives, as the analysis work provides a process context for the research and development activities funded by the Program. The techno-economic models provide a framework that ties technical performance to cost reductions within a biorefinery, providing important guidance on R&D targets and associated conversion costs. Additionally, the project tracks key sustainability metrics across the biorefinery conversion step. The analysis work is peer-reviewed and thoroughly documented in design



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

reports, which are publicly disseminated. The Analysis project has made significant achievements since the 2013 Peer Review, including publication of two new design reports documenting cost projections for both biological and catalytic conversion of lignocellulosic sugars to hydrocarbon fuels, as well as guiding NREL's biochemical platform research toward a new near-term strategy focused on parallel conversion of sugars to both fuels and chemical coproducts.

Overall Impressions

- This is an essential project for BETO. Evaluating research activities of the program and assessing their cost reduction potential or promise should continue to be a primary focus. Remember that a delta cost (cost impact of a project) is much more accurate than the absolute cost (Design Report). A new "simplified" economic analysis is needed to bridge the needs of projects that haven't reached the maturity in conceptualization to warrant a full design report. The Design Report was never intended to be completed for every idea that the program has, only those that reach a level of maturity. The "simplified" method must be standardized, documented and reviewed to reach a level of value justified and required by the program.
- This is great work. Techno-economic modeling is the heart and soul of the research and choosing the right pathways to focus on and move forward. I would like to see feedback from the private sector (if they are willing) to get an outside reality check on assumptions and metrics.
- Overall, this is a great project because it provides industry with tools to analyze both existing and proposed work. The techno-economic analysis work is great, and it would be terrific to adapt it to a simplified tool for analyzing proposed technologies/developments prior to budgeting time and money. It should be a required tool for anyone seeking DOE funding.
- There is a clear and focused work plan, as well as significant progress and relevance. There is good linkage and alignment with other DOE-funded programs. Could this project support more early stage projects to give guidance on cost implication of new technologies (e.g., ionic liquids)?
- This is an extremely important activity to help direct R&D programs. NREL continues to lead the way in the techno-economic analysis and design of biomass to fuels and chemicals processes.

PI Response to Reviewer Comments:

- We thank the reviewers for their complimentary and insightful comments, and appreciate the acknowledgment of the relevance for this project toward supporting BETO and the broader R&D community. Regarding the comments on the merits of conducting a full design report versus more simplified TEA assessments, we share in this sentiment in that design reports do require extensive burdens on time and resources in order to meet the level of quality standards that are expected for NREL's "design report" products. We also support the notion of exploring more simplified TEA approaches for less developed concepts, but caution that sufficient time must still be allotted to conduct adequate modeling, particularly for new, complex, or otherwise poorly documented (in public literature) processes, which can still take considerable time to objectively and credibly evaluate even if not delivered in 'design report' format. In addition, a simplified TEA can risk becoming too simplified to be useful if conducted in a format that loses important thermodynamic information available through rigorous Aspen Plus modeling. This said, this project does support other early-stage R&D projects both internal and external to NREL. For example, we recently hosted a collaborator from LBNL to provide guidance and assist in development of LBNL's ionic liquid pretreatment strategy within the framework of NREL's integrated Aspen Plus process model.

- Regarding the comment on engaging the private sector to solicit feedback on the TEA work, one means of achieving this important step is the design case peer review process, which is undertaken by NREL's design reports prior to public release. This process solicits feedback from stakeholders in industry, academia, and other national laboratories with representation that spans all technology areas covered in the given pathway model. In many cases, the models and resulting cost estimates are modified as a direct result of the peer review feedback received prior to publication of the final report. Additionally, NREL maintains working relationships with outside partners, and strives to capitalize on opportunities for additional modeling feedback, validation, and/or improvement through these channels, as we are able to incorporate such inputs in publicly available reports.

TECHNICAL MARKET ANALYSIS

(WBS#: 2.1.0.101)

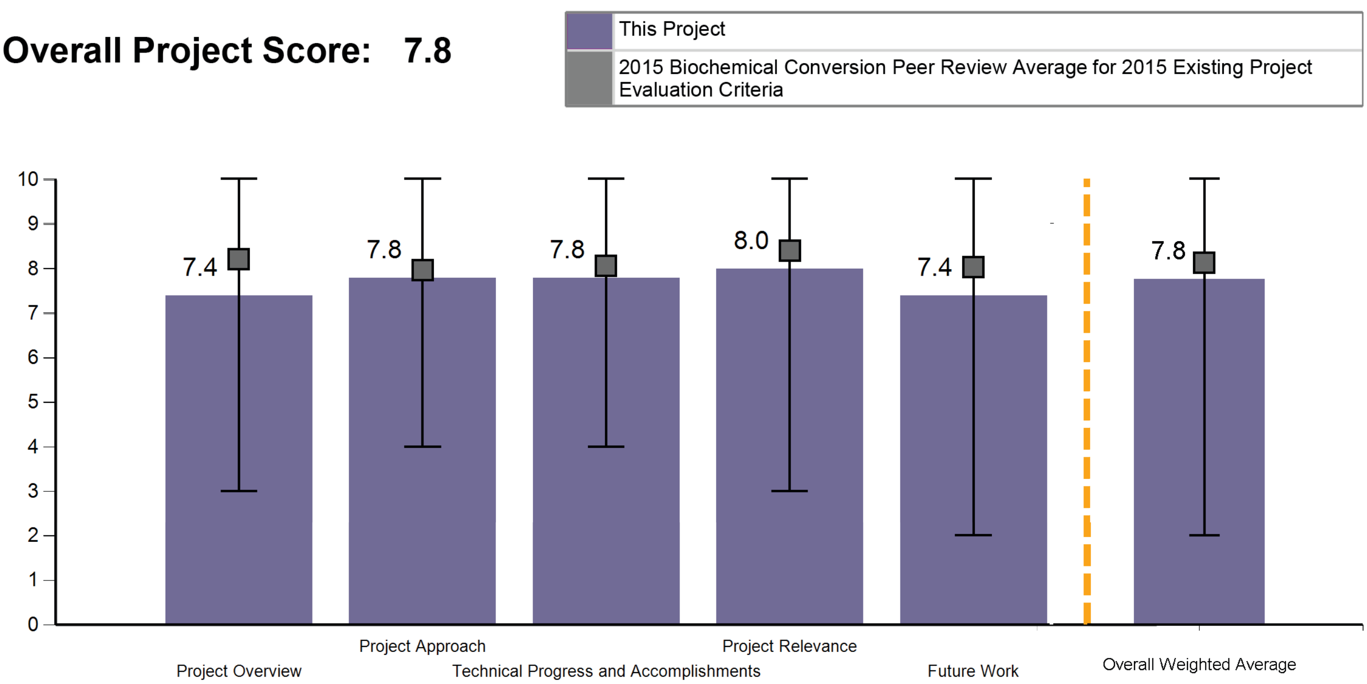
Project Description

Recipient:	PNNL
Presenter:	Jim Collett
DOE Funding FY14:	$158,883
DOE Funding FY13:	$210,017
DOE Funding FY10-12:	$1,218,959
Planned Funding:	$468,680
Project Dates:	10/1/2010 - 9/30/2017

Photo Courtesy of PNNL

Biorefinery process and economic models built in CHEMCAD, and a preliminary, genome-scale metabolic model for the oleaginous yeast Lipomyces starkeyi, were used to simulate the bioconversion of corn stover to lipids, and the upgrading of these hydrocarbon precursors to diesel and jet fuel. The metabolic model was based on the recently released genome sequence for Lipomyces starkeyi and on metabolic pathway information from the literature. The process model was based on bioconversion, lipid extraction, and lipid oil upgrading data found in literature, on new laboratory bioreactor data, and on maximum biochemically feasible yield predictions from the Lipomyces starkeyi metabolic model. The current minimum fuel selling price (MFSP) for a distillate-range hydrocarbon fuel was estimated by the process model to be $9.00/gallon for a 2,205 tons/day dry feed rate. A target case identified opportunities for reducing the MFSP to below $5.00/gallon, such as improving bioconversion lipid yield and hydrogenation catalyst selectivity. Future work will be focused on: (1) estimating the maximum yield and market entry potential of promising polyketide and isoprenoid fuel precursors; (2) updating the prelim-

Overall Project Score: 7.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

inary process model for hydrocarbon fuels with new experimental data; and (3) expanding analysis to other hydrocarbon fuels and chemicals.

Overall Impressions

- Like the NREL project, this serves a useful purpose for other BETO projects being performed and assessing their potential. The project is also contributing new directions on how chemicals might be made. However, an effort needs to be made to standardize the methodology used by everyone performing process engineering and cost analysis of projects for BETO. The NREL methodology has shown to be effective, so maybe this project should accept that. Familiarity with a tool is not the only reason to use a tool.
- Overall research and goals are good. TEA is extremely important to screen viable pathways. Having the model available to the public is important. I would like to see a more formal process and commitment for that.
- This is a meaningful and supportive project that has done good work and, looks like it will continue to do so. There is good integration with industry, both in solicitation of feedback and information and in selection of organisms for work. The project is strongly encouraged to share CHEMCAD model and TEA with industry to allow rough assessment of privately funded research, regardless of the current status of both. There are people out there who are very interested in finding a starting place for analysis that can easily accept a lack of model support. Often this sort of modeling is handed to younger engineers that can reverse engineer the model as an educational experience, too. Excellent project.
- The project offers a good integrated approach combining a detailed metabolic model and TEA to select approaches and drive improvements. The approach seems rather broad and general. It could ould use more specifics in targets and technical approaches to differentiate itself from other similar activities.
- The project team has done an excellent work defining metabolic pathways (genome scale models) and performing economic analysis of the production of industrially relevant molecules. This is an extremely important work to help define chemical targets with market potential.

PI Response to Reviewer Comments:

- We appreciate the useful feedback provided by the Peer Review panel regarding the value of this work and our plans for the coming fiscal year. This project has and will continue to provide PNNL with TEA resources to ensure that our biochemical conversion research is aligned with BETO goals and making progress toward objectives defined in the MYPP. Moreover, it provides opportunities for us to evaluate new technical approaches, to apply our latest experimental data within the context provided by the NREL design cases, and to formally present our findings in relation to specific cost and performance targets.
- We agree that standardizing assumptions are critical for allowing BETO and stakeholders to make relative comparisons between pathways. To that end, PNNL and the other National Labs participate in BETO's regularly scheduled monthly call regarding analysis and sustainability. This ensures that modeling methods and economic assumptions are standardized for all TEAs and LCAs.
- Past experience has shown that the various software packages for generating heat and material balances provide consistent results. Publishing the inputs and outputs of the models in sufficient detail so that they can be used in any software may be preferable to publishing a specific software model that can only be used by a few. Additionally, we suggest that consideration be given to making the cost sheets from TEA models available to the larger community. This will, however, require consensus amongst BETO and the national labs with regard to the best format to use and how best to communicate the category, quality and detail of information supporting the results.

WASTE TO ENERGY LCA

(WBS#: 2.1.0.102)

Recipient:	ANL
Presenter:	Jeongwoo Han
DOE Funding FY14:	$192,193
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$957,807
Project Dates:	10/1/2014 - 9/30/2015

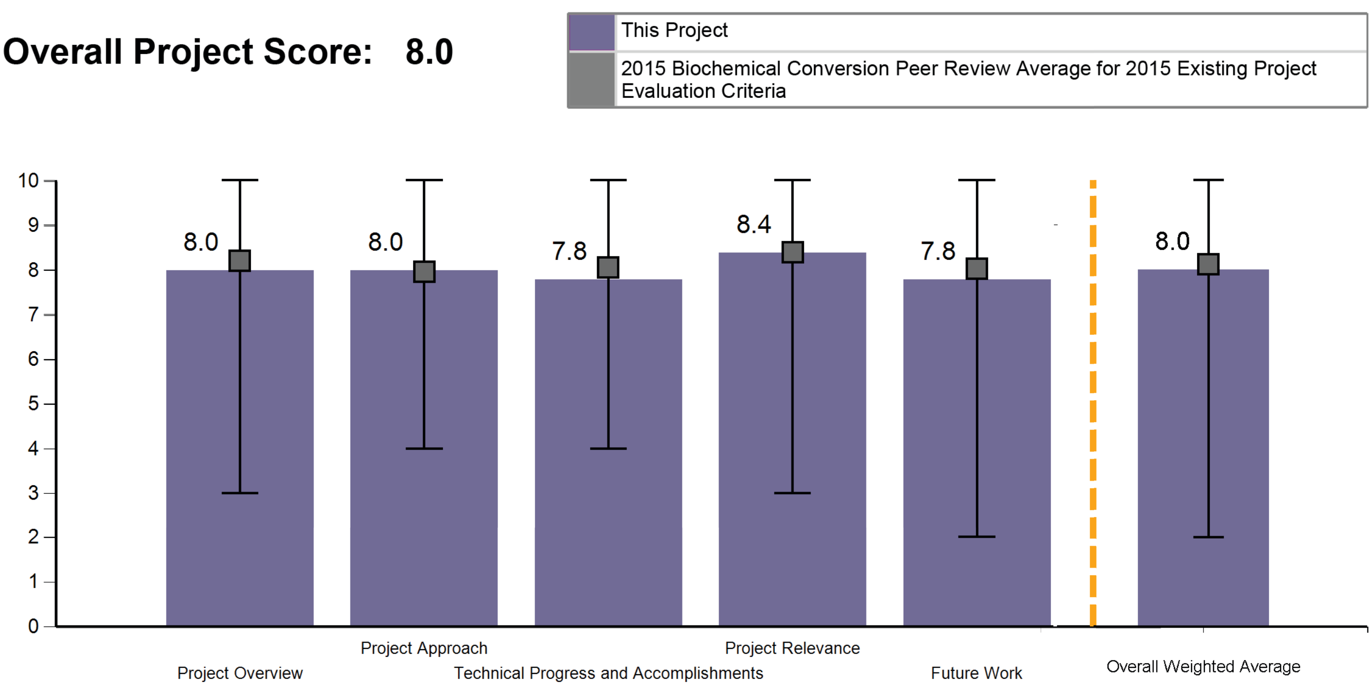
Project Description

Waste is an under-utilized biomass resource and is a high-impact renewable feedstock with collection infrastructure already in place. Thus, waste-to-energy (WTE) technologies can position at a near-term market entry point with a wide spectrum of end products (fuels, chemicals and power) while mitigating methane emissions from current waste treatment. Among various wastes, municipal solid waste (MSW) and biosolids have potential to produce about 590 TBtu per year (equivalent to 5 billion gallons of gasoline or 1/3 of current biofuel production). Economic viability and environmental sustainability, however, have yet to be addressed for widespread deployment of WTE pathways. Thus, for economic viability and environmental sustainability, the techno-economic analysis (TEA) and life-cycle analysis (LCA) of WTE pathways were performed for four pathways: a combination of two conversion technologies [anaerobic digestion (AD) and hydrothermal liquefaction (HTL)]; and two feedstocks (MSW and biosolids). For instance, the predicted minimum gas selling price varies from $5 to $20 per MMBtu for biosolids AD, depending on the plant sizes. LCA showed that WTE pathways reduce well-to-wheels (WTW) greenhouse gas (GHG) emissions by 77-97% relative to petroleum gasoline, which is sensitive to LCA methodology more than technical parameters. The project will continue to investigate and update key TEA and LCA assumptions and to examine process sensitivity and alternatives to increase waste value proposition.

Overall Impressions:

- This project provides a decent approach to help BETO understand the possibilities in WTE.

Overall Project Score: 8.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- This is a very relevant research project.
- This is another project that is critical to the BETO portfolio. Undergoing this sort of research in such a rigorous way with the clear intention of working with and disseminating results to industry goes a long way to rapidly advancing the industry toward commercial applications. For example, showing how waste-to-energy currently is non-competitive with natural gas but providing tools to show how RINs and higher natural gas pricing can impact that is extremely valuable, as is showing that inclusion of current waste disposal fees in the TEA drives the economics toward near-favorable today.
- This combination of techno-economic analysis and lifecycle analysis has delivered useful evaluation of potential waste to energy pathways. Unfortunately the chosen pathways do not readily translate to an economically viable process. But conclusions and assumptions are transparent and variations could make it more economic.
- This project is extremely important since it will define the economics and LCA of waste to energy projects. It will answer questions related to whether anaerobic digestion processes can compete with natural gas and, if not, how such a process can be implemented commercially.

PI Response to Reviewer Comments:

- We sincerely appreciate all reviewers' supportive, complimentary and insightful comments, and appreciate affirmation on the relevance of this project's activities to the BETO mission. Energy development from waste is an important and emerging technology of national interest. Current waste treatment and disposal options consume a significant amount of energy while incurring considerable environmental penalties. Using both TEA and LCA tools, we will continue to study additional pathways that are more promising to make liquid fuels and offer a promising combination of economic and environmental potential. Also, with consideration of waste feedstocks credits (such as tipping fees) or RIN credits, the presented pathways actually offer decent economic and environmental positions. We will continue to verify those findings and report to the public domain.

BIOCHEMICAL CONVERSION AND FEEDSTOCK INTERFACE

(WBS#: 2.2.1.101)

Recipient:	INL
Presenter:	Nick Nagle
DOE Funding FY14:	$2,056,805
DOE Funding FY13:	$1,798,425
DOE Funding FY10-12:	$4,927,353
Planned Funding:	$5,923,670
Project Dates:	10/1/2010 - 9/30/2017

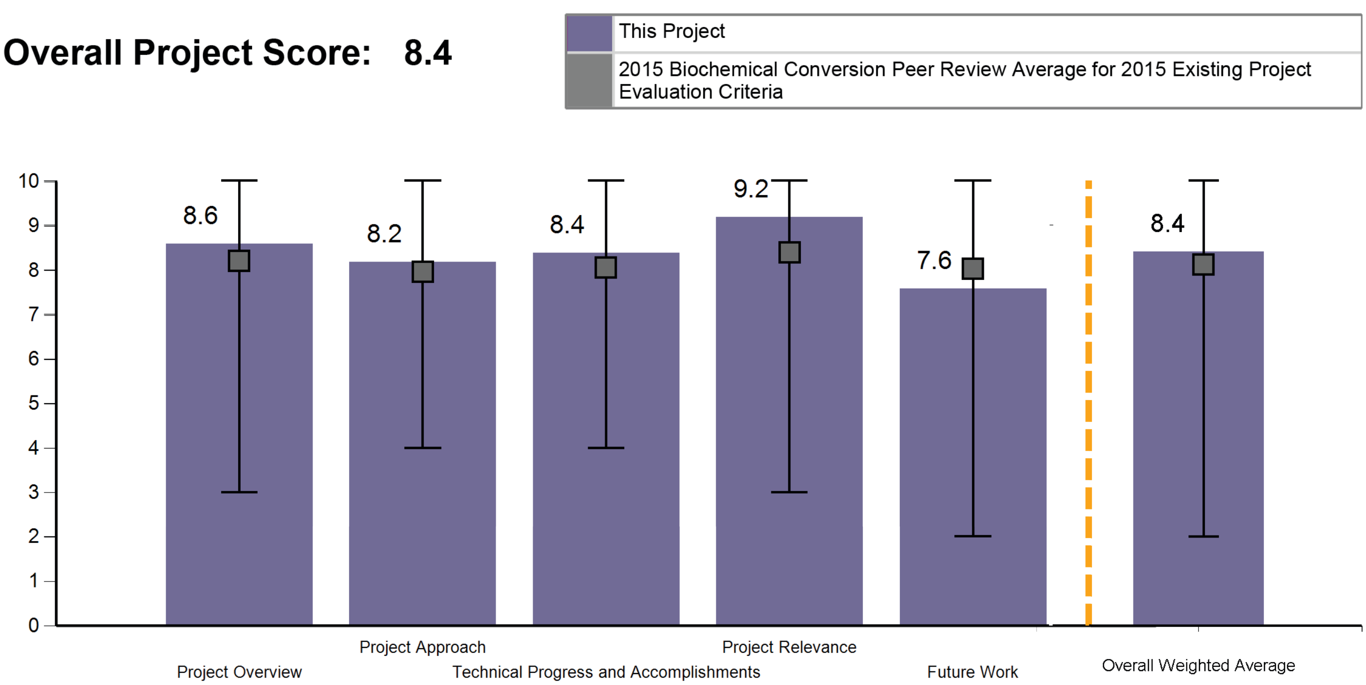
Project Description

The cost to access biomass represents a major hurdle to the economic viability of a feedstock supply chain. A blended feedstock strategy has been proposed to address the high cost of feedstock access and enable feedstock supply systems for biofuel production. This task examines whether blend quality and conversion can be predicted from knowledge of the constituent feedstocks – single-pass corn stover (CS), switchgrass (SWG), paper (MSW), miscanthus (MIS). Compositional analysis, dilute-acid pretreatment (PT), and enzymatic hydrolysis (EH) were performed; sugar yields were measured from combined PT and EH. Predicted glucose yields from combined PT and EH corresponded to measured yields for blends of CS/SWG/MSW and CS/SWG/MIS. There were no significant differences in glucose yield for blends of CS/SWG 80/20 and CS/SWG 50/50 relative to corn stover. Ternary blends of 65/25/10 and 75/15/10 CS/SWG/MSW had glucose yields from combined PT and EH that were statistically equivalent to corn stover. Preliminary data from base-catalyzed depolymerization (BCD) studies suggest that blending and pelleting had no negative impact on aqueous lignin recoveries relative to conventionally ground corn stover. Results suggest that blend performance can be predicted from knowledge of constituent feedstocks. This task demonstrates the potential for pellets and blends to enable feedstock and conversion metrics for the production of sugar and lignin-derived fuels and chemicals.

Overall Impressions

- The project is important to the program and has considerable potential. It needs to get good quantifiable

Overall Project Score: 8.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

milestones, other than just the cost targets set by the analysis team. How will they achieve those, technology steps that will enable those, etc. The project needs to look at pelletization for transportation and then blending of feedstock pellets delivered from various locations. Pelleting enables transportation.

- This work is highly relevant to the industry. Feedstock and understanding feedstocks is key to the path forward.
- The in-depth analysis of feedstocks and incorporation of this data into blending profiles has extremely high potential. Widening feedstock supply locations and providing consistent composition feedstock will have a large impact on not just biorefinery operations, but also scale possibilities.
- The project has very encouraging results on the performance of blended feedstocks that will lower cost and improve flexibility of biomass conversion facilities. The project could have clearer outputs and deliverables, specifically around the number of blends to be validated and predictive models to be delivered. Some of the data didn't seem to directly address the conclusions made. The studies seemed more focused on detecting differences between densified feedstocks rather than the differences between blends.
- This is a very relevant project and the results will have a dramatic impact on the real world situation of using agricultural feedstocks harvested in different geographies and different seasons. There may also be an opportunity to help direct compositions of purpose grown energy crops.

PI Response to Reviewer Comments

- Regarding the impact of blending prior densification, we fully agree with the reviewer's comment that pelleting is a key operation that enables transportation. In the review, we presented some of our preliminary data from an initial blending and pelleting study. For this study, we examined a scenario where blending occurred prior to the densification step. This was a strategy, not an economic analysis for the impacts of densification on feedstock logistics (economic analyses for densification are being performed in the Size Reduction, Drying and Densification of High Moisture Biomass project and the Feedstock Supply Chain Analysis project). There has been no final determination regarding at what point blending will occur in the supply chain (e.g., before pelleting or after), although it does seem likely that pellets of single feedstocks would be blended together once in the pelleted format. The interface team realizes and acknowledges that a strategy such as this (blending prior to pelleting) may result in a product that is only usable in a specific refinery or single end-use scenario, which is not an effective means for mobilization of feedstocks and an emerging biorefining industry. On a system level view, this might not be the optimal way to pellet due to business dynamics, because you tie your blend to an individual process. However, this initial study did demonstrate that, if you blend before you pellet, there is an energy benefit. This may only apply in certain business structures.
- Regarding the focus on densification, we have previously focused on the impact of densification via pelleting of biomass on the conversion process (Ray, et al. 2013), given the positive impact of densification on reducing transportation cost. In FY14, our limited survey of feedstocks blends showed that blending and densification of herbaceous feedstocks did not increase biomass reactivity and demonstrated some positive impacts on biomass flow properties. However, we did not further characterize differences between the blends other than total sugar and lignin release and, rather, we focused an comparing the pelleted blends and their single feedstock components to the non-pelleted blended and single

feedstocks, assessing the impact of densification on blending disparate feedstocks. As we move forward in FY16 and beyond, we will focus on identifying key difference between blended feedstock.

- In summary, we value the comments and suggestions from the reviewers, as these will be used to enhance and focus the Feedstock Interface Project. Their time and effort in providing these comments is greatly appreciated. Moving forward, we will further characterize feedstock blends with respect to additional conversion processes, addressing both scale and continuous operation, and providing performance information to industry and key stakeholders. We will align our on-going and future lignin work with the existing Lignin Utilization task, providing both a pathway and rationale for addressing the impact of feedstock processing on lignin quality and quantity. Lastly, we will continue to review our existing and future AOPs to ensure the appropriate targets and metrics used to chart progress continue to support the larger BETO mission for renewable fuels.

DETERMINING THE IMPACT OF MSW AS A FEEDSTOCK BLENDING AGENT ON PRETREATMENT EFFICACY, HYDROLYSATE PRODUCTION AND CONVERTIBILITY

(WBS#: 2.2.1.103)

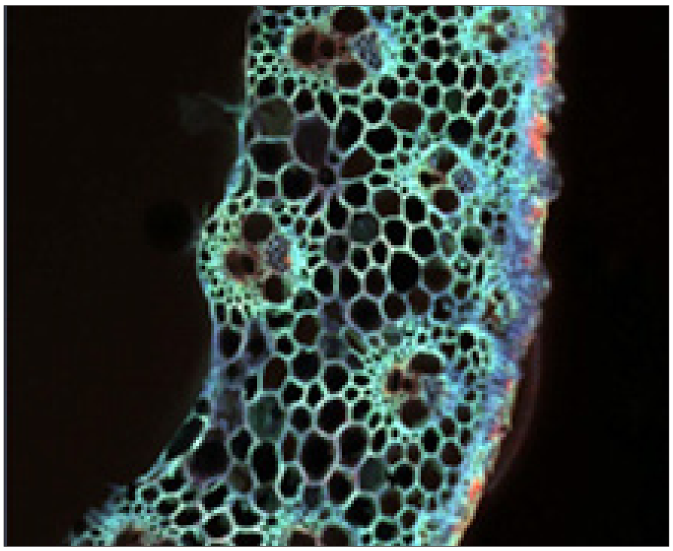


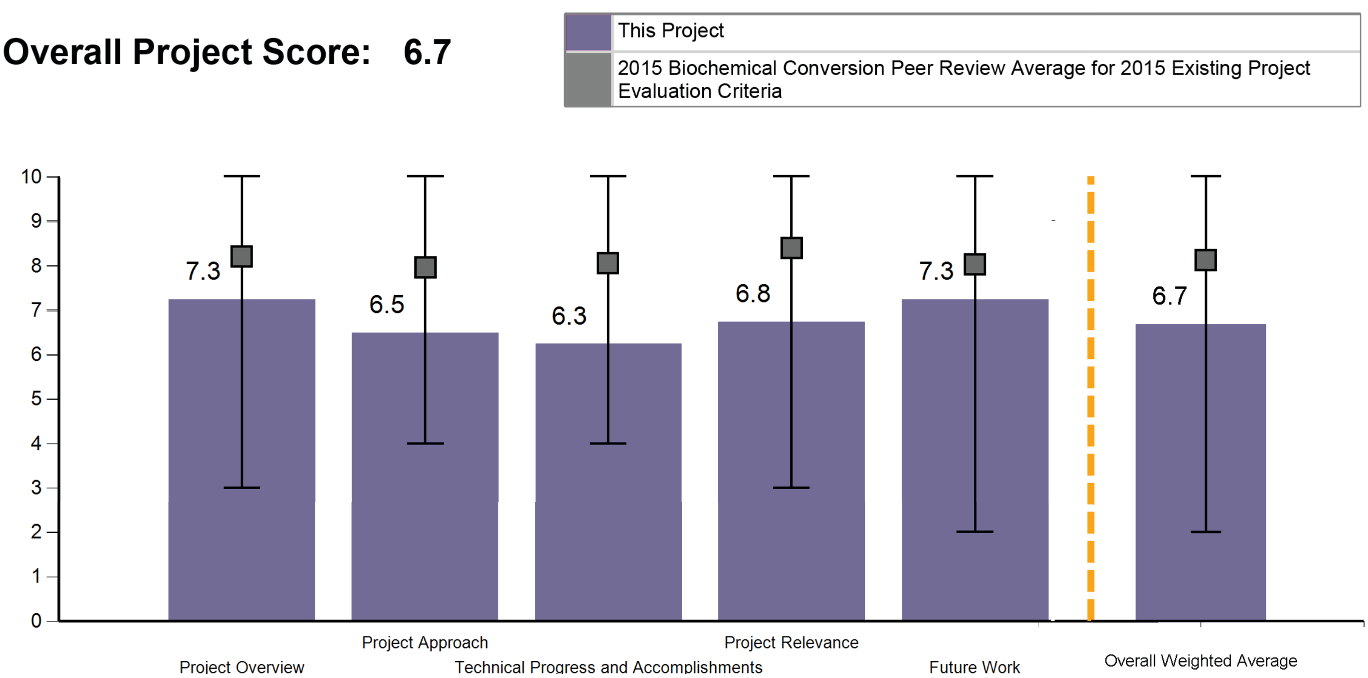
Photo Courtesy of SNL

Recipient:	SNL
Presenter:	Seema Singh
DOE Funding FY14:	$202,876
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$277,124
Project Dates:	10/1/2014 - 9/30/2015

Project Description

Renewable energy technologies are being looked at as significant new sources to meet our current and future energy needs. Securing cost-competitive reliable sources of feedstock in quantities large enough to meet our energy needs is still challenging. Significant attention has been historically given to agriculturally derived feedstocks; however, a diverse range of wastes, including municipal solid waste (MSW), also have potential to serve as feedstocks for the production of advanced biofuels. These have not been extensively studied within the BETO Biochemical Portfolio to date in terms of conversion efficiency and/or hydrolysate quality. Moreover, the blending of different types of feedstocks to decrease costs and maximize availability

Overall Project Score: 6.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

is quickly gaining prominence within the field, but very little analysis has been completed within the Biochemical Portfolio to determine the impact of these blended feedstocks on the overall process efficiency of a wide range of platform technologies. Given the seasonal availability of plant-derived feedstocks, and the continual supply and established infrastructure for MSW, it may be advantageous to consider use of separated MSW as an advanced biofuels feedstock, especially as a blending agent to help normalize the composition of the biomass inputs to a biorefinery that has a well-defined tolerance to variation in biomass composition, high-sugar yielding feedstocks and biomass conversion technologies goals of BETO's Biochemical Platform Multi-Year Program Plan.

Overall Impressions

- This could be an important project for BETO, but I don't think it is being approached properly. The focus should be to just use the same pretreatment as the other blending project as an assay tool and study the dynamics of MSW variability and supply and try to determine how MSW could be incorporated into a biorefinery feedstock blend. That focus seems to be missing.
- The focus on MSW as a blending stock has huge potential on improving the logistics and the economics of biomass conversion commercialization. It is encouraging that yield and rheology are being considered in the work, but it is advised to focus on realistic MSW for future work. Hand-selected feedstocks can artificially lower the prevalence of contaminants that must be addressed before commercialization is an option.
- A compelling case is presented for inclusion of MSW as a blend component for biomass feedstocks. However, the use of new ionic liquid pretreatment in the study makes it difficult to relate this work to existing baseline pretreatment and processing technologies. I would like to see this program use benchmark feedstocks and pretreatments to separate the effects of ionic liquids and MSW blends. New ionic liquids, particularly renewable, lignin-derived versions, could change the economics of ionic liquid (IL) pretreatment. Dividing the work completely into separate projects might also be advantageous.
- There was very little information regarding the true cost of MSW (sorted) that is appropriate for this process; using $0.01/ton is not realistic. The linkage of ionic liquid pretreatment and hydrolysis to other BETO-funded projects was difficult to understand.

PI Response to Reviewer Comments

- All of our future efforts are utilizing realistic MSW feedstocks that will also have realistic costs that will be used to determine techno-economics of the entire process. We respectfully disagree about the absence of a robust baseline. Very early on in the indirect liquefaction development effort, we conducted a substantial comparative study with dilute acid pretreatment (*Li C., Knierim, B., Manisseri, C., Scheller, H.V., Vogel, K., Simmons, B., Singh, S. Comparison of Dilute Acid and Ionic Liquid Pretreatment of Switchgrass: Biomass Recalcitrance, Delignification and Enzymatic Saccharification. Bioresource Technology, 2010, 101(13)4900-4906*). INL has another project with NREL to study the impact of MSW blends on dilute acid pretreatment, and this project is focused on the development of a cost-effective and scalable indirect liquefaction process for those same MSW blends. The results from the two projects will be evaluated using a robust TEA that uses the same assumptions as the NREL dilute acid baseline that enables the effective comparative assessments issue to become apparent, understood, and solved.

PRETREATMENT AND PROCESS HYDROLYSIS

(WBS#: 2.2.3.100)

Recipient:	NREL
Presenter:	Melvin Tucker
DOE Funding FY14:	$1,562,665
DOE Funding FY13:	$5,640,952
DOE Funding FY10-12:	$18,759,258
Planned Funding:	$5,057,536
Project Dates:	10/1/2010 - 9/30/2017

Project Description

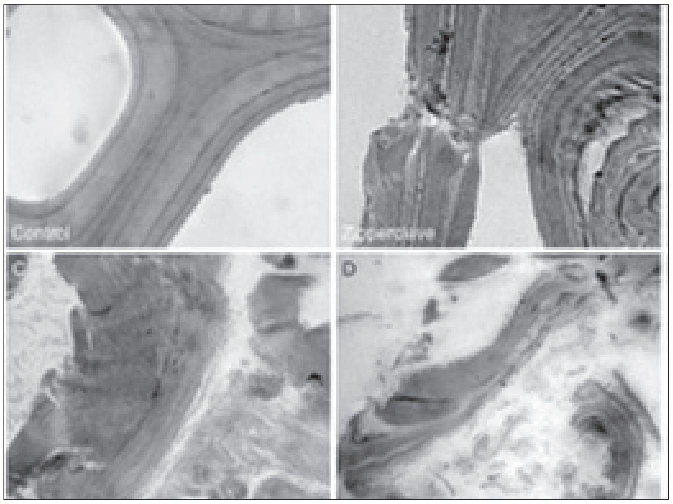
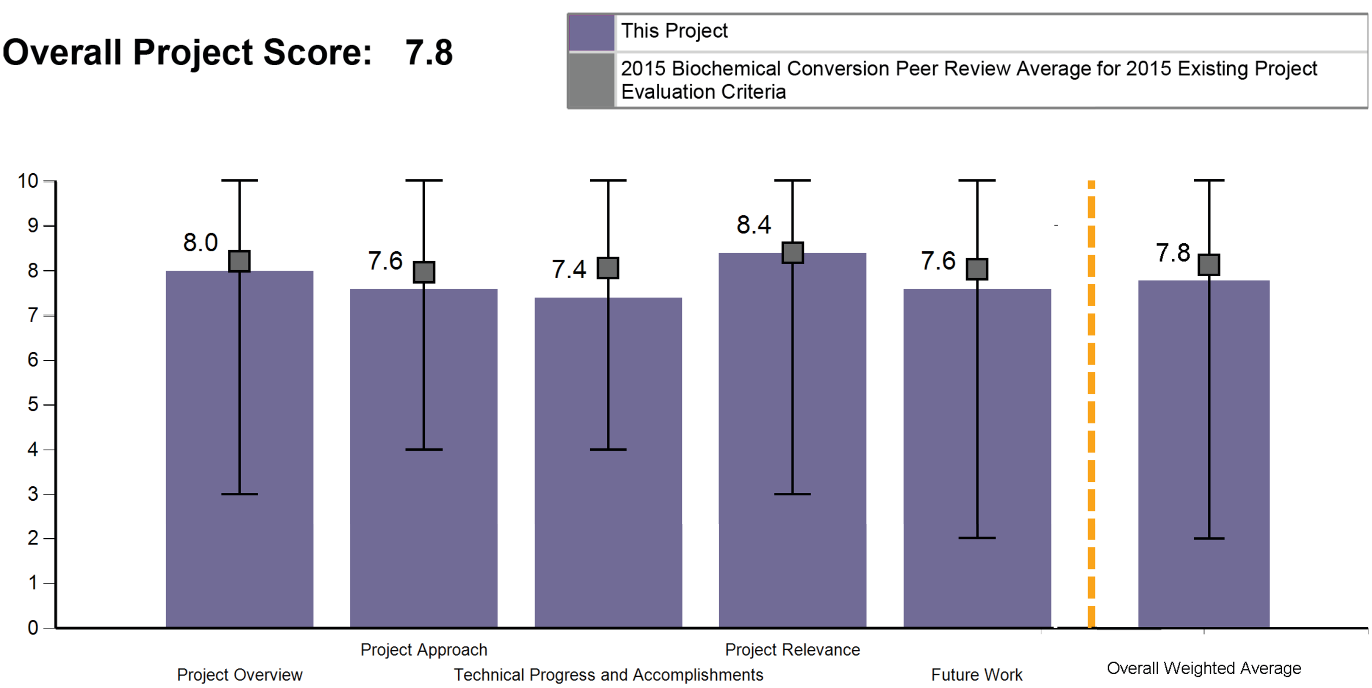


Photo Courtesy of NREL

The Pretreatment and Process Hydrolysis project performs R&D to show cost effective production of high concentration sugar syrups and low molecular weight lignin fragment streams that are low in toxic inhibitors and poisons for biological and catalytic upgrading of biomass to biofuels and bioproducts to meet BETO MYPP 2017 and 2022 goals and targets. The sugar syrups and lignin produced from both dilute acid pretreatment and the dilute alkali deacetylation and mechanical refining (DMR) processes will be generated from individual corn stover, miscanthus, switch grass, and poplar feedstocks, in addition to various bi- and tri-blended and densified feedstocks supplied by INL. To meet the 2017 targets, a solid-liquid (S/L) separation into separate C5 and C6 sugar rich streams is required. Therefore, the slurries from each process step developed in this project will be supplied to other projects within the Biochemical Platform for testing to meet the 2017 goals and targets for possible scale up and integration at the pilot scale. The DMR process may possibly be integrated and scaled up to meet the 2022 demonstration goals and targets. Techno-economic analyses are performed at every major step developed within the project for the

Overall Project Score: 7.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

dilute acid pretreatment and DMR processes. The overarching goal of the project is to develop a process that is economic, uses less water, energy, and chemicals and is scalable to the commercial scale.

Overall Impressions

- This is a good project and is a logical follow-up to the pretreatment development work that has gone on for many years at NREL. We see the cost goal for the entire process, including feedstocks cost reductions. It would be nice to see the cost reductions due only to this work.
- A lot of work has been done on using refiners in the industry and the work has not had a lot of success. This research takes a little different approach and may benefit and facilitate advancements in the industry.
- Overall, this looks like a good project that is working to support BETO goals and provide technology alternatives. There is some concern that irrelevant factors are driving the work (e.g., pulp and paper mills) and that the focus on zymo is not well supported, but it is clearly making good progress.
- Good progress has been made on a range of conditions and configurations. There is clearly a large body of work behind the figures. Because of the short review time, it was difficult to understand how well the data supported the conclusions of the studies.
- The project involves next generation pretreatment technologies to reduce potential inhibitors (acetic) and include size reduction (mechanical refining) to improve conversion processes (and lowering cost due to enzyme addition). In addition, the "split stream" approach is important for the coproduction of lower value fuels (from the C6 stream) and higher value chemicals (from the C5 stream).

PI Response to Reviewer Comments

- We appreciate the reviewers' comments regarding the applicability and progress of the dilute alkali and/or acid pretreatments, and DMR process approaches for producing low cost sugar and reactive lignin streams for bioconversion to intermediates and hydrocarbon fuels covered in this work. The reviewers' comments concerning pulp industry conversions are appropriate, because of the substantial costs and economic uncertainties associated with pulp mill conversions. However, DOE has engaged in efforts to support re-purposing of pulp and paper facilities as biorefineries, and our pursuit of the DMR technology is related to this purpose.
- The higher sugar yields in both dilute acid pretreatment and the DMR process reported in this project are the direct result of the considerable investments made by DOE in enzyme technology development, incurred by cost sharing with several of the enzyme companies for advanced enzyme technologies. The higher yields possible with the latest enzyme technologies may improve the economics of converting pulp mills to biorefineries. In addition, DOE and DuPont have invested considerable funding in improving Zymomonas to the point where a 30 million gallons/year cellulosic biorefinery in Nevada, Iowa, is possible.
- Our use of Zymomonas as a model organism to test the toxicity of the dilute acid and DMR hydrolyzates produced in this project is based on the extensive knowledge gained at NREL in the past. The Zymomonas organism that will be used in this commercial scale plant is jointly engineered with DuPont scientists. Zymomonas has one of the highest rates of converting sugars to the central metabolite, pyruvate, which can then be used by appropriate, metabolically engineered Zymomonas strains to produce a number of intermediates suitable for upgrading to hydrocarbon fuels, such as butanediol, isoprenes, polyhydroxyalkanoates, etc. If future sugar to intermediates for hydrocarbon production cannot utilize aerobic fermentation processes to lipids because of the very high costs and energy consumption required for aeration, then anaerobic processes will be needed, and Zymomonas has shown promise in anaerobic fermentations.

NEW CATALYTIC CONVERSION OF LIGNOCELLULOISC BIOMASS TO HYDROCARBON FUELS

(WBS#: 2.2.3.101)

Recipient:	PNNL
Presenter:	Mike Lilga
DOE Funding FY14:	$329,220
DOE Funding FY13:	$397,705
DOE Funding FY10-12:	$0
Planned Funding:	$1,223,075
Project Dates:	10/1/2012 - 9/30/2017

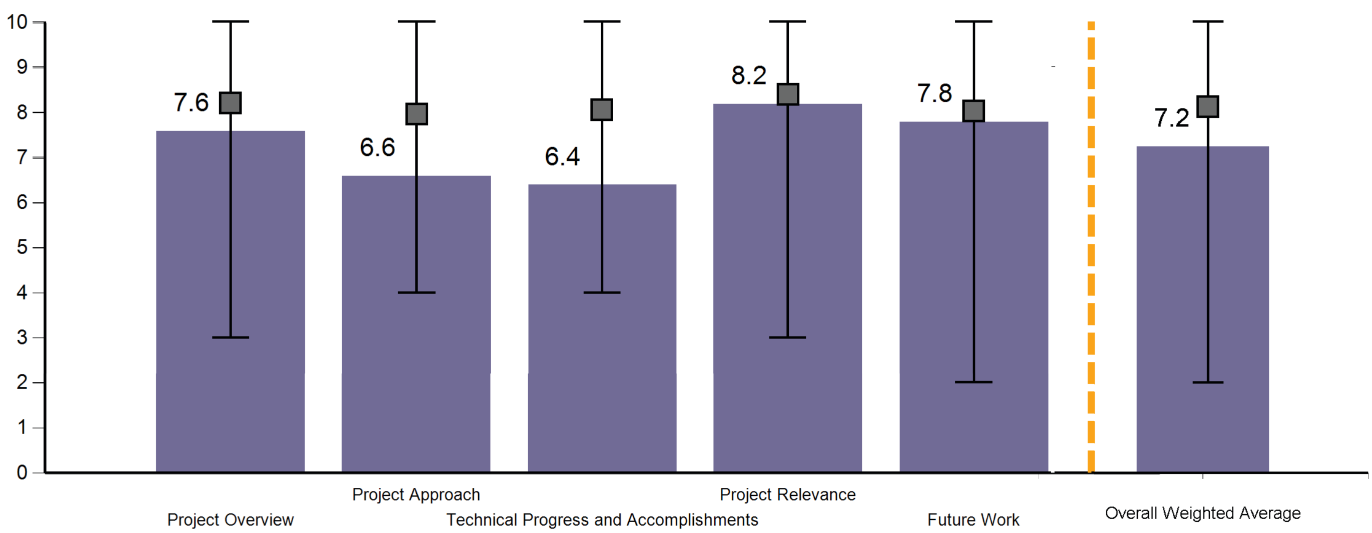
Project Description

Current thermal methods from lignocellulose result in primarily aromatic products (fast pyrolysis, hydrothermal liquefaction), but routes to paraffinic and isoparaffinic fuel blend stocks are lacking. Catalytic conversions could produce paraffins and isoparaffins, but ash in the feedstocks fouls catalysts and scales reactors during processing. The goal of this project is to develop catalytic routes to open-chain hydrocarbon fuels from lignocellulosic feeds. A new deconstruction technology is being developed that uses a novel medium to recover carbohydrates. High degrees of deconstruction to recover mostly oligomeric sugars, while leaving the ash components behind, has been found. As part of the overall strategy, a process to catalytically convert levulinic acid to hydrocarbons is being developed. In a single process step, levulinic acid is converted to a partially-deoxygenated organic liquid with distillation properties very similar to diesel. Future work will include catalytic conversion of oligomers to levulinic acid to link these process steps into an overall biomass to hydrocarbon fuels process. TEA and LCA will be undertaken to assess economic viability and guide future efforts. The work addresses the need for technically and commercially viable biorefineries to produce liquid transportation fuels and chemicals from biomass. It addresses the barriers identified by

Overall Project Score: 7.2

This Project

2015 Biochemical Conversion Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

BETO and is expected to contribute to attaining cost targets, increase energy security, and minimize reliance on foreign petroleum.

Overall Impressions

- This could be a good project, but it is difficult to judge the relevance of whether a process could be envisioned without a description of what a production pretreatment process might look like. You would not have to disclose intellectual property (IP) to conceptualize the pretreatment configuration. It is even more important that an economic evaluation be conducted when you cannot convey the pretreatment IP. Reporting the economics might help us understand the future viability of the process and whether or not it should be continued without knowing the IP. Without either, it is difficult to judge.
- This is a good generic platform for research to produce sugars that can be utilized in most biochemical/catalytic processes.
- This project may have great potential, but it is disconcerting that so little economic analysis has been done. On first glance, there are several items that could significantly impact commercialization potential that should be evaluated. Given that much of the process is novel, techno-economic analyses should have been performed to help direct the R&D effort. It is strongly recommended that this be completed immediately.
- This is differentiated work to make products of open chain hydrocarbon molecules. There has been good progress toward demonstrating new reaction pathways. It would be good to see the use of techno-economic analysis and more relevant sugar feedstocks earlier in the experimental work.
- No economics have been analyzed yet; not even a cost analysis of the liquid being used in the process. It seems more like a technical feasibility assessment. From a high level, it appears this will be a costly process.

PI Response to Reviewer Comments

- Thank you for the review comments. We presented a flow chart outlining our overall vision to show how the apparently disparate activities we are conducting are actually part of a unified approach to lignocellulose conversion to hydrocarbon fuels. We chose the deconstruction and levulinic acid to hydrocarbon fuels tasks because, in our view, they were the most challenging, yet the most important to demonstrate before the overall vision could be realized. Not to say the oligomer to levulinic acid conversion will be easy, but there is certainly more literature in that area.
- Significant progress has been made since the last review. Flow deconstruction is new and has demonstrated improved performance over earlier batch studies. Discovery that ash components do not transfer to the sugar phase in batch experiments is remarkably significant and is new information. The levulinic acid conversion data is totally new and also remarkably significant. Clearly, there is more to do. But in our opinion, we've demonstrated what we said were the hardest parts. Connecting the dots by demonstrating oligomer conversion to levulinic acid and use of the "dirty" levulinic acid in the conversion reactor now become priorities.
- Techno-economic analysis is to be conducted in FY15. The technical challenges we have overcome to bring the technology to the current level have been large. In fact, our course has changed significantly on both the deconstruction and levulinic acid conversion tasks. The levulinic acid conversion work was surprising and could not have been predicted. We understand the importance of TEAs and conduct them regularly to guide research. In this case, however, there was enough uncertainty in process configurations and pathways that we felt an early TEA would not have been a meaningful exercise. We are now at a point, however, where pathways are established enough, and variations

(including process/reactor configurations) can be envisioned well enough, that resources can be spent confidently to produce a useful TEA.

- The chemistries and processes are totally different than most are familiar with. The deconstruction, in particular, is unique, yielding low-to-no ash sugar streams. Ash content associated with current biomass deconstruction methods presents tremendous challenge to catalytic sugar upgrading. The role of the national laboratories is to do everything we can to ensure opportunities for tech transfer, provision of licensing rights, and commercialization are secured so that the technology can be put to work to bring a return to the country. Following IP protection, results of this work will be presented at a professional society meeting to begin dissemination of information. Discussions with potential industrial partners will continue in order to move this technology toward eventual commercialization.

ENHANCED ANAEROBIC DIGESTION

(WBS#: 2.2.4.100)

Recipient:	ANL
Presenter:	Meltem Urgun-Demirtas
DOE Funding FY14:	$231,916
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,318,084
Project Dates:	10/1/2014 - 9/30/2017

Project Description

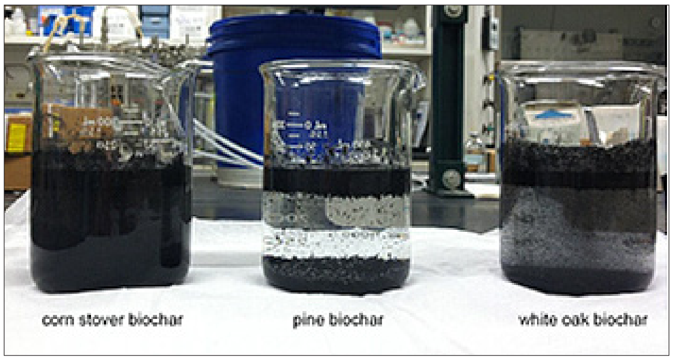
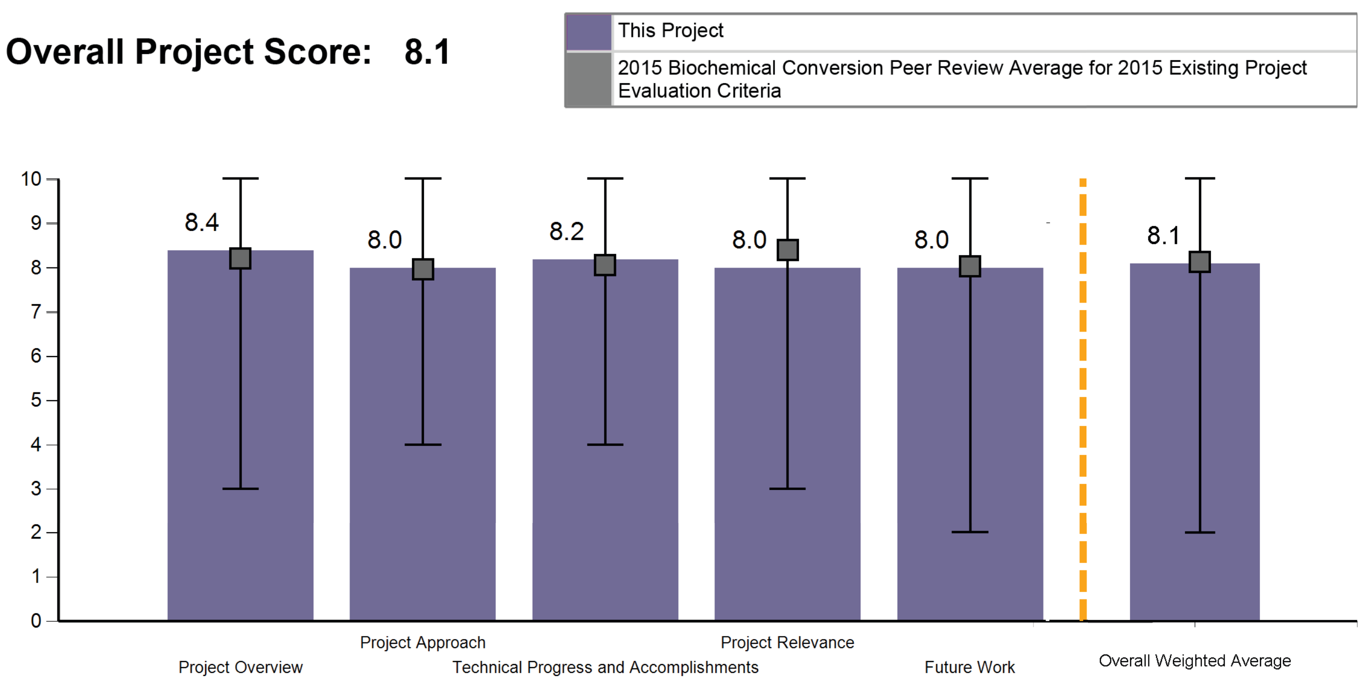


Photo Courtesy of ANL

This project will develop low-cost processes for waste-to-energy to produce biomethane and hydrocarbon precursors. The project goals are to transform negative-value or low-value waste streams into high-energy-density, fungible biomethane and hydrocarbon precursors through targeted research, development and demonstration. The project will start with sludge generated during wastewater treatment as feedstock.

From earlier results, the project team will be able to produce a biogas with ~90% methane content rather than 55-70% methane produced in conventional digesters using ANL's novel process. This process will accelerate biological methane production rates while sequestering CO_2 via natural dissolution of Ca/Mg. The first project goal is to replace olivine/serpentine rocks used in Argonne's patented process (US 8,247,009) with biochar to produce biogenic methane with economically useful compositions, close to the pipeline quality (>90% CH_4) due to: (1) an increase in methane production rates; (2) no need for the extensive gas clean up and upgrade; (3) no need for olivine/serpentine mining; (4) further increase in the dissolution rates of calcium and magnesium; (5) a source of micronutrients and



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

alkalinity required for anaerobic microorganisms; and (6) a soil amendment for use as a fertilizer. The second project goal is to produce lipid hydrocarbon precursors suitable for hydrotreating that will be compatible with petroleum-based fuels and which can be used as drop-in replacements with little-to-no modification.

Overall Impressions

- The project seems to be linked to the biomass pyrolysis biochar process. This is far from an established industry. For the near term, should they be looking at other "catalysts"?
- The reactor seems to be a novel design with positive results. The capture of CO_2 and sulfur in the reactor (in-situ) is very interesting, plus the prcess produces >90% methane. What are the next steps for methane as far as converting to liquid hydrocarbons? Or is the objective to produce lipids (Task 2)?
- This is an interesting project that utilizes biochar in an innovative manner and provides the potential to create clean biogas cheaply in a commercial environment. The approach of working with industrial facilities from the beginning and incorporating techno-economic analyses between each scale-up are excellent.
- The project has produced very promising results with biochar to improve performance of anaerobic digestion of biosolids. Techno-economic analysis will be key for determining if this leads to improved economics. The development of a process for biosolid conversion to lipid intermediates is early stage, but an interesting approach to valorizing these waste biosolids as a feedstock.
- I am not certain of the connectivity between Task 1 (biogas production) and Task 2 (lipid production). Enhanced anaerobic digestion will improve the conversion of waste products into more valuable materials, however, biogas is more expensive and contains more impurities as compared to natural gas.

PI Response to Reviewer Comments:

- Tasks 1 and 2 are separate product pathways built from the same feedstocks: biogas and hydrocarbon fuels. Task 1 - Biogas now qualifies as a D3 cellulosic biofuel under RFS2. Task 1 reduces cost to meet transportation fuel specifications from biogas. This will help industry to meet cellulosic biofuels mandates. Task 2 maximizes market penetration. BETO's primary target is hydrocarbon replacements for existing liquid fuels. Task 2 opens a new pathway to produce liquid hydrocarbon biofuels that meet RFS2 D3 (cellulosic biofuel) mandates. Task 1 is more short term and Task 2 is more long term. Both enable BETO to advance waste-to-energy. Regarding biogas quality, there are commercial technologies to meet CNG and LNG purity levels. This project brings the costs down significantly. Regarding costs for natural gas, fossil-based natural gas does not meet RFS2 mandates and cannot address this market. Therefore, conventional natural gas does not compete with biogas. This project reduces costs for biogas production and upgrading and is expected to out-compete existing biogas processes.

- The biochar industry is emerging in the U.S., associated with the fast development of biomass electric power plants. Woody biomass is the main feedstock for the bio-electric power plants in the U.S., with a net power generation of 43.1 billion kWh in 2014. There are 135 facilities (as of April 21, 2015) utilizing forest wood, wood waste and logging and mill residues as the feedstock (Biomass Magazine, 2015). Assuming that a 10-MW-capacity plant consumes 10 BDT/hour (BDT = bone dry ton) (Mayhead, 2010) and that gasification or pyrolysis process produces 10-20% biochar on the feedstock dry weight basis (Brewer, et al., 2012), the bio-electric power plants in the U.S. could generate 4.3 to 8.6 million tons of ash annually, which can be used as a substitute or replacement of biochar.

- The scope of this project includes development and deployment of new processes to produce either renewable natural gas via biogas or hydrocarbons via fatty acid intermediates. Fatty acids are captured as an intermediate in the digestion process. Conversion of methane to liquid fuels and chemicals has significant potential, but is beyond the scope of this phase of the project. We are considering partners for downstream methane conversion in future project phases.

DIRECT CATALYTIC UPGRADING OF CURRENT DILUTE ALCOHOL FERMENTATION STREAMS TO HYDROCARBONS FOR FUNGIBLE FUELS

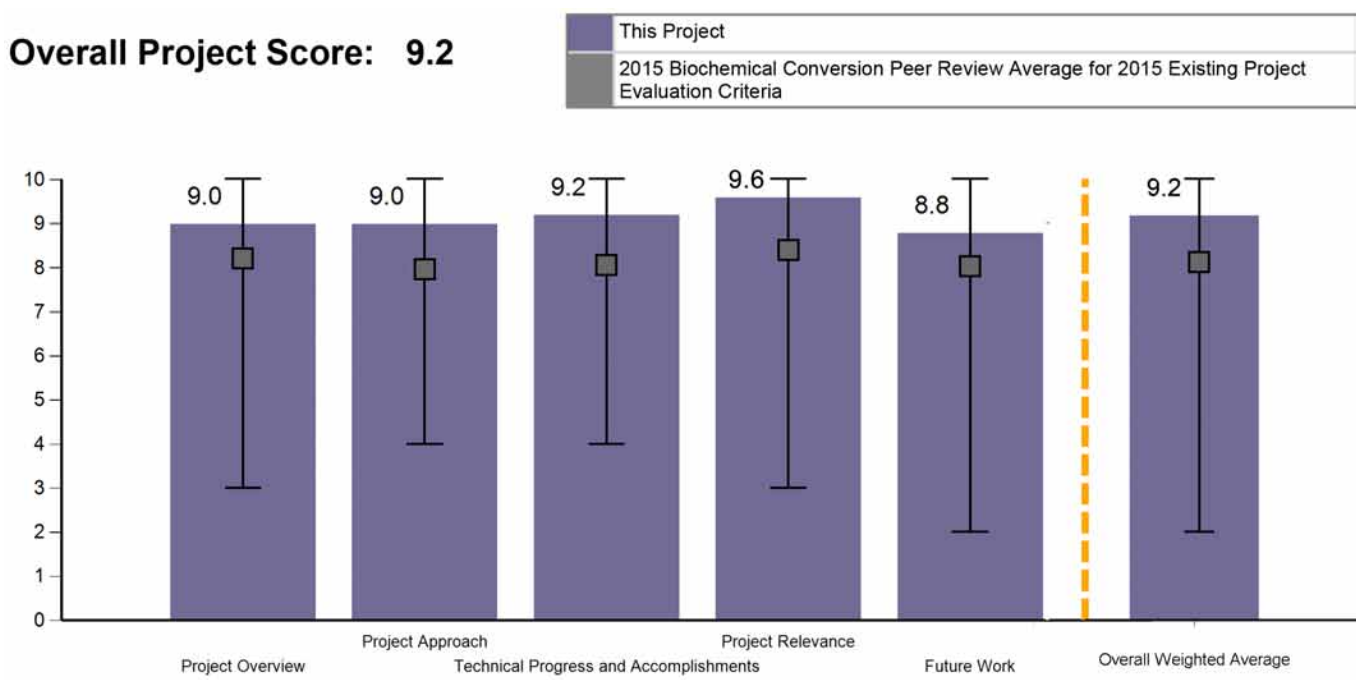
(WBS#: 2.3.1.100)

Recipient:	ORNL
Presenter:	Brian Davison
DOE Funding FY14:	$538,430
DOE Funding FY13:	$365,023
DOE Funding FY10-12:	$98,153
Planned Funding:	$748,394
Project Dates:	10/1/2011 - 9/30/2017

Photo Courtesy of ORNL

Project Description

The project team developed catalysts that selectively convert aqueous ethanol and fermentation streams to aliphatic and aromatic hydrocarbons. The project assists rapid deployment of usable fungible blendstock(s) as part of the BETO conversion goal in advanced biofuels. As an add-on technology, it increases markets for current and future cellulosic ethanol infrastructure by upgrading into blendstocks for gasoline, diesel, or jet. Challenges and success factors included: passed go/no-go decision with catalyst durability of >200 hours; produced 4 liters of gasoline and 1 liter of diesel/jet blendstocks; and ORNL licensed the IP portfolio to Vertimass in 2014. A current driver is improved fuel quality to aide in certification (decrease C2 and benzene). Technical accomplishments include: catalytic conversion of ethanol to C3 to C15 blendstock, including non-precious metal catalysts on zeolites; 100% conversion to hydrocarbons and water, including 300-350 °C and atmospheric pressure, no added hydrogen; and durable catalyst (>200 hours) over multiple regeneration cycles. Water concentration had no impact on ethanol



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

conversion, so direct fermentation streams could be used. Engine experiments show combustion similar to gasoline and energy balance is slightly exothermic with novel mechanism. The project will provide comparable estimated costs by replacing the cellulosic ethanol dehydration unit in TEA with NREL.

Overall Impressions

- This is a good project with good results, moving on to commercialization. Generally, it is a success story.
- I would like to see a lot more data on the durability of the catalyst and the impact of organic acids on catalyst life. Very interesting.
- Although not yet complete, this project looks like it has the potential to be a major success for the BETO portfolio. The use of ethanol as a feedstock can go a long way to allowing existing cellulosic ethanol projects to move toward commercial demonstration, and the ability to handle dilute ethanol streams will have a significant impact on the economics of those facilities. The durability of the catalyst is encouraging, and migration of the industry from ethanol to hydrocarbon drop-in fuels has enormous potential.
- This is a well-planned, well-executed project which has developed an innovative and promising technology for conversion of ethanol to a fungible hydrocarbon for gasoline. This project was a highlight from the peer review and should serve as a model for other technology projects.
- Excellent work and excellent progress.

PI Response to Reviewer Comments:

- We have lots of results regarding catalyst durability and impact of organic acids. Due to limited presentation time, not all of this information was presented and some of these tests were from a prior Fiscal Year. These data support the summarized catalyst durability of much greater than 200 hours with regeneration; though they were from shorter runs under a wide variety of conditions. The tested organic acids (such as acetic acid) had no apparent effect on the V-ZSM5 zeolite and were also converted by the catalyst.

CATALYTIC UPGRADING OF SUGARS

(WBS#: 2.3.1.101)

Recipient:	NREL
Presenter:	David Johnson
DOE Funding FY14:	$1,174,524
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$5,039,454
Project Dates:	10/1/2014 - 9/30/2017

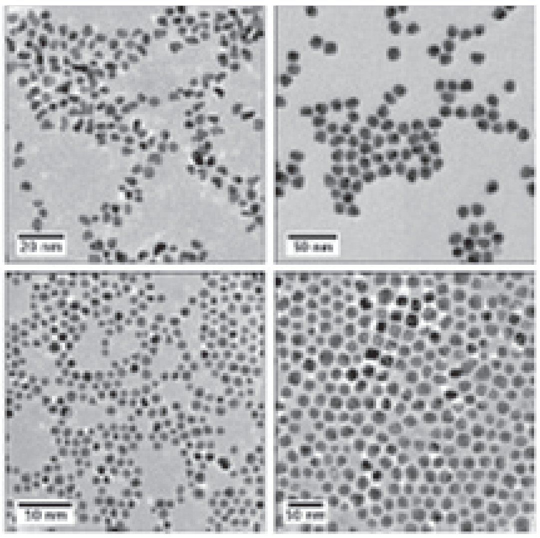
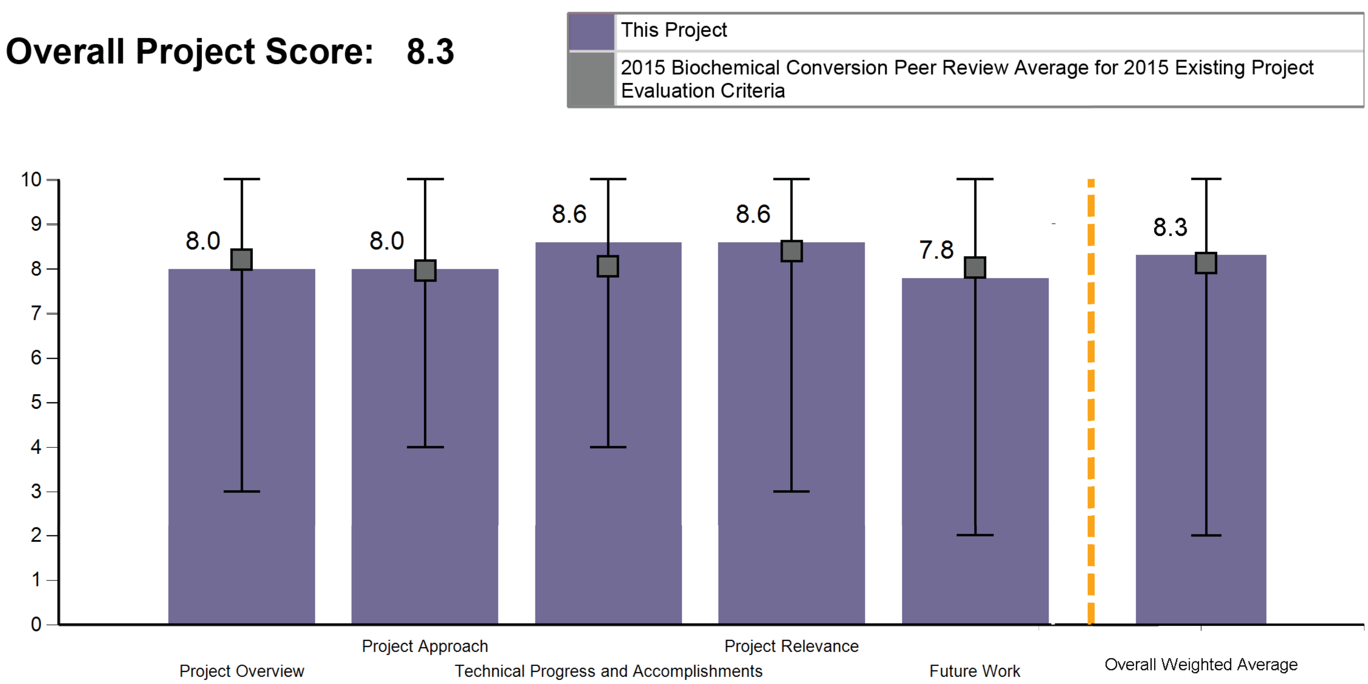


Photo Courtesy of NREL

Project Description

The main objective of this project is to develop catalytic transformation routes that efficiently upgrade sugar-derived intermediates into fuel products or value-added coproducts that enable meeting the BETO's 2017 Multi-Year Program Plan goal of a minimum fuel-selling price (MFSP) near $5.00/gge. The fuel products will be hydrocarbons compatible with blending into the existing fuel distribution infrastructure that fit within the specifications for gasoline jet or diesel fuels. Coproducts will be higher value chemicals that increase the market size of coproducts derived from lignocellulosic sugars. A route to alkanes in the jet to diesel fuel range is being developed based on hydrodeoxygenation of intermediates made from furfural in the C10 to C20 range. Hybrid biochemical-thermochemical routes based on microbial fermentation of sugars to polyhydroxybutyrate or lipids, which can then be thermally and catalytically converted to hydrocarbons from C10 to C20, are also being studied. In addition, separations/catalytic approaches to products derived from succinic acid are being developed. This research directly supports BETO's goals to demonstrate conversion of sugars into hydrocarbons



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

that can be used as advanced drop-in biofuels. The expected impact of this project to the bioenergy industry is to demonstrate processes at the laboratory scale that decrease the risk of commercializing production of advanced biofuels and organic acid coproducts from lignocellulosic feedstocks.

Overall Impressions

- This is a good project. It is very important to pursue the "combined" biological step to platform chemical followed by further, simple, well understood chemical processing. I am concerned about economic evaluations lagging considerable work. There might be a need to conduct a "short-cut" economic evaluation, but one must be careful that this is done to some specific, reviewed and documented procedure and that it does not become a substitute for a more complete analysis later. I caution that rigorous economic analyses can be very time consuming and short-cut methods (if not done carefully) can be useless, misleading, and a waste of time.
- Producing jet fuels from intermediates is very relevant and important research.
- This project has significant potential, and it is good to see coproduct and downstream chemical production work tied to hydrocarbon fuels production. Commercialization potential for the nanoparticle catalyst will be interesting to observe as the project progresses. It is important that techno-economic analysis (TEA) be considered early with projects like these. While it is clear that the project is interested in working with existing models to support the industry and the BETO portfolio, additional effort should be taken to make sure it happens.
- The project uses creative approaches to generating hydrocarbons from biomass. It would be good to see use of preliminary TEA to guide and constrain research.
- This is extremely valuable work investigating alternative conversion chemistries and pathways. There is a lot of potential in the methods being investigated in this program.

PI Response to Reviewer Comments:

- We thank the reviewers for their positive comments. We agree with the reviewers that more interaction with the TEA group will be beneficial to the direction of our research, and this will occur as often as is feasible. It is our expectation that these interactions will lead to technical targets that will become the focus of our research.

HYDROLYZED LIGNOCELLULOSE AS A FEEDSTOCK FOR FUELS SYNTHESIS

(WBS#: 2.3.1.103)

Recipient:	LANL
Presenter:	Andrew Sutton
DOE Funding FY14:	$230,307
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,253,396
Project Dates:	10/1/2014 - 9/30/2015

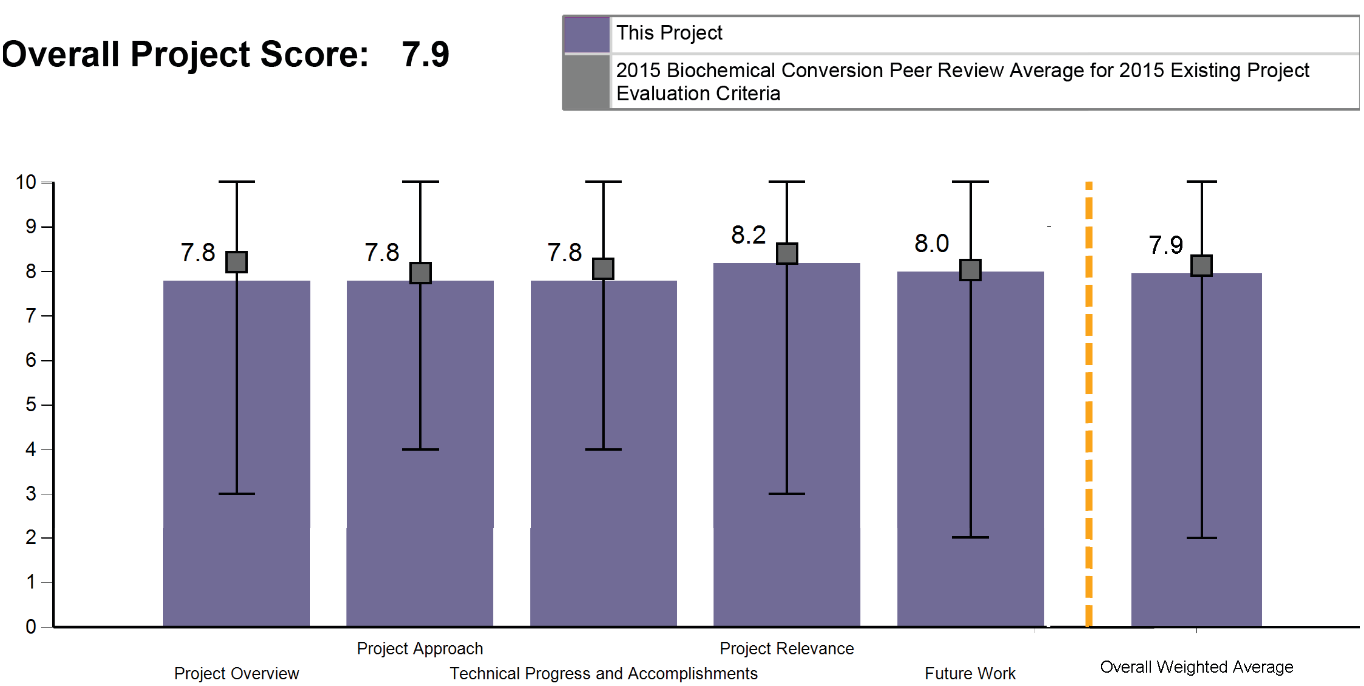
Project Description

Recently, organocatalyzed aldol chemistry has been developed at LANL to extend the chain length of furan aldehydes. This method of chain extension can be performed using a variety of donors to allow molecules with between 8 and 16 carbon atoms to be synthesized. These molecules share common functional group combinations comprised of furans, olefins, carbonyls, and hydroxyl groups. This project aims to apply recently developed C-C coupling and hydrodeoxygenation (HDO) technologies to molecular feedstocks close to sources of raw biomass (i.e., lignocellulosic hydrolysates). Once a better understanding of catalytic HDO systems has been developed, the work will move toward improving the process using lower temperatures, lower pressures and cheaper catalysts. The project will use mild conditions and simple catalysts in chemical processes to convert biomass hydrolysates to fuels and feedstocks as a viable alternative to fermentation routes. In its approach, LANL converted starch into cyclized tetrahydrofuranyl-furan derivatives and even performed the same reaction with unpurified starch extracted from a potato. The resultant species share the same functional groups as the aldol products, and similar reaction conditions can be used to convert these molecules into branched alkanes. Each additional step required to prepare a chemical adds additional cost, infrastructure and complexity, which results in higher production cost. The costs are reduced by eliminating the processing steps.

Overall Impressions

- This is a good project and a good alternative for converting sugars to fuels. We need to keep in mind

Overall Project Score: 7.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

the high cost of large pressure reactors and might want shorter reaction time as a milestone.

- The project is moving in the right direction to reduce capital and operating costs. I would really encourage a techno-economic analysis (TEA) soon.
- Catalytic conversion of biomass with limited downstream upgrading has significant potential in the commercial biomass portfolio. The fact that this project utilizes fairly mild conditions and commercially available, inexpensive catalysts is very encouraging.
- The project uses innovative chemistry to produce hydrocarbons from biomass. Selection of catalysts and conditions was generally driven by economic considerations, but it would be helpful to have a more holistic TEA for some of the proposed pathways. I recommend this group connect with TEA modeling activities at NREL and other labs working on chemical catalysis projects to approach the cost estimates in a consistent way.
- The project had long reaction times with the potential to be very costly; however, this is a very important activity.

PI Response to Reviewer Comments:

- We appreciate the reviewers' comments and their understanding of the advances we have made in lowering operating conditions, moving to cheaper catalysts and reaction optimization as we move towards further economic analysis and process flow development. The reviewers note that "successful completion will have a significant impact on state of the technology" and that this project aligns well with BETO's goals. Now that we have developed an efficient and "innovative chemistry to produce hydrocarbons from biomass," our future work (dependent on continued funding) will aim to encompass all the reviewers' comments regarding scale-up, catalyst reuse, and economic analysis to build robustness and diversity into the continued use and development of hydrolysate as a biomass feedstock.

BIOLOGICAL LIGNIN DEPOLYMERIZATION

(WBS#: 2.3.2.100)

Recipient:	NREL
Presenter:	Gregg Beckham
DOE Funding FY14:	$222,410
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,752,590
Project Dates:	10/1/2014 - 9/30/2017

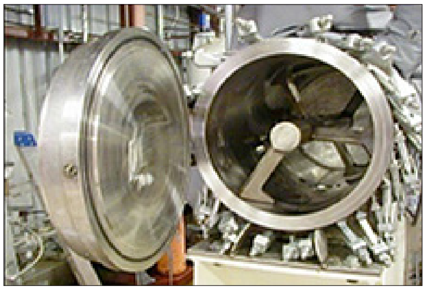
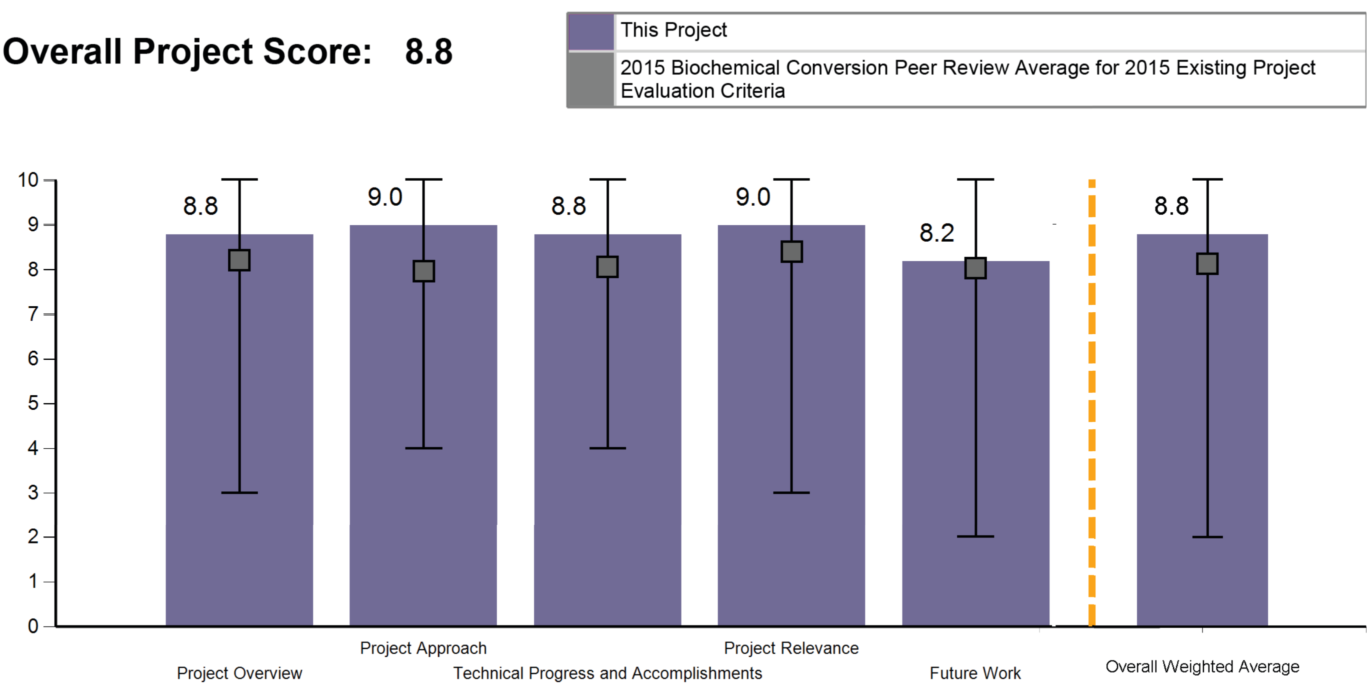


Photo Courtesy of NREL

Project Description

Lignin valorization will be necessary to meet the BETO cost target of $3/gge hydrocarbon fuel production by 2022. To that end, the Biological Lignin Depolymerization project aims to develop a biological approach to depolymerize residual process lignin for subsequent conversion to coproducts, in support of BETO's $3/gge hydrocarbon fuel cost target for 2022. This project is a joint effort between NREL and SNL, funded as a seed project in FY14. In FY14, baseline performance of natural and synthetic ligninolytic cocktails was established on deacetylated, risk-refined, enzymatically hydrolyzed (DDR-EH) lignin, which is the substrate of choice due to its likely inclusion in a 2022 demonstration. FY14 outcomes include identification of enzyme cocktails that depolymerize solid lignin. The project identified primary challenges in biological lignin depolymerization around: (1) the need for robust assays to monitor lignin depolymerization; and (2) the need for a "sink" during depolymerization, as lignin-derived species readily repolymerize. The strategy to overcome the challenges identified in FY14 involves the use of a biological "sink" to prevent repolymerization in the form of an aromatic-catabolizing bacterium. Multiple bacteria are now being screened in concert with extracellular lignin-degrading enzymes. Additional work

Overall Project Score: 8.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

is aimed at using synthetic biology to accelerate enzyme discovery and to elucidate catabolic mechanisms of lignin-derived species, with the aim of developing optimal conversion systems.

Overall Impressions

- This project shows great potential and is needed by the industry. The result could be immediate use with very large initial volume, but to get that the project will need to include some "commercial" lignin in the development. It is fine to be working on the new process configuration for lignin fractionation that NREL has envisioned, but the project should leave out the industrial lignin that is being produced.
- A lot of challenges ahead, but, really, it is great research.
- This is an outstanding project. The work being done is not only commercially relevant, but utilizes lignin from likely commercial processes, rather than from unrealistic sources. There is a large number of publications being produced to help drive additional research. The process impacts the "whole barrel" initiative, and there is strong integration with other BETO projects and heavy focus on techno-economic analysis to drive the work. The project has the potential to contribute more to the portfolio than perhaps most projects out there.
- Peroxidases and laccases have been well studied for lignin degradation. This project uses a novel approach to using base catalyzed decomposition or alkaline extracted lignin liquor to generate higher quality, more useful lignin feedstocks for conversion/upgrading. The project plan and experimental approach are very well developed and designed.
- This is an extremely relevant project since it is commonly believed that a high value coproduct will be needed in order to achieve fuel economics for hydrocarbons from lignocellulosic biomass. Lignin is a valuable raw material that, to date, is being used as boiler fuel; however, it can be converted into higher value products under the right processing conditions.

PI Response to Reviewer Comments

- We thank the reviewers for their positive comments and constructive feedback. We will incorporate these ideas into our future research plans and milestones. We certainly agree that biological approaches to convert lignin to value-added coproducts has significant potential to have impact on the integrated biorefinery concept. Regarding the impact to existing processes that use different pretreatments than mechanical refining, we will be evaluating various process-relevant pretreated biomass substrates with our biological approaches going forward including those relevant to pretreatments being done industrially today.

BIOGAS TO LIQUID FUELS AND CHEMICALS USING A METHANOTROPHIC MICROORGANISM

(WBS#: 2.3.2.102)

Recipient:	NREL
Presenter:	Mike Guarnieri
DOE Funding FY14:	$137,586
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,362,414
Project Dates:	10/1/2014 - 9/30/2015

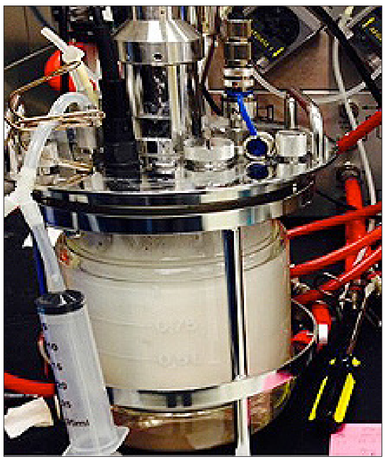
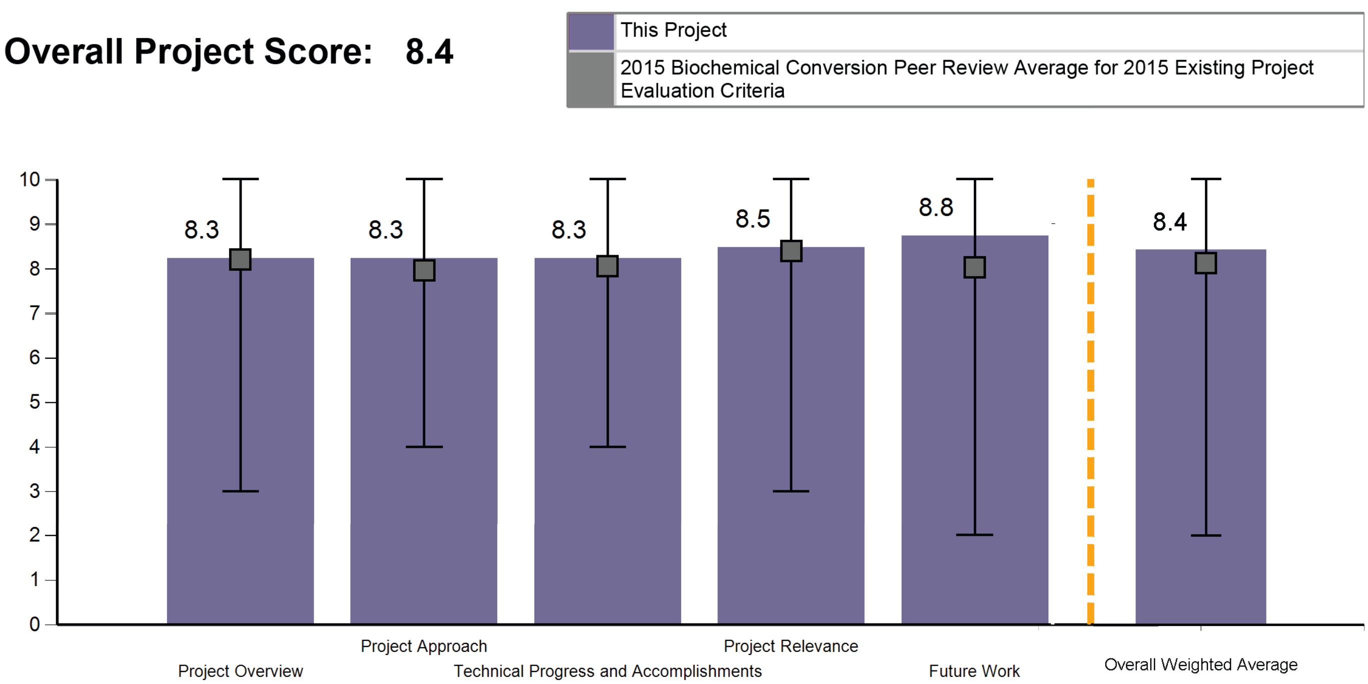


Photo Courtesy of NREL

Project Description

Methane-rich biogas, derived from anaerobic digestion of waste stream sources such as municipal solid waste operations, biorefineries, and agriculture operations, offers a renewable alternative to natural gas as a feedstock and intermediate in bioprocesses. Initiated in FY14, this project aims to demonstrate a biogas-to-liquid fuels and chemical bioprocess. Specifically, our efforts will target biological conversion of methane to lipids and lactic acid through metabolic engineering and fermentation optimization. This work is relevant to BETO's Multi-Year Program Plan and will develop cost-effective, integrated waste-to-energy processes for the production of advanced biofuels and bioproducts. This project will result in the development of a novel, high-impact bioprocess that offers an alternative to conventional sugar-based bioprocesses, and will achieve proof-of-concept for the production of fuels and chemicals from biogas. Genetic tool development, gas mass transfer, and efficient productivity are among the major challenges facing industrial application of methane biocatalysis. FY14 efforts successfully employed genetic engineering and fermentation optimization strategies to concurrently



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

produce lipids and lactic acid. A key collaboration with University of Washington was initiated to facilitate flux balance analyses, which will further inform strain-engineering efforts. FY15 efforts will focus upon enhanced carbon conversion efficiency from methane to biomass and products.

Overall Impressions:

- This is a good project, exploring some genetic engineering that has not been done yet. It fits well within the BETO portfolio.
- A viable commercial path was identified and the use of techno-economic analysis as basis is a good justification.
- This is a relevant project not only for the waste-to-energy pathway, but because it is pursuing gas-phase fermentation and producing data that will be very useful for the industry as a whole. It is very good to see a project focused on techno-economic analysis as a research driver, especially given the major breakthroughs that will be required to commercialize this technology. Such effort is encouraging, as it indicates that there could be large-scale demonstration in the mid-term.
- The results are encouraging from an economic and technical perspective. Economic viability of the concept is critically dependent on cost effective biogas production. There are good linkages and synergies with other programs, particularly the waste-to-energy pathway analysis.

PI Response to Reviewer Comments:

- Our team thanks the reviewers for their encouraging and positive commentary. As noted by the review panel, we feel this work will have a broad impact on both the BETO waste-to-energy platform as well as industry-wide methane bioconversion efforts. The development of methane biocatalysis strategies offers a means to expand BETO's feedstock portfolio and represents a significant commercial opportunity to deploy waste-to-energy technologies. Additionally, this work represents proof-of-concept for an array of additional methane biocatalysis strategies, opening the door for feedstock and bioproduct expansion in an emerging bioeconomy, which in turn will encourage the creation of a new domestic bioenergy industry. We appreciate the reviewers' recognition of the synergy this project will provide to other programs. Our team is excited to continue these efforts and looks forward to continued progress in the development of a viable biological methane conversion platform.

FUNGAL GENOMICS

(WBS#: 2.3.2.103)

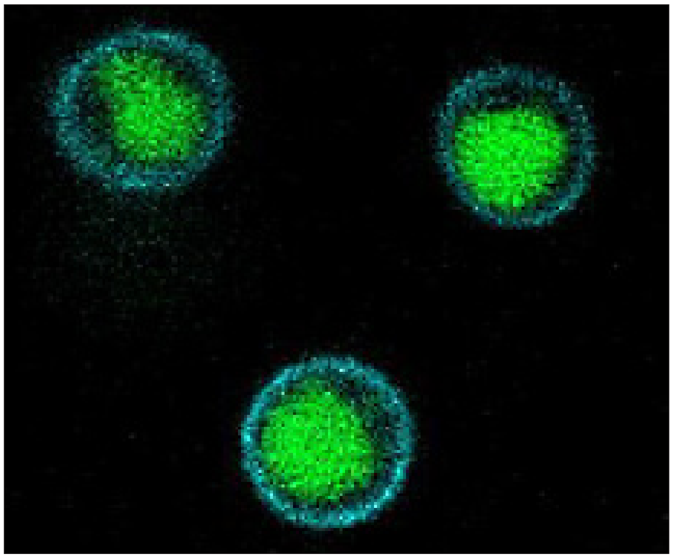
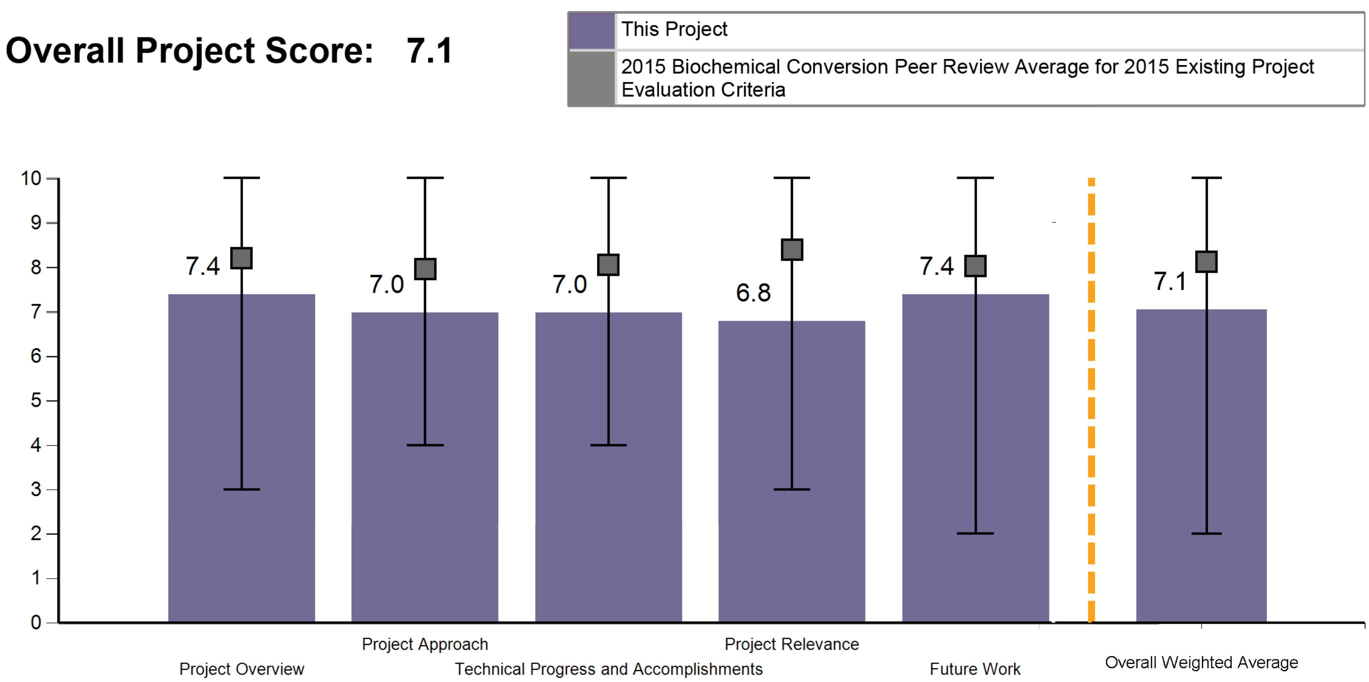


Photo Courtesy of PNNL

Recipient:	PNNL
Presenter:	Jon Magnuson
DOE Funding FY14:	$1,475,492
DOE Funding FY13:	$1,540,007
DOE Funding FY10-12:	$7,168,876
Planned Funding:	$0
Project Dates:	10/1/2010 - 9/30/2017

Project Description

Fungi are key members of the existing and future biorefinery industry for the production of fuels, bioproducts and enzymes. The principal goal of this project is the development of robust fungal biorefinery-compatible organisms and their associated bioprocesses for efficient production of hydrocarbon biofuels, biofuel precursors and bioproducts. Efficiency in this context means improving TRY (titer, rate and yield) of lipids (fuel precursors) and bioproducts from challenging lignocellulosic sugars. This research addresses the technical barrier element of Biocatalyst Development and is relevant to meeting the BETO's 2017 and 2022 cost targets for hydrocarbon biofuels. We are focused on understanding the fungal platform organisms using systems biology techniques followed by genetic manipulation of the platform fungi using genes identified through those approaches. The project team is concurrently developing and applying bioprocess techniques and analysis for assessing these organisms under conditions mimicking those in a biorefinery. The team has made major strides in improving TRY of lipids in Lipomyces starkeyi and developing genetic engineering tools for Lipomyces



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

starkeyi. The team's existing expertise in the manipulation of Aspergillus niger for bioproducts and relatively new expertise in Lipomyces starkeyi for lipids provide the foundation for continued success during the remainder of the project.

Overall Impressions

- I wonder why the program needs fungal development for large volume chemicals. Seems more like a project to keep an expertise working. Should consider whether this function is really needed.
- C15 terpene as the target molecule is good. A lot of work done on C15s from sugar via yeast fermentation by Amyris. A good molecule to make fuels and chemicals. Lipid is a different spin on this interesting research.
- This project is an example of good integration with other national laboratories and collaborators, driving toward greater probability of success. Much of the work has been done with pure sugar substrates, but it's good to see a move toward hydrolysates and building inhibitor tolerance. It is also encouraging to see interaction with industry advisers to help guide the project direction.
- This project seeks to leverage PNNL's historical strengths in fungal genomics to develop new pathways to produce hydrocarbons from renewable biomass. Good progress has been made in improving the performance of the Lypomyces and Aspergillus strains are targeted by the project. However, it is unclear how economic considerations are used to select strains and target products and guide the technology program. Furthermore, the approaches to strain engineering do not appear to be differentiated from other strain development programs. I encourage this project to apply more rigorous techno-economic analysis and incorporate more innovated strain engineering approaches that would enable the broader scientific community.
- There are advantages on the product side for these alternative organisms. PNNL has a long history of working in fungal genomics; however the scale-up of fermentation will be challenging.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

SYNTHETIC METABOLIC PATHWAYS FOR BIOCONVERSION OF LIGNIN DERIVATIVES TO BIOFUELS

(WBS#: 2.3.2.104)

Recipient:	ORNL
Presenter:	Adam Guss
DOE Funding FY14:	$205,720
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,224,280
Project Dates:	10/1/2014 - 9/30/2015

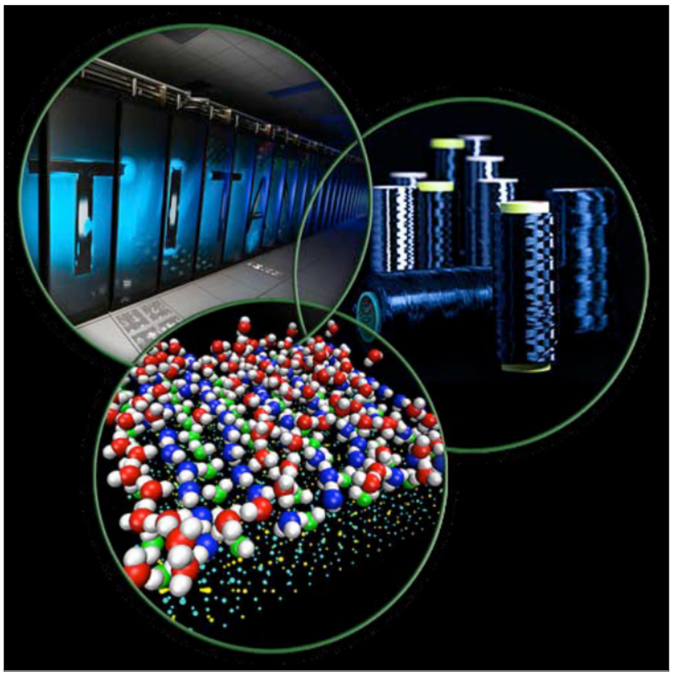
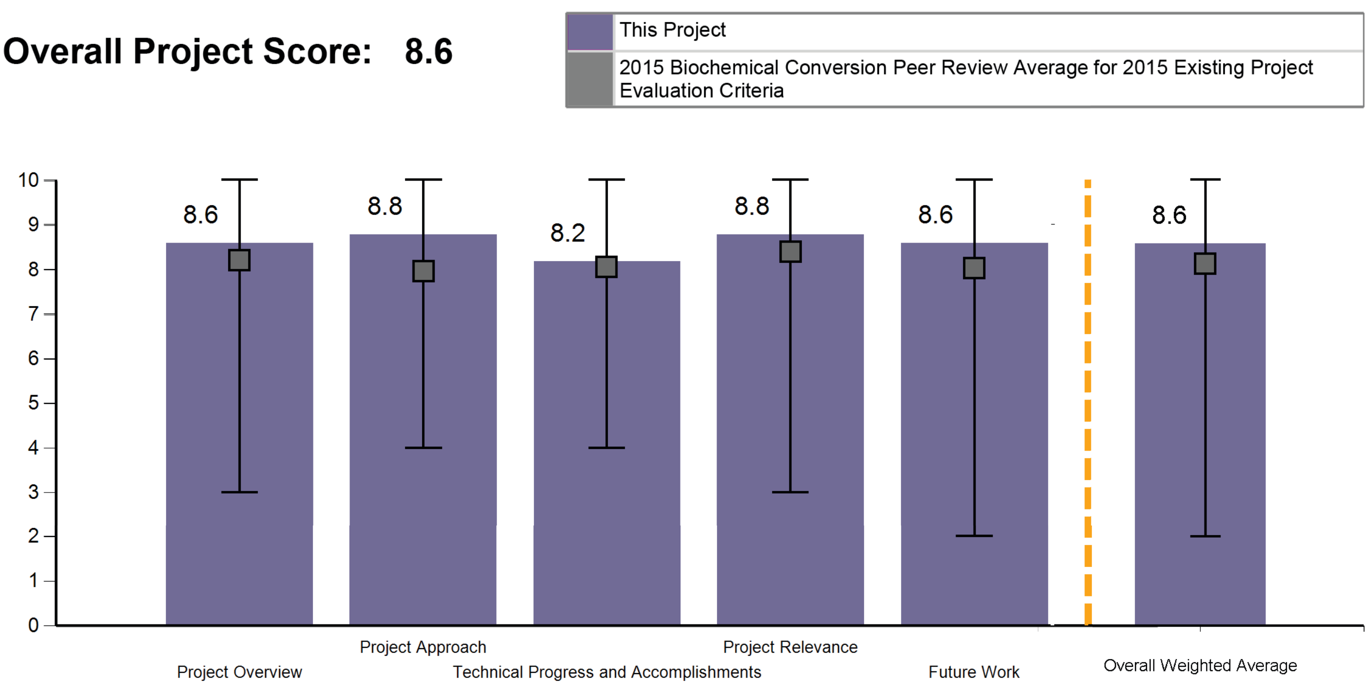


Photo Courtesy of ORNL

Project Description

Lignin accounts for ~25% of plant biomass, but it is underutilized during biofuel production. A mature cellulosic biofuels industry will produce an estimated 300 million tons of lignin-rich material. Adding value to the lignin fraction of biomass will be critical to meeting biofuel cost targets. The project is developing biocatalysts to convert the lignin-rich streams into value-added products. Initial efforts targeted engineering E. coli to catabolize aromatic compounds such as protocatechuate (PCA). Introduction of the Pseudomonas putida 3,4 ortho cleavage pathway for PCA degradation into Escherichia coli allowed for utilization of PCA as the sole carbon and energy source. Further genetic modification enabled E. coli to convert PCA into a target compound at up to 22% of theoretical yield. Challenges in E. coli

Overall Project Score: 8.6



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

include robustness in lignin-rich streams and the complexity of simultaneous expression of the many aromatic catabolic pathways. Therefore, current work focuses on engineering P. putida, which natively catabolizes aromatic compounds in lignin-rich streams, to convert lignin into value-added products such as polyhydroxyalkanoate. Further, the project team is screening potential lignin-degrading microorganisms to identify the best at lignin deconstruction and catabolism for future metabolic engineering efforts. Genetically modifying these microbes to efficiently produce fuels and chemicals from low value lignin streams will improve biorefinery economics and help reach biofuel cost targets.

Overall Impressions

- This is the type of work that the program needs. The only concern is whether or not the project should also be looking at some lignin that is coming from current producers (POET-DSM, Abengoa, or DuPont), as well as the new lignin that NREL is generating from a new pretreatment.
- This is good work. There are a lot of challenges, but the path forward seems to be really well thought out.
- This project has high relevance, and it is good to see progress is being made toward lignin utilization for something other than fuel. The current utilization appears to be with model compounds, so it will also be good to see progress made with polymeric lignin, but there are indications of success here that are encouraging. It is also good to see a migration toward actual hydrolysates, which is clearly planned. Polyhydroxyalkanoate (PHA) is not necessarily the best chemical product to be producing, though, the project is encouraged to look for additional value-added products.
- This is a well-defined project with good strategic alignment. There is good coordination with other national laboratories and DOE activities.
- We need to understand the choice of PHA as the final product. What is the rationale for other value-added products? We need to understand the impact of using lignin as a feedstock on life-cycle analysis of a commercial plant (i.e., GHG and fossil fuel displacement); this is part of the program. Not all of the lignin is needed to fuel the plant, so some is left over for conversion.

PI Response to Reviewer Comments

- Thank you for the insightful and helpful comments. We are focusing on PHAs as one of the target molecules because it is natively made by P. putida and preliminary techno-economic analysis (TEA) suggests that PHA production from lignin could be economically viable if sufficient yields and titers are achieved. However, we also understand that there is risk in focusing on a single compound, and that there are also risks associated with targeting PHA production. Therefore, we are also targeting production of other value-added products. The choice of alternate products are based on TEA, including but not limited to consideration of market size, current market value, and the cost of separation from the alkaline pretreated liquor.
- We have not yet performed LCA specifically for PHAs, but LCA was done for adipic acid by our collaborators at NREL, where the LCA looks very promising for lignin conversion to adipic acid as a coproduct rather than use of lignin as a boiler fuel.* It is also worth noting that 100% lignin conversion to a coproduct is likely impossible, so only a fraction of the lignin will be converted to a coproduct in this case. (**Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute-Acid and Enzymatic Deconstruction of Biomass to Sugars and Biological Conversion of*

Sugars to Hydrocarbons PDF. Davis, R.; Tao, L.; Tan, E.C.D.; Biddy, M.J.; Beckham, G.T.; Scarlata, C.; Jacobson, J.; Cafferty, K.; Ross, J.; Lukas, J.: Knorr, D.; Schoen, P. 147 pp. NREL Report No. NREL-TP-5100-60223, October 2013)

- We do not currently have plans to pursue lignin-rich streams from lignocellulosic biofuels companies. However, in another project, our collaborators at NREL are looking at the depolymerization and upgrading of Deacetylated/Mechanical-Refined, Enzymatically Hydrolyzed (DMR-EH) lignin. As research on that pretreatment advances, we will also examine the resulting lignin as an alternate feedstock for our engineered microbes. In regard to acid pretreated lignin, our collaborators at NREL are working with acid pretreated lignin, and, therefore, we can tailor our biological approach to lignin that is similar to some industrial lignin. Ultimately, the processes under development here are not necessarily solely applicable to Alkaline Pretreated Liquor, but rather can and will be applied to other lignin depolymerization strategies.

BIOLOGICAL UPGRADING OF SUGARS

(WBS#: 2.3.2.105)

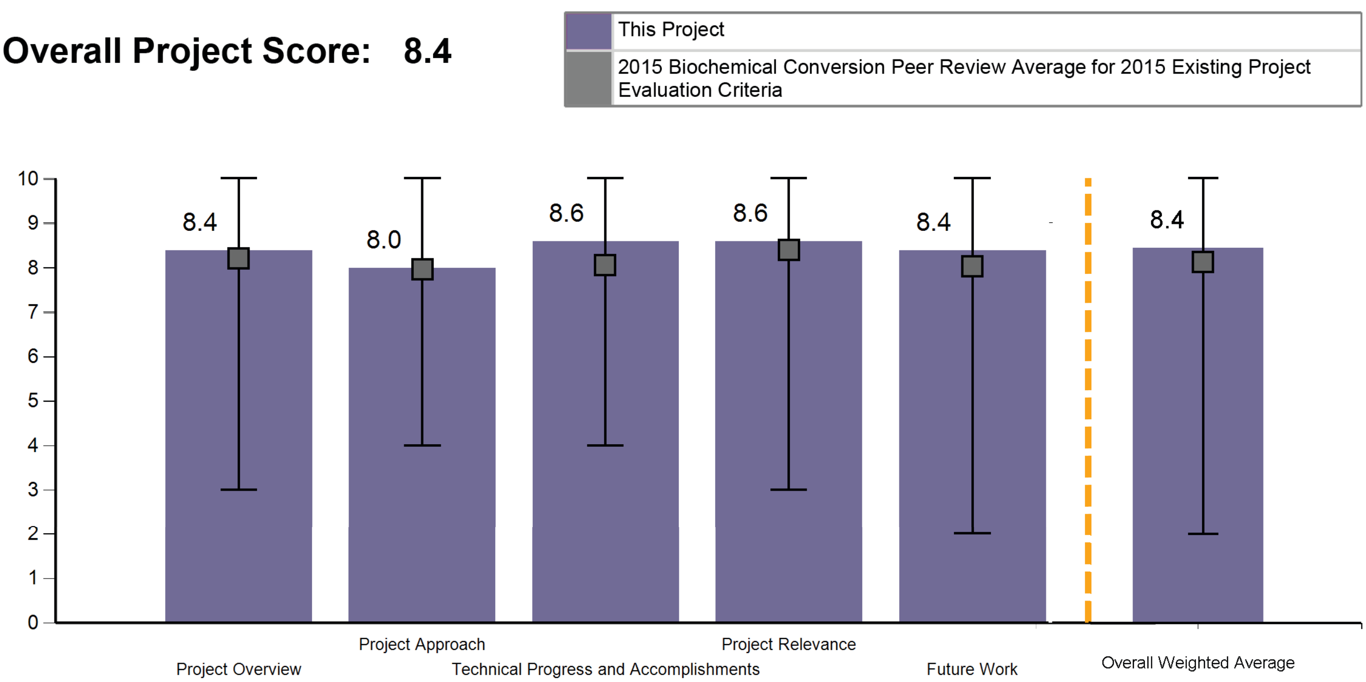
Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Gregg Beckham
DOE Funding FY14:	$471,568
DOE Funding FY13:	$396,486
DOE Funding FY10-12:	$0
Planned Funding:	$0
Project Dates:	10/1/2014 - 9/30/2017

Project Description

The BETO 2017 demonstration will include upgrading of a C5-sugar rich stream to a coproduct (succinic acid or SA) and a C6-sugar rich stream to lipids (a diesel blendstock precursor), a process configuration that will be required for an integrated demonstration of BETO's 2017 hydrocarbon fuel production goal of $5.00/gge. To that end, the objectives of the Biological Upgrading of Sugars Project (new in FY15) are to develop production strains for lipids from C6 sugars and for SA from C5 sugars. This project includes efforts in strain evaluation, fermentation development, and strain engineering and evolution. The project team collaborates closely with BETO projects at NREL in deconstruction, separations, catalysis, and integration, thus ensuring a clear path to demonstration of the 2017 technology goals. The project goals by year are as follows: FY15: survey a wide range of strains for lipid and SA production in collaboration with the Bench-Scale Integration Project. Performance data toward the technical targets will inform a down-select process at the end of year. FY16: strain engineering, evolution, and adaptation of top SA and lipid strains will be conducted on biomass-derived hydrolysates toward improving productivity toward technical targets. FY17: co-optimization of deconstruction, fermentation, sepa-

Overall Project Score: 8.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

rations, and catalysis will be conducted. Data from this project will inform TEA models for state of technology evaluations in the Biochemical Platform Analysis project.

Overall Impressions

- With the program process set as it is and succinic acid and lipids selected as the products of choice, this is an excellent task.
- This is interesting research. The fuel/chemical combination is key.
- This is a good project, but almost seems to be two parallel projects working toward a common goal. Utilization of C5 for succinic acid and C6 for lipid production by a different organism raises questions as to commercial viability, as it is moving down a path long-traveled by unsuccessful projects. Separation of the streams increase capital costs, footprint, and complexity, but the inclusion of value-added products in the process (such as those produced from this project) may offset those issues. The focus should be on making chemical precursors in lieu of products that have the potential to flood the market immediately upon commercial scale application, since the scale economics may well be driven by C6 utilization.
- This is a very well-conceived and planned project for converting biomass sugars into hydrocarbons. The selection of strains and target molecules are clear and methodical. Some of the strains and approaches are innovative and promise to deliver some new options for hydrocarbon production.
- This is a very relevant program due to the poor theoretical yields of hydrocarbons from sugars (resulting in poor economics). The coproduction of a value added chemical will aid in the overall economics; however, there are potential market size issues. The market size of succinic acid is far smaller than hydrocarbons, therefore one may saturate the chemicals market quickly, which may limit the size of the hydrocarbon end of the process. Thus, this may require multiple coproducts be made instead of one. Also, the capital and operating costs of a "split stream" biomass conversion process may be more than the combined approach. This should be monitored.

PI Response to Reviewer Comments

- We thank the reviewers for the positive comments, and we agree that production of coproducts alongside fuels will be critical to the economics of the integrated biorefinery.
- Regarding coproduct choice and market disparity between fuels and chemicals, we note that succinic acid is merely a single example of a chemical precursor that we can make from biomass. We fully agree with the reviewer that there is a scale disparity issue between fuels and any one single coproduct, thus warranting the development of additional coproduct routes. For targeted demonstrations, we have to choose a reasonable number of coproducts to demonstrate in an integrated fashion to illustrate the biorefinery concept. Importantly, our integrated process is modeled on using sugar streams from industrial biomass deconstruction (acid pretreatment and enzymatic hydrolysis), thus many different coproduct trains developed by others could potentially be integrated into this approach in a modular fashion, well beyond succinic acid. Overall, we envision coproduct selection being entirely market-driven, and not easily defined by a single biorefinery model example as the one we are working toward on the Biological Upgrading of Sugars Project.
- Regarding the comment on making chemical precursors, we are collaborating with the Catalytic Upgrading of Sugars Project, presented by David Johnson, to use succinic acid as a chemical precursor/platform chemical. Specifically, in that collaborative project, we are demonstrating chemo-catalytic transformations of hydrolysate-derived succinic acid to additional, large market, high value chemicals. Essentially, the "end product" is not just succinic acid, but rather a broad

slate of molecules that one can derive from succinic acid.

- Also, we are conducting rigorous techno-economic analysis to estimate the capital and operating costs of the plant that would produce both fuels and coproducts. Initial cost estimates, as the reviewer suggested, indeed demonstrate that the higher value coproduct has the ability to significantly offset the increased capital and operating costs and still have a substantial, positive impact on the overall fuel selling price. These results will be compiled and reported in future reports.
- Regarding the comment in terms of two parallel projects; this project indeed represents parallel strain and process development tasks toward fuels and coproducts from lignocellulosic hydrolysate. Given the major challenges in integration, we feel that these activities need to be conducted hand-in-hand as different strains will require different considerations that will have impact on the overall process.
- We again thank the reviewers for their insightful comments, which will be used to direct our research in this project going forward.

LIGNIN UTILIZATION

(WBS#: 2.3.4.100)

Recipient:	NREL
Presenter:	Gregg Beckham
DOE Funding FY14:	$1,172,790
DOE Funding FY13:	$886,109
DOE Funding FY10-12:	$0
Planned Funding:	$3,841,102
Project Dates:	10/1/2012 - 9/30/2017

Photo Courtesy of NREL

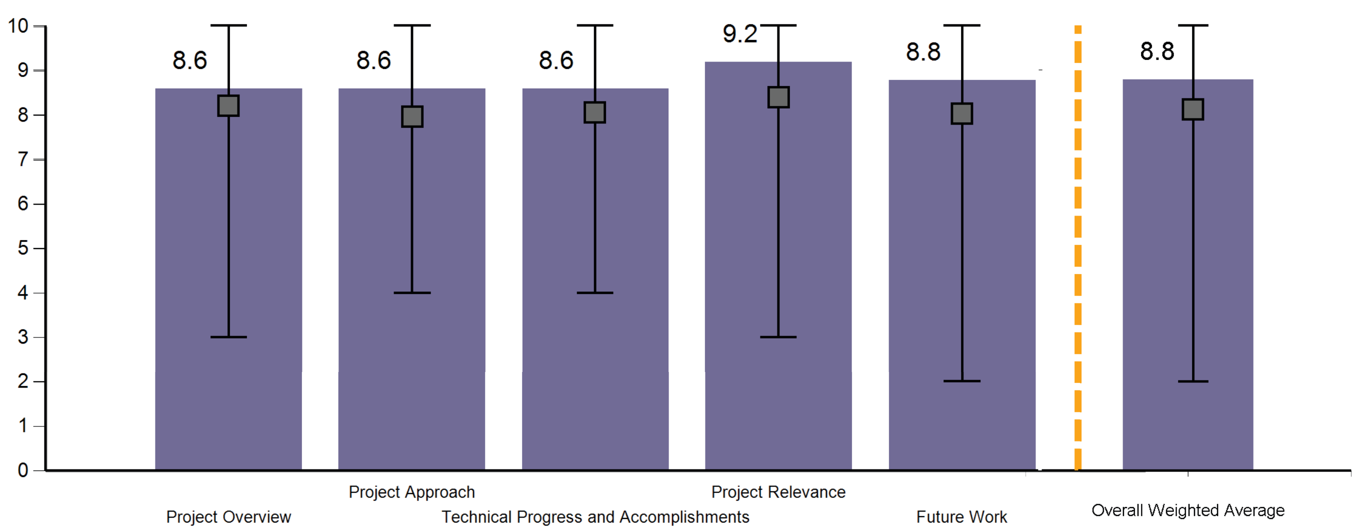
Project Description

This project focuses on the development of cost-effective, integrated lignin valorization strategies with a primary emphasis on: (1) lignin-centric pretreatment strategies that selectively remove lignin from whole biomass; (2) catalytic or thermal lignin depolymerization approaches that are able to deconstruct residual lignin following polysaccharide removal; and (3) development of integrated biological and catalytic upgrading strategies of lignin streams to value added coproducts. This project will directly support the 2017 and 2022 goals through research and development towards valorization of lignin streams to value added coproducts. As identified in the 2013 NREL Design Report (R. Davis, et al.), lignin valorization will be essential to meet the 2022 goals of $3.00/gge hydrocarbon fuel. Research in the last two years has shown that alkaline pretreated liquor can be biologically upgraded to value-added coproducts such as medium-chain-length polyhydroxyalkanoates or muconic acid. Research also showed that base-catalyzed depolymerization is a simple, effective depolymerization strategy for lignin deconstruction to upgradeable low molecular weight aromatic compounds. Going forward, the project team will focus on the integration of lignin depolymerization with a biological-catalytic upgrading strategy. Transition of the pathways investigated in this project to industry

Overall Project Score: 8.8

This Project

2015 Biochemical Conversion Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

will be conducted in collaboration with commercial partners and in communication outreach via patents and publications.

Overall Impressions

- It is very timely to get into lignin conversion as the country is about to be producing over 1,000 ton/day of by-product lignin from the three conversion facilities coming on-line. They would all like to have a value add over burning. Could BETO play a role of surveying what "lignin" is coming from these plants, and what its variability is with changing feedstocks and process conditions? What do the producers want from DOE? "Lignin," as the mixture comes from the biorefinery, is not all the same; what challenges will be faced in converting it? It is a great time to be doing this. Let's take advantage of the timing and not waste any resources or time (not to say that this task is, but let's take a little closer look).
- One comment is that the commercial plants coming on line all use acid pre-treatment, not alkaline. Are there any plans to look at acid pretreatment derived lignin? Very interesting research.
- Lignin utilization is critical to near-term and mid-term commercial success. This project is making significant progress toward allowing commercial utilization of the lignin stream. Integration with other lignin-related projects is high, which is encouraging and has the potential for a high level of synergy, enhancing probability of success.
- This is very interesting and strategic work. The project seems aligned and connected with other projects and development.
- This is excellent work with tremendous potential. It could really change the economics of a biorefinery if the lignin is taken advantage of.

PI Response to Reviewer Comments:

- We very much appreciate the positive comments from the reviewers. We definitely agree that lignin valorization will be of paramount importance for the integrated biorefinery. We have worked with one current producer of lignin from an ethanol plant and are planning to reach out to other industrial-scale producers to initiate collaborations.
- Regarding the comments on working with acid pretreated lignin, examination of this substrate is a large component of our current research in terms of depolymerization catalysis (e.g., with base-catalyzed depolymerization). The primary acid-pretreated lignin we are working with comes from the NREL Integrated Biorefinery Facility, which employs a pilot-scale acid pretreatment reactor followed by enzymatic hydrolysis with a modern industrial enzyme cocktail. We are conducting a significant amount of depolymerization research on this substrate as it is certainly of interest to current producers of cellulosic ethanol.
- We stress, however, that our biological funneling approach to upgrade lignin does not require an alkaline approach for depolymerization. Rather, we are working with a broad range of collaborators as well as in our own project to depolymerize lignin via different approaches, and integrate that with a downstream biological funneling process.
- The comment regarding engaging industry as to ways to help is excellent, and we will work with BETO and industry to address that question going forward.

BENCH SCALE INTEGRATION

(WBS#: 2.4.1.100)

Recipient:	NREL
Presenter:	Nancy Dowe
DOE Funding FY14:	$888,452
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,335,953
Project Dates:	10/1/2014 - 9/30/2017

Photo Courtesy of NREL

Project Description

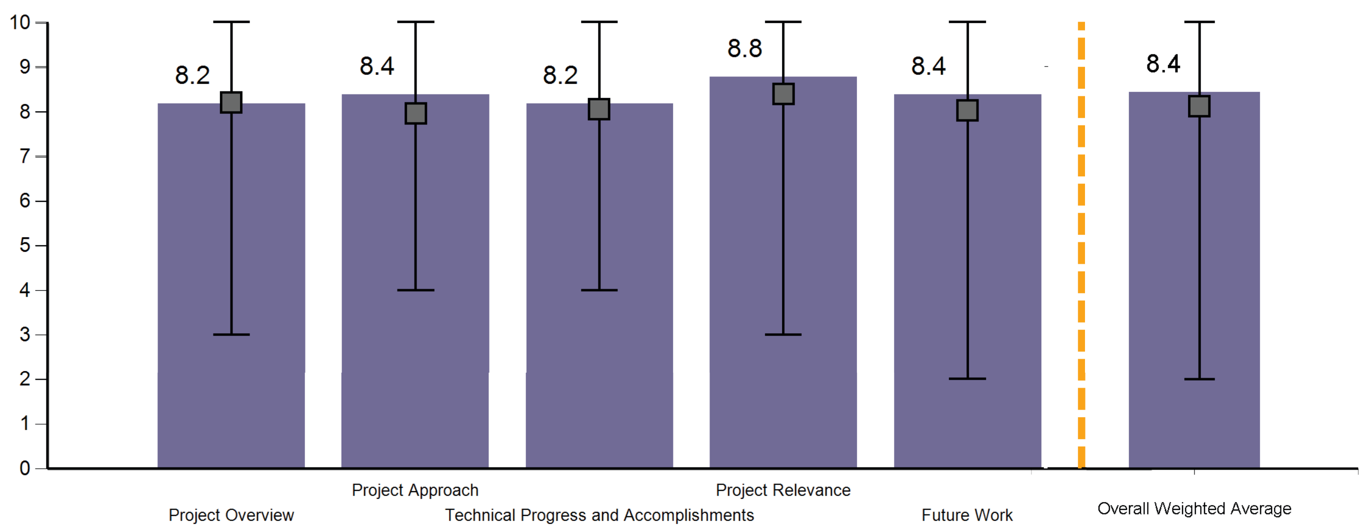
The BETO Biochemical Conversion R&D projects are focused on converting biomass to transportation fuels at a near term cost target of $5.00/gge by 2017. The objective of the Bench Scale Integration (BSI) project is to integrate developed technologies that will lead to a demonstrated process that meets the 2017 cost targets. The 2017 technology demonstration will convert cellulose to a renewable diesel blendstock (lipids from oleaginous yeast) and the hemicellulose fraction to a coproduct, succinic acid (SA). Fermentation process development and sugar production from pretreated feedstock will be the primary focus of the project from FY15 through FY17. The complexity of the process makes it challenging to meet the short time frame from development to demonstration. BSI will work closely with projects developing strains, pretreatment, analytical, separations technology, and techno-economic modeling to integrate the unit operations. Data from BSI will be used to update yearly state of technology reports and further develop TEA and LCA models made available to the public.

Overall Impressions

- This is a good project. The 2017 and 2022 goals will be proven out at this scale before they can go to pilot. This is a much more efficient way than just

Overall Project Score: 8.4

This Project
2015 Biochemical Conversion Peer Review Average for 2015 Existing Project Evaluation Criteria



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going to pilot.

- NREL's reports on similar ethanol bench scale plants were extremely valuable to the private sector. This works ties together much of the research being done in the industry and facilitates the pathway to scale up to pilot and demonstration plants.
- This is a good project and milestones and goals are clearly quantified and achievable. Separations are apparently going to be considered in a downstream project, but definitely need to be considered. It is an ambitious project, but integration with industry and collaborators should hopefully help drive it to successful completion.
- This project plays a key role in scaling up and integrating technology developments from different projects. The studies are done in a rigorous and consistent fashion enabling objective assessment of performance improvements.
- Bench scale integration of the various processing steps is an important stepping stone toward piloting and commercial scale.

PI Response to Reviewer Comments

- We thank the reviewers for their positive comments and appreciate their acknowledgement of the importance of integrating the process at bench scale to facilitate scale up. We recognize the importance of developing processes in an integrated way because often changes to one part of the process affect multiple areas. We also strive to work at concentrations that are relevant and develop protocols that can be scaled to NREL's pilot plant. The project goals are driven by the techno-economic modeling, which keeps the project focused on the R&D necessary to achieve cost targets. Data generated from this project feeds back to annual state of technology reports from NREL's Biochemical Analysis project, which tracks research progress. We also maintain a close association with industry by providing information on biocatalyst performance in a process context, which we hope will aid in scale-up.
- This project is closely aligned with NREL's strain development, pretreatment, pilot scale integration, analysis, and separations projects. We evaluate strains and pretreated feedstock under process relevant conditions. We are particularly keyed into separations; both from needing biomass sugars for fermentation and producing material for downstream processing. Even though some of the research resides outside bench scale integration, there are multiple shared milestones that keep all the projects working closely together as we develop the technology.

SEPARATIONS DEVELOPMENT AND APPLICATION

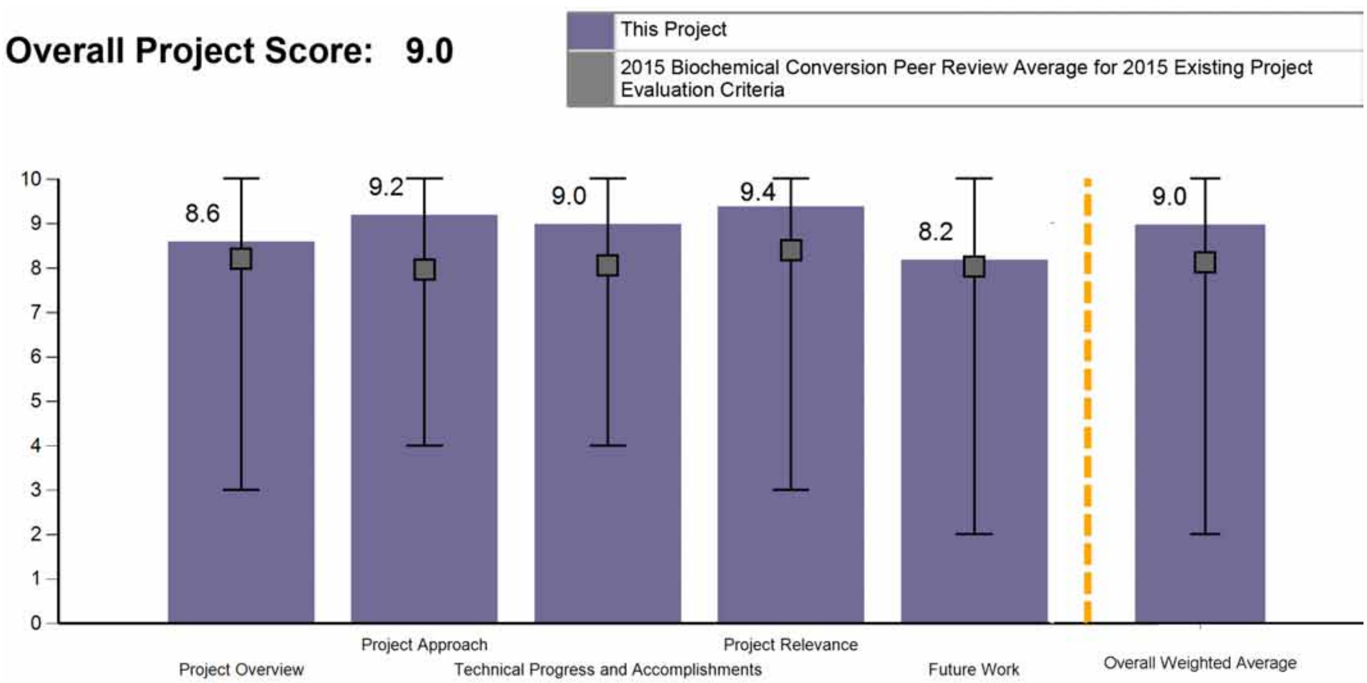
(WBS#: 2.4.1.101)

Recipient:	NREL
Presenter:	Jim McMillan
DOE Funding FY14:	$1,435,942
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$3,023,996
Project Dates:	10/1/2014 - 9/30/2017

Photo Courtesy of NREL

Project Description

This project performs cost-driven separations R&D to improve the efficiency and economics of producing and recovering biofuels from biomass. It supports BETO's 2017 and 2022 biofuels production cost goals. Separations being researched include upstream solid-liquid separations (SLS) and hydrolysate liquor concentration to prepare C5-rich and C6-rich sugar streams for biological upgrading, and downstream recovery of lipids produced from the C6-rich sugar stream. The project's scope and schedule are primarily driven by the need to identify and establish separation processes that can meet the performance and cost targets to be demonstrated in FY17. Techno-economic analyses informed by performance data from this project have been and will be used to guide R&D direction/priorities. In FY13-14, the project began developing SLS, dewatering and slurry rheometry techniques to support the 2017 demo, and it also demonstrated at a proof-of-concept level continuous enzymatic hydrolysis (EH) technology as a promising longer-term option. In FY15-17, the project will also begin examining lipid recovery. FY15 priorities are: (1) develop effective SLS method for clarifying post EH slurry; and (2) screen at least seven or more potentially lower cost methods for recovering lipids than HPH-based methods. FY16-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

17 priorities are: (1) optimize SLS and concentrative separations for C5 and C6 sugar streams; (2) refine and optimize lipid recovery methods that pass down-select criteria; and (3) Scale up methods for use in integrated demonstration.

Overall Impressions

- This is an essential project for the process of making lipids and solids-free fermentations and it has good approaches.
- Separations has been a challenge throughout the history of the program. The emphasis on the chemical products makes this research even more applicable and urgent.
- This project has the potential to have an extremely large impact on the industry as a whole. Separations have been a major concern for over a decade, and commercialization efforts are often hampered by this process. Given this, it would be expected that there would be more commercial/industrial integration with the project. Scale is a huge issue that could be addressed, as well. Often, pilot equipment performs drastically differently from bench-scale or even commercial-scale equipment, and it is critical to identify technology testing limitations. This project has the potential to help with that.
- This project seeks to provide a technical and economic evaluation of different separation technologies. While cost effective separation technologies are critical to the success of most public and private biomass conversion processes, there has been very little public research on the subject. This project is well designed and will deliver a valuable assessment to the community. Ideally, the same framework could be utilized to provide a standard assessment for emerging separations technologies.
- This is a very important task since there are a number of unit operations in the biomass conversion process that can benefit by improved separations technologies.

PI Response to Reviewer Comments:

- We appreciate the peer reviewers' efforts to assess and review this project. We are pleased the review panel sees value in the project's planned separations R&D for integrated biomass biochemical conversion/sugar platform process development. We agree that scale remains a challenge and that industry engagement is essential and will continue to strive to maximize the value of this project's work products to achieving BETO's cost goals.

PILOT SCALE INTEGRATION

(WBS#: 2.4.1.102)

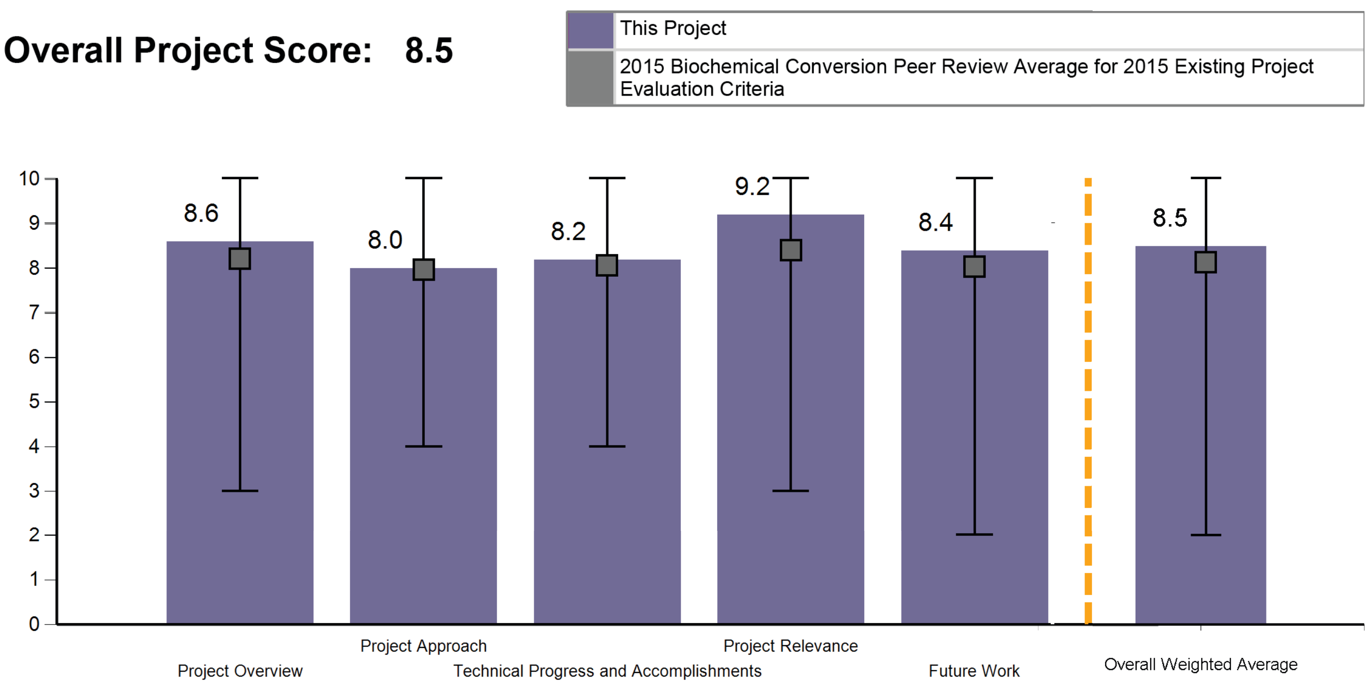
Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Dan Schell
DOE Funding FY14:	$2,290,374
DOE Funding FY13:	$4,852,296
DOE Funding FY10-12:	$20,448,394
Planned Funding:	$7,291,950
Project Dates:	10/1/2013 - 9/30/2017

Project Description

The Pilot Scale Integration project's high level goal is to perform R&D and to support safe pilot-scale operations needed to demonstrate integrated performance meeting BETO's hydrocarbon fuel cost targets. To do this, the project maintains the functionality and operational readiness of the pilot plant located at NREL and evolves its capability to perform process integration work for BETO and industrial clients. The project team also performs near-term applied research using the capabilities of the pilot plant to understand issues impacting process performance (pretreatment or enzymatic hydrolysis) or investigate equipment/scale-up concerns (e.g., aeration in large tanks) with significant uncertainties. A challenge is to install and troubleshoot new process or equipment options at pilot scale. In the past two years, new efforts have improved pilot plant operations (e.g., new feed systems) and safety (e.g., ongoing process hazard analysis and dust mitigation). A method for on-line measurement of residence time distributions was implemented in a continuous pretreatment reactor. Aeration performance and cost in large-scale vessels is now better understood. Work has advanced alkaline pretreatment as a possible future option for utilizing lignin to produce fuels and chemicals. Finally, the pilot plant was heavily used by

Overall Project Score: 8.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

industrial clients with these projects totaling about $4.5 million of work in FY13/14 and nine new projects were initiated in the same time frame.

Overall Impressions

- The project offers an important function to the program if they want to maintain a relevance to the process designs they make and to be a resource for outside developers to try out processes.
- The NREL pilot plant is an important research vehicle for government and industry parties. Keeping this area up to speed with the latest trend in unit operations and processes is important.
- This is another great industry-supporting project. There is plenty of work performed on in-house projects that supports BETO and MYPP goals, but the availability of the equipment for industry process development work is great. Improvement in pilot-scale testing since the last review is very clear, and integration with techno-economic analysis projects is key.
- The NREL pilot plant has provided valuable scale up data to the biomass conversion community for years. This project has continued to maintain, develop, and deliver on this mission.
- The ability to integrate the various processes at pilot scale is extremely important and invaluable.

PI Response to Reviewer Comments

- We appreciate the reviewers' comments and their efforts reviewing this project. We will continue to evaluate pilot scale processing needs and acquire capabilities with BETO's support to make the biochemical pilot plant a relevant facility for industry and BETO to develop and test new hydrocarbon fuel production technologies.

CELLULOSIC BIOMASS SUGARS TO ADVANTAGED JET FUEL

(WBS#: 2.4.1.200)

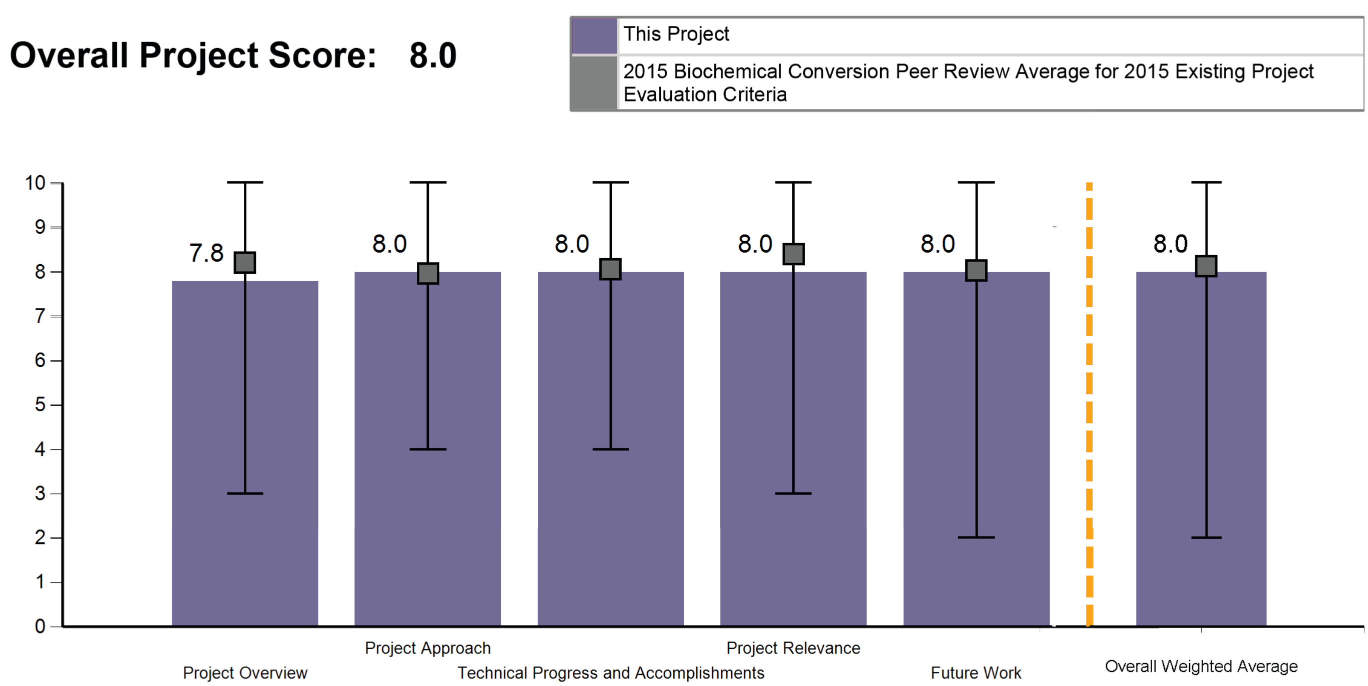
Recipient:	Virent
Presenter:	Randy Cortright
DOE Funding FY14:	$2,683,382
DOE Funding FY13:	$1,302,899
DOE Funding FY10-12:	$1,302,899
Planned Funding:	$939,028
Project Dates:	10/1/2011 - 9/30/2015

Project Description

The purpose of this project is to demonstrate the technical and commercial feasibility of producing liquid fuels, particularly jet fuel, from lignocellulosic materials, such as corn stover. To achieve this, National Renewable Energy Laboratory's (NREL's) expertise in corn stover deconstruction has been paired with Virent/NREL hydrolysate conditioning capabilities and Virent's novel BioForming® process. The project will produce an advantaged jet fuel which has been shown to meet or exceed specifications for commercial and military jet fuel through Fuel Readiness Level 5 (TR-5). In addition to the core technology at NREL and Virent, the project is leveraging the skills and expertise of Idaho National Laboratory (INL) for the procurement, storage and analysis of the corn stover, Northwestern University for fundamental modeling of lignin deconstruction to improve overall carbon recovery, and NREL's catalyst characterization capabilities to understand catalyst deactivation mechanisms. Since inception in Q4 of 2011, the program has progressed through Benchmark and Intermediate Validation and has made substantial progress toward the Final Validation targets in April 2015.

Overall Impressions

- A concern is that the catalyst is sensitive to SiO_2 as feedstocks like corn stover that will not be able to be removed before hydrolysis and will need to be removed from the sugars. I am not sure of the cost of that.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- Drop-in fuels are an important part of the future. Getting the volume to provide enough fuel to test and certify is important. Being proactive in getting the fuel ASTM certified is good.
- The combined biochemical/chemical process is seeing a resurgence in popularity as hydrocarbon production is taking preeminence over alcohol and oxygenated product production. This project does a good job supporting that work by proving general viability. Additional catalyst work will be needed to support commercialization. It will be telling to see how rapidly the process moves toward commercialization on private funding; with luck, it will be very rapid. This is the sort of project that could truly benefit the industry as a whole, and the BETO portfolio in particular, with publication of lessons learned.
- The project demonstrates successful execution of a well-designed project. Considerable progress has been made toward improving catalyst performance and economics, delivering a technology package that is nearly ready for the next stage of development.
- This has been a highly successful program demonstrating the catalytic conversion of sugars into hydrocarbon fuels and high value chemicals with competitive economics. In addition, it has pointed out the importance of defining specifications for sugar hydrolysates.

PI Response to Reviewer Comments

- Virent has done extensive investigations of the effects of silica on our catalyst system and how to mitigate these effects through hydrolysate clean-up, process conditions, and catalyst design. These investigations included both technical evaluations as well as influence on the overall cost to the process.
- Technical work on this project ends on April 30, 2015. Virent will be completing a final report of the project, and it is planned to published at least one paper on what was learned in this project.

DEVELOPMENT OF A THERMOPHILIC CONSOLIDATED BIOPROCESSING ORGANISM FOR BUTANOL PRODUCTION

(WBS#: 2.4.3.100)

Recipient:	INL
Presenter:	Vicki Thompson
DOE Funding FY14:	$204,467
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$555,533
Project Dates:	10/1/2014 - 9/30/2017

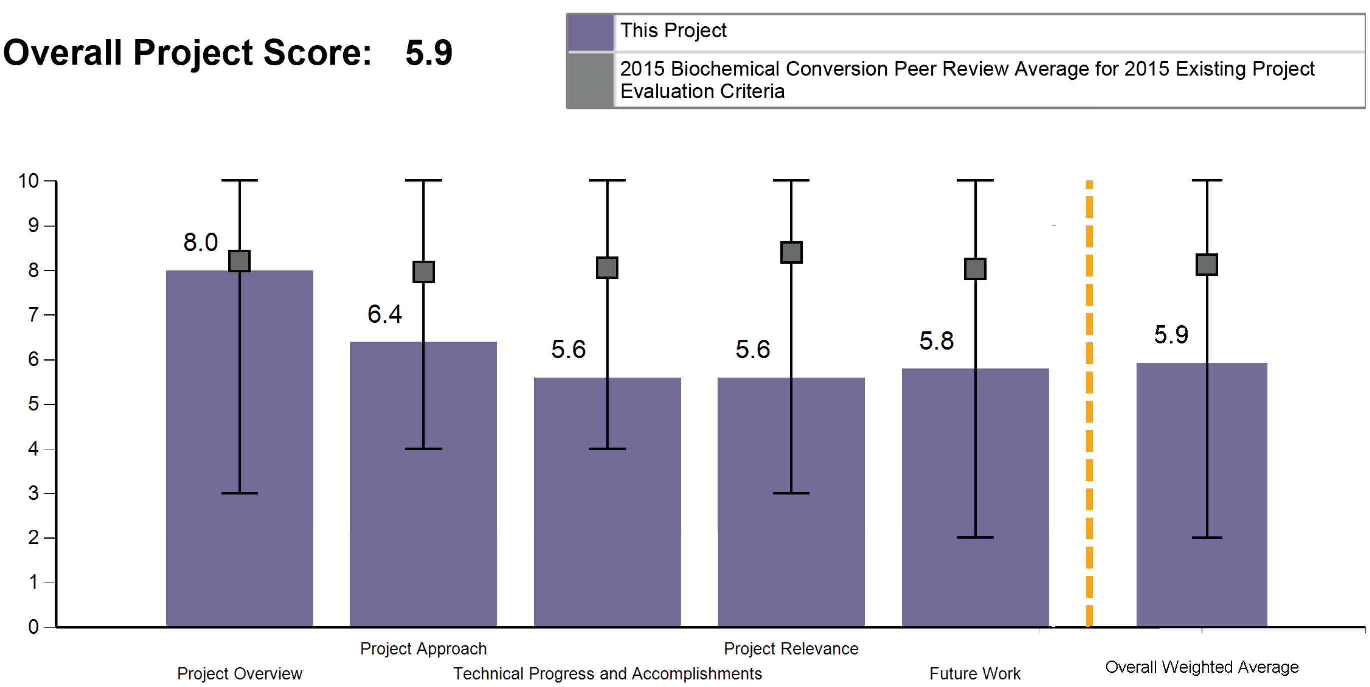
Project Description

The purpose of this project is to reduce both the capital and operating costs in the biochemical conversion of sugars to fuels and products through the development of a thermophilic saccharification and fermentation system. This project leverages thermophilic lignocellulosic hydrolysis enzymes that have been developed by INL, SNL, and NREL. The project will develop blends with these enzymes that maximize sugar production as well as genetically engineer a thermophilic organism to produce butanol. The thermophilic system will allow decreased pretreatment severity, reduced losses due to thermal decomposition, reduced sterilization costs, and reduced cooling and neutralization costs. Since the enzymes and fermentation organism are matched for temperature and pH, the enzyme hydrolysis and fermentation steps can be integrated and, potentially, the pretreatment step. The higher temperature will also allow the system to incorporate gas stripping to remove butanol, which reduces purification costs and alleviates solvent toxicity to the fermentation organism. Challenges for this project include development of genetic engineering tools for butanol pathway development. This project was funded in FY14 and, to date, has developed an enzyme blend yielding 53% glucose and 95% xylose on pretreated corn stover. The resulting hydrolysate was tested for fermentability and found to produce as much butanol as a glucose-only control.

Overall Impressions

- This is interesting research. A significant increase in butanol yields lends itself to future work.

Overall Project Score: 5.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- Progress has clearly been made with this project, but there are some questions that should be considered going forward, such as benefit versus commercial butanol processes. Integration or collaboration with some of the lignin utilization projects would benefit the project. It would be good to see a clear pathway toward successful cellobiohydrolase (CBH) inclusion, given that the project is essentially in competition with a commercialized process.
- High temperature cellulases have long been regarded as an enabling technology for improved biomass conversion economics. Developing high temperature cocktails from thermophilic bacteria has been attempted before without commercial success. These enzymes are more expensive to produce than fungal standards used today and, therefore, must be much more active to be competitive. The use of ionic liquid pretreatment for testing enzymes confounds the results making it difficult to gauge the performance of these new enzymes. I recommend the use of a benchmark feedstock (e.g., NREL corn stover) and enzyme cocktail (e.g., CTEC) in these studies.
- This seems to be more of an enzyme discovery effort than anything else. There is quite a lot known already about thermophilic bacterial cellulose hydrolysis and there are a multitude of technical and commercial challenges. It will be very difficult to compete with high yielding commercial enzyme preparations from Trichoderma reesei.

PI Response to Reviewer Comments

- We are using enzymes that have already been characterized by ourselves and our partners. The effort is focused more toward developing enzyme blends that give good yields of glucose and xylose. In FY14, most of the project effort was focused on developing that. However, future work is much more focused on genetic engineering of a thermophilic butanol-producing organism.
- We will continue to benchmark against commercial enzyme preparations throughout this project. This will include benchmarking against dilute acid pretreated corn stover and using commercial enzyme cocktails. We are actively seeking CBHs for our enzyme mixture and the SNL enzyme component of this project has focused on that.
- This project is TRL-2, so commercialization is not a near-term goal. However, we have examined expression of our enzymes in some commercial fungal expression systems and some achieved acceptable levels of expression. In future work, we intend to collaborate with enzyme producers to develop commercial strains for expression of these enzymes. We have included Green Biologics as one of our partners so that the process we develop has benefit versus commercial butanol processes.
- The benefits of thermophilic enzymes and fermentations have been well recognized in the literature and by our commercial partner. We started this work at INL with a Laboratory Directed Research and Development (LDRD) project to find and characterize thermophilic enzymes aimed at hydrolysis of lignocellulose. However, our goal was always to develop a combined thermophilic saccharification and fermentation process. We specifically targeted lignocellulose since there are a number of places in the saccharification and fermentation of lignocellulose that would benefit from thermophilic processing. Among these are matched pH and temperature conditions for the saccharification enzymes and fermentation organism, reduced need for fermenter cooling and sterility, and the ability to strip off product from the fermenter due to increased volatility at thermophilic conditions. The latter not only reduces the costs for product separation, but also relieves product inhibition and importantly allows the potential for development of a continuous process. While it is true that potentially any set of thermophilic enzymes could be utilized, the enzymes that we developed provide a logical starting point to define an effective cocktail of thermophilic lignocellulose degrading enzymes. Notably, we also included enzymes from other sources in addition to the ones that we developed previously.

TARGETED MICROBIAL DEVELOPMENT

(WBS#: 2.4.3.102)

Recipient:	NREL
Presenter:	Michael Himmel
DOE Funding FY14:	$1,240,387
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$6,666,018
Project Dates:	10/1/2014 - 9/30/2017

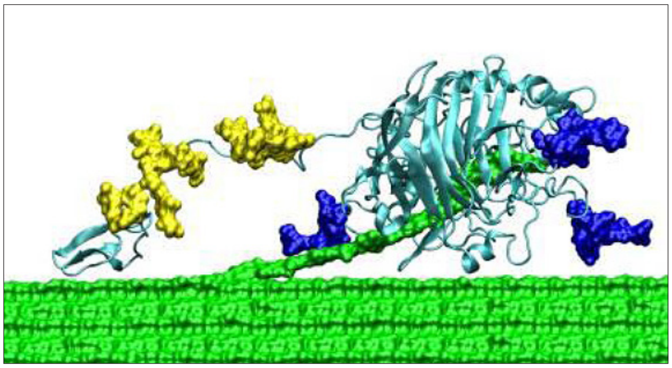
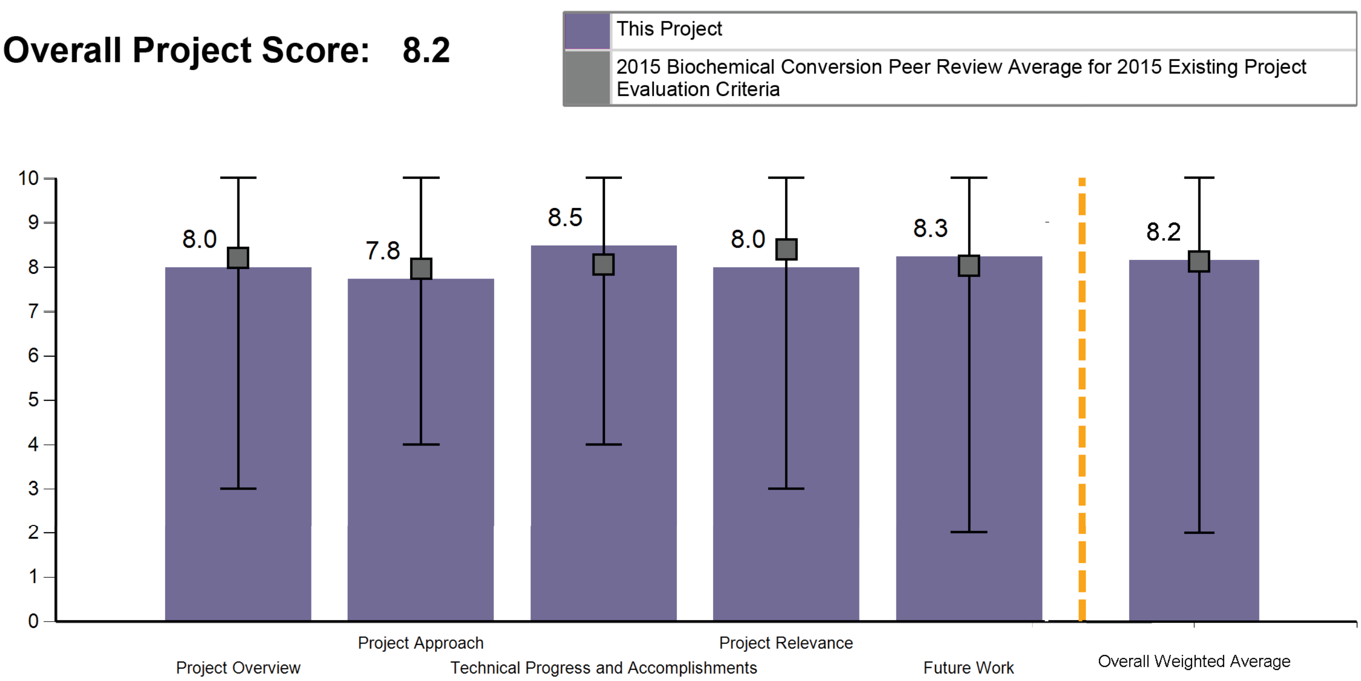


Image Courtesy of NREL

Project Description

The goal of this project is to develop novel pathways for advanced biological upgrading of sugars to lipids (FY17) and to hydrocarbons (FY22) by developing efficient and rapid carbohydrate utilization, high carbon efficiency, and cost effective processes to support BETO's 2022 goal of producing advanced hydrocarbon fuels at $3.00/gge. To achieve this goal, the project team has designed three experimental tasks: Working in Z. mobilis, Task 1 will recruit genes to channel pyruvate to acetolactate, acetoin and then to 2,3-butanediol, and further maximize its flux by considering various gene sources, optimizing the gene expression, and protein engineering if necessary. Task 2 will evaluate anaerobic microbes that produce C3-C8 species amenable for separation and upgrading, as well as conduct systematic survey of scientific and patent literature for fermentation, separations, and catalysis readiness. Task 3 will investigate novel DMC concepts impacting FY22 goals that can drastically reduce the cost of producing hydrocarbons. Critical technical challenges include high carbon yield from glucose, as well as xylose, product secretion/recovery, and the high cost of cellulase/hemicellulose enzymes. The project recently demonstrated transformation of the wild type and engineered Yarrowia strains to produce a fully active trio of cellulase and duo of xylanase enzymes from T. reesei.

Overall Project Score: 8.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This is a good project and it is focused on what the overall 2017-2022 project plan needs. I would question the 2017-2022 direction regarding aerobic lipid fermentation to make fuels directly from the fermentation. I would suggest fermentation to a platform chemical followed by potentially much easier and more well-known chemical processing. An example would be fermentation to isobutanol followed by chemical transformation (dehydration, oligomerization, hydrogenation) to jet fuel. There are many examples of chemical transformations like this to useful products from platform chemicals. This happens to be the Gevo route, but other chemicals are similar platforms, succinic acid for example, but it is also somewhat difficult to recover.
- Future work seems like a logical continuation of the current path, based on lessons learned from the initial research.
- It is never too early to perform a techno-economic analysis on a project; indeed, it is often a requirement prior to funding any industrial R&D project. There is promise in several aspects of this research, but it has a feel that there is research going on because there has always been this research going on. It is strongly encouraged, given the extended timeline on two of the three tasks, that time be spent on an objective economic analysis, potentially with direct industry input, to validate the effort that has taken place. There have been the same concerns expressed over the last two reviews, project management needs to pause and consider them seriously.
- This project has a wide scope of activities and is making good progress towards well-defined goals. NREL continues to champion Zymomonas as a host for biofuels/biochemicals, but it is not clear if this platform organisms is industrially relevant. Engineering oleagenous yeast for direct microbial conversion to lipids is an innovative, high impact approach.

PI Response to Reviewer Comments

- We thank the reviewers for their comments. We agree with the suggestion to conduct TEA analysis for Tasks 1 and 3 (preliminary TEA has been conducted and will be revisited going forward).
- It is our strategy to work toward the direction recommended by the reviewer; however, the aerobic oleaginous yeast project was the BETO platform for 2017. Pursuant to more recent guidance from DOE, we are now focusing on 2,3-butanediol (BDO) from Zymomonas (or isobutanol as suggested by the reviewer) and fatty alcohols (a secreted product that can be recovered readily from the fermentation broth) from oleaginous yeast. This latter process can be further extended to direct microbial conversion (DMC) approaches.
- We do consider Zymomonas mobilis to be an industrially relevant organism today, as shown by the U.S. Patent record where 18 companies have filed patent applications directed to Z. mobilis as an industrial microbe. Moreover, a 30 million gallons / year commercial demonstration plant using Zymomonas technology is being built by DuPont.

BIOCHEMICAL PROCESS MODELING AND SIMULATION

(WBS#: 2.5.1.100)

Recipient:	NREL
Presenter:	Michael Crowley
DOE Funding FY14:	$1,592,995
DOE Funding FY13:	$5,008,489
DOE Funding FY10-12:	$19,162,873
Planned Funding:	$5,362,106
Project Dates:	10/1/2010 - 9/30/2017

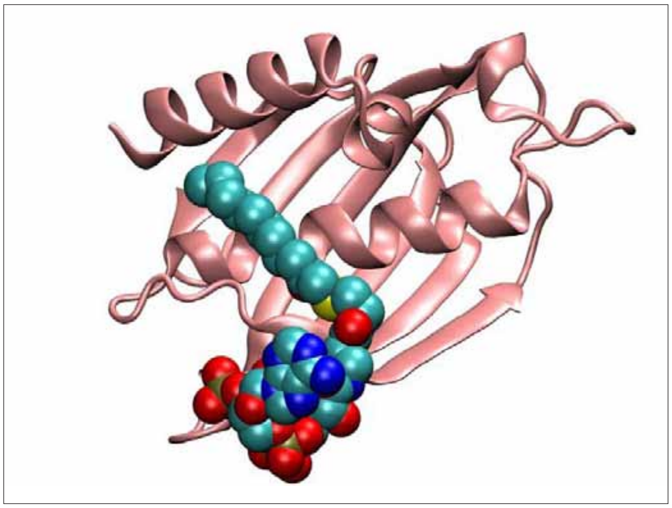
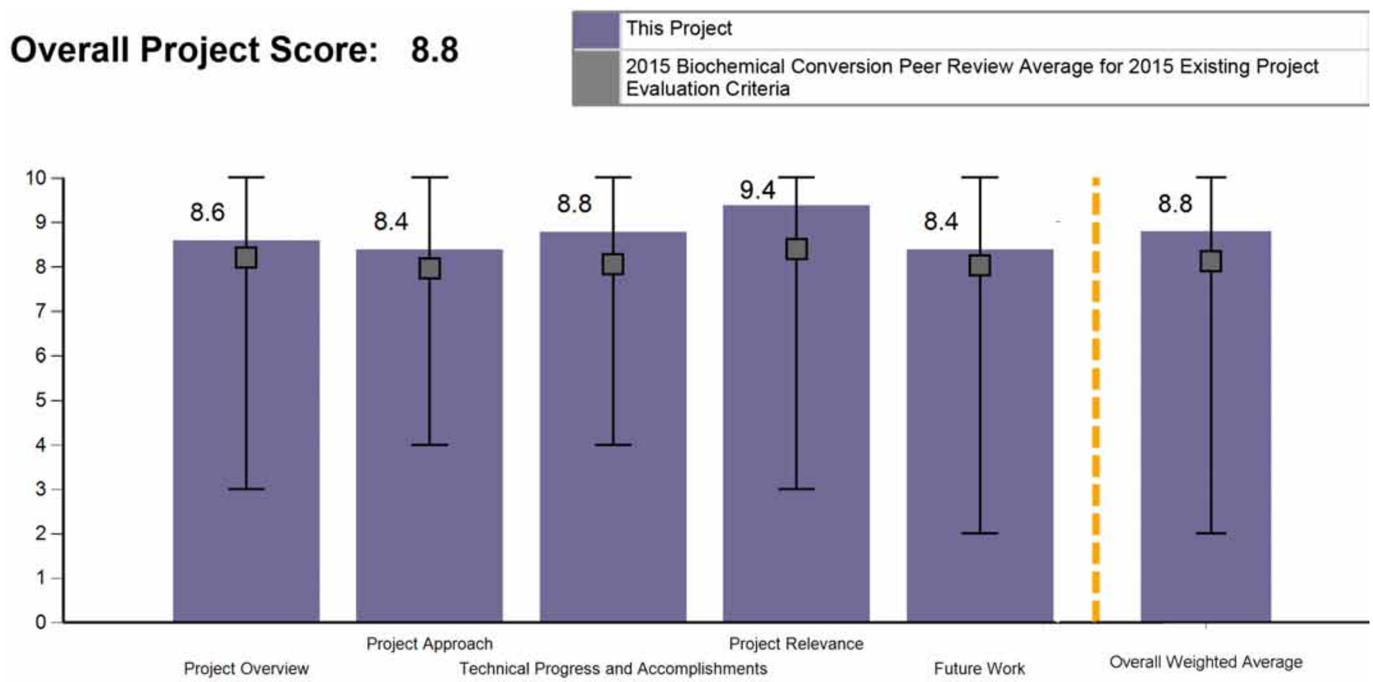


Image Courtesy of NREL

Project Description

This project provides valuable insight into the complex molecular and macroscopic processes in biofuel production. It is highly productive and collaborative with a multitude of publications, milestones, and deliverables. The Task 1 goal is to understand and redesign the enzymes for cocktails for hydrolysis of biomass and for sugar upgrading. It reduces the cost of hydrolysis and upgrading through increased performance and selectivity of enzymes, principally, cellulolytic enzymes and hydrocarbon-producing enzymes. The hydrocarbon-producing enzymes are a key element of 2017 and 2022 targets. Task 2 models molecular and metabolic to improve product yields and titers for selected fermentative microbial strains. Progress within this project directly impacts the current state of technology by streamlining efforts to produce cost efficient advanced fuels and high value chemicals. Task 3 focuses on developing



Whiskers represent the range of scores for ea Whiskers represent the range of scores for each evaluation criteria across all projects continuum-scale predictive capabilities used to make informative engineering calculations in support of process design, parameter optimization, and estimation of operating costs. The tools accelerate biomass conversion technology development, contributing to 2017 and 2022 advanced biofuels cost targets. By the end of FY17, the project will have working mechanistic models for pretreatment, enzymatic hydrolysis, and aerobic fermentation, providing accurate and tunable data for techno-economic analysis models, supplementing laboratory experiments and empirical scale-up models.

Overall Impressions

- This is a great project and significant progress has been made in this area, both in the scientific world and its application and in-house at NREL. Development and application of these models in-house at NREL are much better than simply collaborating with the many universities active in these areas. Because the applications are somewhat different at NREL, building an in-house expertise does just that; it builds up and gets better.
- Understanding the enzyme mechanism is relevant research and being able to model and translate to the macro process world is huge.
- It is great to see modeling and simulation as part of the portfolio. As possible, the project should consider making available to the public versions of the models at different stages. Continuous support of the models is of far less importance than availability, and much of the industry needs a starting point for detailed R&D analysis (especially TEA).
- This project takes a sophisticated approach to modeling at different scales. The project seems well connected with other activities and focused on key areas where modeling can provide actionable insights. It would be good to see some more examples where models have led to optimization strategies that were verified experimentally.
- This is an extremely important activity to guide the researchers and predict changes that need to be made. A challenge will be how to model real world substrates and situations such that accurate predictions can be made.

PI Response to Reviewer Comments

- The project team strongly thanks the reviewers for their efforts and dedication to this process, and for their highly constructive, motivating, and validating remarks. They have taken an objective and positive approach to analyzing, evaluating, and questioning these publicly funded research results in acccordance with new visions in BETO research and development. As the reviewers remark, our direction is to gain advanced insights into what the barriers to biofuels are, and what simulation and modeling can do to reduce them through a combination of insight, understanding, and prediction.
- This project has been, and continues to develop into, a source of insight and prediction into the development and design of enzyme technologies. The project has produced over 10 publications a year, which are highly cited and useful to other research and to industrial development. The thrust is to increase the project's interaction with experimental and engineering projects to increase its relevance and effectiveness in reducing the MYPP barriers in real industrial settings. This is being accomplished with increased collaborative efforts with experiment and engineering where barriers are identified and targeted for research, development, and solutions by enzyme design and metabolic modeling of the specific barriers identified.
- The in-house expertise has, in fact, increased and become significantly better at both the theoretical modeling and the application of the modeling and simulation, and prediction to real systems with the aim of not just reproducing observed behaviors reliably, but also reliably predicting modifications to

improve cost and production performance. We have identified several upgrading pathways and enzyme bottlenecks, which we will be modeling strategically with the aim of reaching BETO targets more quickly and with a rational design approach.

- Until now, mechanistic process modeling development has been focused on capturing relevant phenomena and validating models against experimental data. Our models are now nearing sufficient maturity to make systematic predictions of some conversion processes. We hope to first use the models to gain mechanistic insights and predict qualitative trends, hence informing high-level decision making and pointing the way for the most impactful laboratory experiments. Model simulations capable of quantitative process optimization are currently underway and will be providing valuable insight into pretreatment and upgrading industrial processes, especially the process of aerobic fermentation.
- In all research efforts in this project, the results are published such that both the findings and the methods will be available to researchers outside NREL. Most of the software is available and much of what is developed inside this project is added to and included in widely and publicly distributed software packages such as molecular dynamics programs. We will add to our publications more example input data and may set up a publicly available web site to make models, examples, and tutorials available. Where new software is generated, we will explore avenues for making it available in FY16, adhering to NREL/DOE policies for releasing software technology.

ANALYTICAL DEVELOPMENT AND SUPPORT

(WBS#: 2.5.1.101)

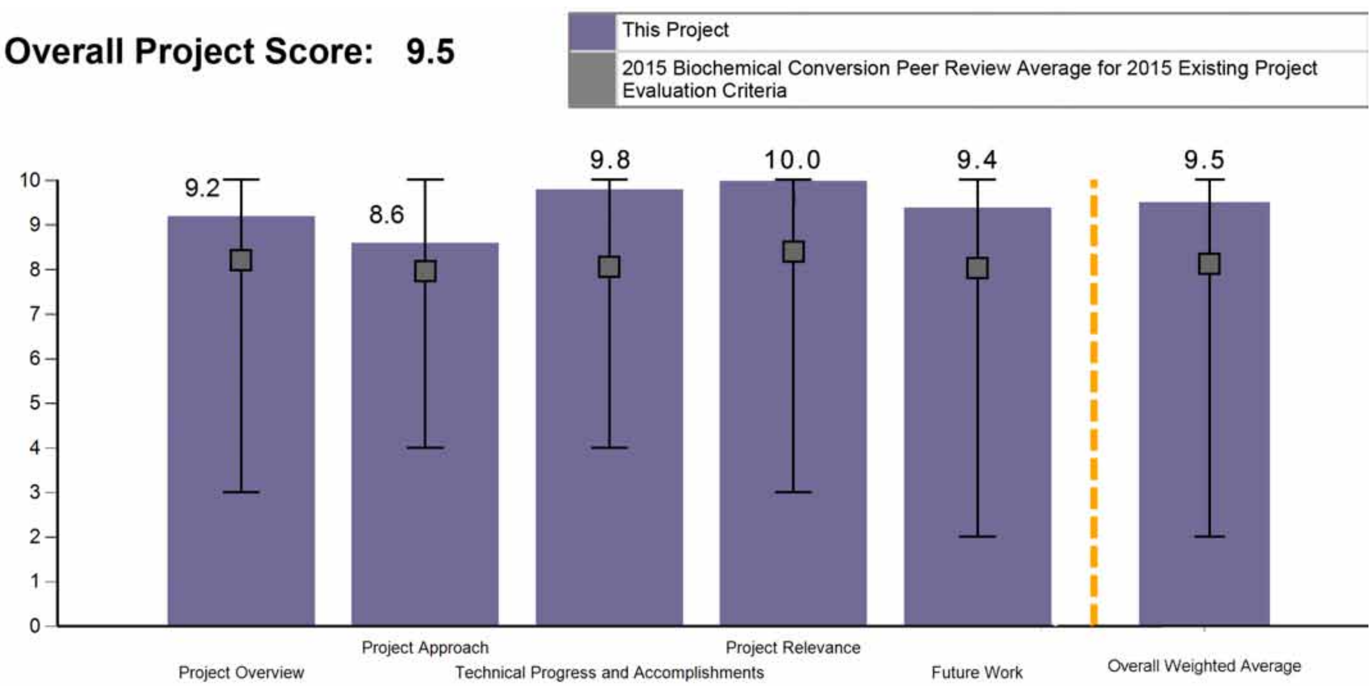
Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Ed Wolfrum
DOE Funding FY14:	$1,202,558
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,170,125
Project Dates:	10/1/2014 - 9/30/2017

Project Description

The objectives of this project are twofold: to develop and implement new analytical techniques in collaboration with other researchers at NREL; and to maintain the analytical chemistry resources currently in place at NREL. The project will address these objectives by separating the project into two complementary tasks.

In Task 1, the project team will identify critical analytical needs for the compositional analysis of biomass feedstocks and conversion process intermediates within the biochemical platform and to develop conventional and high throughput methods to meet these needs. In Task 2, the team will provide "day-to-day" support for analytical chemistry within the biochemical conversion platform. Specifically, this task coordinates analytical requests from experimental projects on the platform; provides routine repair, maintenance, and QA/QC oversight of analytical instrumentation [e.g., high performance liquid chromatography (LC), gas chromatography (GC), mass spectrometry (MS), and hybrid LC/MS and GC/MS systems]; manages and partially funds



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

service subcontracts for shared equipment within the platform; and supports a Scientific Data Management System (SDMS) to collect and archive analytical data from across the platform. Finally, the project team maintains and improves existing NIR calibration equations, keeps the NREL biomass analysis website (and associated Laboratory Analytical Procedures) current, and responds to specific analytical questions from internal and external stakeholders.

Overall Impressions:

- This is absolutely the most important support project and the system will come to a halt without this being done correctly. This activity has stepped up over the years to enable all of the NREL success and also made pioneering inroads into the fundamental analysis and support to the industry.
- The importance of the analytical methods and procedures and the ability to deliver quality data in a timely manner are significant.
- This is a great project that has focused its effort on allowing other projects to progress and/or be completed successfully. It sounds like the method development effort is proactive and stays ahead of industry, which is is great news. Integration with paying customers has allowed the project to progress with nominal funding that should continue in order to support this terrific resource.
- This is a key activity that seems to run well, responding to the needs of customers, and providing critical data and methods to the community.
- This is one of the most important activities in the program. Consistent and reliable data is of utmost importance.

PI Response to Reviewer Comments

- We thank the reviewers for their kind comments. We agree that it is very important to ensure the highest quality data is generated from the research being performed at NREL. We believe our success in this area can be attributed in no small part to our continued close collaboration with our colleagues, who are essentially our most important clients; nobody conducts analytical chemistry as an end in itself. By recognizing and responding to their needs, we believe we remain as a valuable and relevant resource to the platform and to the wider bioenergy community.

ADVANCED SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) FOR BIOCHEMICAL PROCESS INTEGRATION (WITH BEND)

(WBS#: 2.5.1.102)

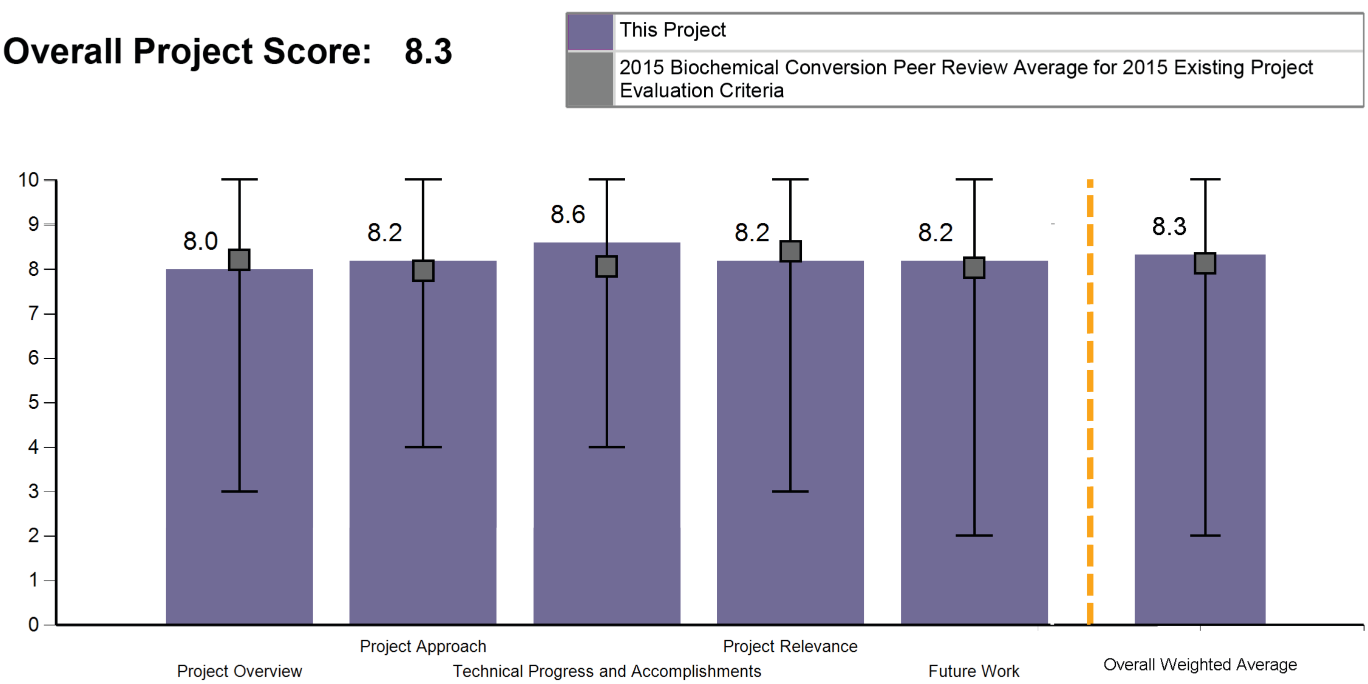
Recipient:	PNNL
Presenter:	Jim Collett
DOE Funding FY14:	$194,079
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,005,921
Project Dates:	10/1/2014 - 9/30/2017

Photo Courtesy of PNNL

Project Description

Commercial viability of advanced biofuel biorefineries will depend on their ability to process lignocellulosic feedstocks that may vary significantly with seasonal conditions and by regional source. Moreover, maximizing the incorporation of lignin solids into the final fuel has been identified by BETO as a critical factor for cutting production costs of advanced hydrocarbon biofuels to $3.00/gge. Attaining complete bioconversion of high-solids feedstocks into value-added fuels or products was specifically endorsed by industry representatives at the 2014 BETO Process Integration and Carbon Efficiency Workshop. As such, the project team is developing Process Analytical Technologies (PAT) to optimize bioconversion of biomass feedstocks with variable compositions and high levels of suspended lignin. The objectives of this project are to: (1) enable real-time tracking of critical process parameters in bioconversions of variable, high-solids feedstocks within bioreactors via the novel application of dielectric spectroscopy (DS) and near infrared spectroscopy (NIRS) tools that comply with industrial process analytical technology (PAT) standards; (2) reduce bioconversion scale-up risks by using PAT to optimize

Overall Project Score: 8.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

bioreactor process control systems in the laboratory under actual industrial conditions; and (3) ensure that these same PAT tools and control systems will scale up and directly integrate into the Supervisory Control and Data Acquisition (SCADA) networks of commercial biorefineries.

Overall Impressions

- The project is a good idea and it has a reasonable set of instrumentation to start with. There has been good cooperation from the firms that make sensors. The project team is cautioned to make sure that the benefits for better control are cost effective. In other words, do the fermentations benefit from closer control?
- Online analyses of high solids streams would be a big step in operations in the future and impact profitability. Real-time feedback on what is happening in the reactor should allow for a much more efficient operation. I would like to see a TEA on having this kind of SCADA installed on a plant.
- This is an excellent project that is thinking ahead of much of the industry. How we control our processes will have a major impact on how efficient they are, yet it seems it's not a topic considered very often. The PI has clearly considered a large majority of the available projects and is focusing on technologies that will be required for successful completion of these projects.
- New instrumentation and control strategies will be necessary for commercializing biomass conversion processes. This project has identified several commercial-ready solutions that can be adapted for these processes. Publication of the resulting work will facilitate the work of others in this space.
- Online process controls are extremely important for efficient large-scale processes.

PI Response to Reviewer Comments

- We appreciate the useful feedback provided by the peer review panel on the goals and objectives of the advanced SCADA project, and on the progress that we have made thus far. We agree that it will be important to demonstrate that tracking an expanded set of bioconversion critical process parameters via near infrared and dielectric spectroscopy will indeed enable superior biorefinery process control, and will reduce the need for expensive offline sample analysis procedures.
- Our integration of the latest commercial-off-the-shelf PAT into our laboratory-scale 30-liter bioreactors will help us to develop control strategies that scale up to enable real-time process adaptation to feedstock variation at the biorefinery level. This may enable predictions of the range of adjustments in unit operations that a biorefinery might be reasonably expected to accommodate in response to feedstock variation, and to what degree the ability to adapt to certain kinds of variation (such as inhibitor variation in lignocellulosic hydrolysates) must be engineered into specific strains of industrial microbes. Moreover, our use of the same PAT equipment that would be found in a biorefinery will facilitate the "scale-down" of problems that have been identified during biorefinery operations, and to simulate them at the laboratory scale. Where possible, we will integrate our findings into TEA cost and performance models to predict the costs of deploying advanced PAT at the plant scale.
- Outside of big pharmaceutical companies, there are few other laboratories with sterilizable-in-place bioreactors such as ours that are equipped with the collection of advanced, industrial-grade PAT tools that we have assembled with the support of BETO and our industry partners. Our goal is to use this valuable, public resource at the laboratory scale to identify and overcome bioconversion challenges, and to publicize our progress in academic and trade journals, in meeting presentations, and at workshops that we can hold for industry stakeholders.

ADVANCED BIOFUELS FROM CELLULOSE VIA GENETIC ENGINEERING OF CLOSTRIDIUM THERMOCELLUM

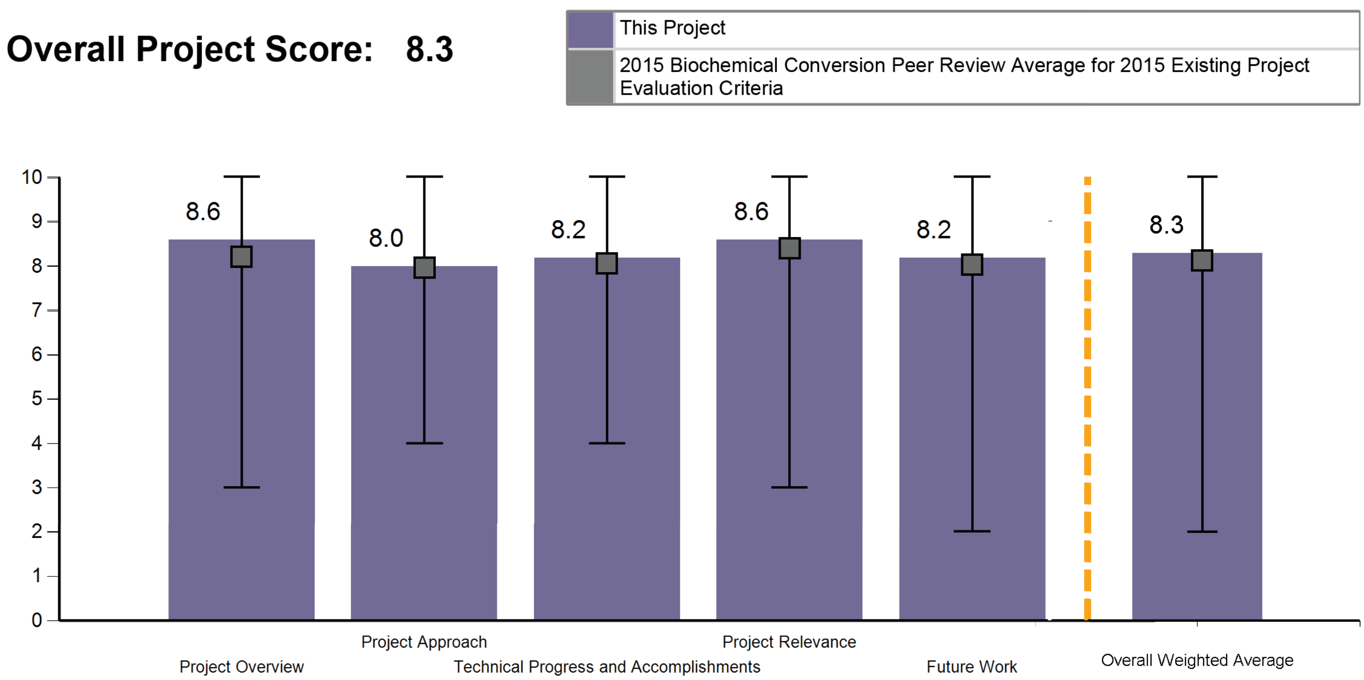
(WBS#: 2.5.3.100)

Recipient:	NREL
Presenter:	Pin-Ching Maness
DOE Funding FY14:	$163,530
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$246,470
Project Dates:	10/1/2013 - 10/1/2014

Photo Courtesy of NREL

Project Description

The objective of this seed project is to develop a sustainable pathway to produce isoprene (C_5H_8; 2-methyl-1,3-butadiene), a chemical and biofuels precursor, using renewable biomass feedstock. Isoprene can be catalytically upgraded to branched alkanes with fuel properties ranging from jet fuels, to gasoline, to diesels. The project aims to convert cellulose to isoprene through genetic engineering in the cellulose-degrading bacterium Clostridium thermocellum to express the isoprene synthase (IspS) enzyme from plants. This approach is feasible with the proprietary genetic tools developed in-house. Due to the thermophilic nature of C. thermocellum, one concern is whether IspS is thermal tolerant. The project team expressed in E. coli two plant IspS: kudzu (Pueraria montana) and hybrid aspen (Populus canescens). In vitro assay, also verified that both IspS are thermal tolerant at up to 55 °C, an ideal growth temperature of C. thermocellum. Both IspS were successfully expressed in C. thermocellum, with an isoprene titer near 20 µg/g cell dry wt. detected (FY14 BETO go/no-go decision). Future



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

research will focus on optimizing the key steps in the isoprene pathway to further boost its titer. This seed project has provided the proof-of-concept for isoprene production. Upon further optimization of its titer, rate, and yield, it has immense potential to generate infrastructure-compatible, energy-dense, hydrocarbon-based biofuels to reach the cost target of $3.00/gge by 2022, a performance goal of BETO.

Overall Impressions

- This is a nice project. I am not sure why the consolidated bioprocessing (CBP) path route was undertaken. Wouldn't it be wiser to get the isoprene production set first, and then go after the CBP?
- ISPS sequence for 18 species is great progress. The project identified amino acids for thermochemical tolerance and built a mutant library.
- This is an interesting project; one of the few to produce a gaseous product. However, there are questions as to whether this is the correct organism to use, and whether the ethanol production pathway interferes. Knocking this out could be problematic for energy production. Based on the work done to date, these questions should be answered by the project prior to close-out and it should be interesting to see the results.
- This is an efficient, well-structured project delivering results. There is some uncertainty on feasibility of final results, but the project team seems to understand the risks and identified actions to address them.
- This is a very interesting and relevant project. Isoprene can be used as a fuel precursor or in synthetic rubber. There will be a number of technical challenges that the project needs to overcome; however, the PI presented approaches to address them.

PI Response to Reviewer Comments

- We thank the reviewers for their complimentary and insightful assessment of this seed project. We appreciate the acknowledgements from the reviewers that excellent technical progress has been made to date, that a consolidated bioprocessor approach can streamline biomass conversion process and diversify the BETO portfolio with high relevance, and that the production of non-toxic gaseous product helps its recovery. Below are our responses to the Overall Impressions stated above.
- The reviewers asked if C. thermocellum is the correct organism to use, as it needs to make ethanol to survive, hence reducing the cellular flux toward isoprene production. Wild type C. thermocellum indeed produced ethanol as a major metabolic byproduct. Yet, based on a recent publication by Lee Lynd's group (J. Bacteriol, 2015, 197: 1386-1393), the ethanol-encoding gene was deleted successfully and ethanol was not produced in the mutant. The mutant displayed no growth defect and instead produced more lactate and hydrogen as the new metabolic sinks. This result demonstrates the metabolic flexibility of C. thermocellum that, in the absence of an ethanol sink, cells re-route metabolic flux to new sinks to maintain redox balance. It also implies strongly that isoprene production could potentially serve as the new sink in lieu of ethanol production when the latter pathway was deleted from the genome.
- The reviewers also asked if it would be wiser to get the isoprene production set first and then go after the consolidated bioprocessing. Our rationale is that the PI's team has already developed the proprietary genetic tools to manipulate the glycolytic pathways of C. thermocellum, a CBP microbe. Therefore, it would streamline the work load to engineer a foreign isoprene pathway in this microbe directly (we did this already), followed by manipulating its metabolic flux toward boosting isoprene productivity (ongoing work). Genome engineering conducted in one microbe is not always portable in another microbe as each displays its own metabolic plasticity. C. thermocellum is already a specialist in cellulose hydrolysis and this research will not modify its CBP property. Engineering this CBP model microbe directly will expedite progress as advancements made are more relevant, impactful, and could apply directly to isoprene production from cellulose for scale-up applications in the long run.

MAXIMIZING MULTI-ENZYME SYNERGY IN BIOMASS DEGRADATION IN YEAST

(WBS#: 2.5.3.200)

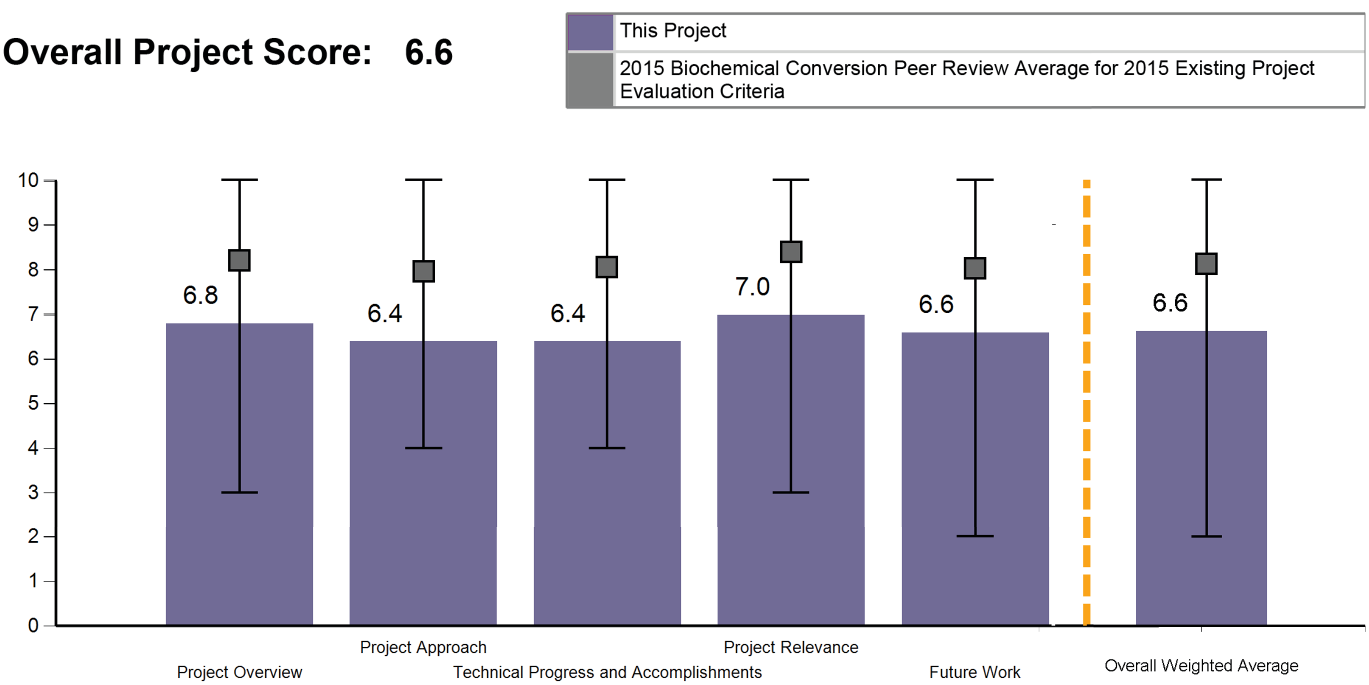
Photo Courtesy of J. Craig Venter Institute

Recipient:	J. Craig Venter Institute
Presenter:	Yo Suzuki
DOE Funding FY14:	$402,986
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$830,292
Project Dates:	10/1/2013 - 9/30/2015

Project Description

Although biomass-active enzymes are known to act synergistically in nature, the interactions among these enzymes have yet to be fully explored for creating organisms suitable for industrial saccharification of lignocellulosic materials. We are using a synthetic biology approach to generate Saccharomyces cerevisiae strains carrying a synergistic set of enzymes toward cost-effective conversion of biomass to sugars. In this approach, the project will first generate yeast strains, each containing multiple exogenous cellulase genes separately integrated into different loci. Next, gene assortment will be used via repeated rounds of mating and meiosis to generate numerous strains expressing various combinations of enzymes. These strains will then be screened using a viability-based assay to identify enzyme

Overall Project Score: 6.6



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

combinations that are effective in degrading lignocellulosic materials. The improvements of strains will be evaluated with respect to the amount of externally added cellulase cocktail needed to reach a benchmark saccharification level set by a control strain. Therefore, this study is relevant to cost reduction via reducing enzyme loads. The project team has established a mini-scaffoldin system for displaying enzymes on the yeast cell surface; synthesized codon-optimized genes for 98 enzymes from a variety of organism; introduced most of them as expression constructs into yeast; and so far confirmed activity for 28 enzymes. The team has started generating and evaluating multi-enzyme strains.

Overall Impressions

- This is an interesting project. I think the project needs to look at how the most cost effective enzymes on the yeast surface are working in concert with the added enzymes. Perhaps cheaper enzymes can be added and used as the complementary cocktail to save money overall. These attached enzymes will never do the whole saccharification and are only meant as a supplement.
- Overall, this project looks like excellent molecular biology at the cost of commercialization potential. There has not been sufficient discussion of the potential to overexpress enzymes. Indeed, at one point, there is discussion of recycling the organism with enzymes attached to the cells, which would lead one to conclude overexpression is a definite possibility without a means to shift metabolism to the target molecule. The long fermentation times and relatively low titer seem to support this.
- The synthetic biology approach utilized to produce cell-associated combinations of cellulases on yeast is quite novel and has established technical feasibility. From historical work on cellulases, it is not clear that there are great performance gains to be had by introducing new combinations of these enzymes. I am not convinced this is the best application of this exciting synthetic biology technology and I recommend the project team connect more thoroughly with industry and subject matter experts on cellulase development.
- This project involves designer cellulosome on the surface of yeast expressing both bacterial and fungal genes. Other companies have spent substantial amounts of time expressing various cellulases in yeast and are in the process of commercializing those strains. Functional expression of the fungal cellobiohydrolases on a cellulosome matrix will be very challenging.

PI Response to Reviewer Comments

- The method based on randomization and screening for identification of synergistic combinations of enzymes is the focus of our project. To demonstrate the utility of this method, we have to express enzymes like others do and validate the strains we will generate. However, it is not in our interest to drive the innovation in the latter space. Our central motivation is to have our unique and powerful method for discovering enzyme synergies integrated with existing programs. We have already succeeded in expressing and secreting over 40 enzymes as free and active enzymes in yeast. Some of these enzymes may not be incorporated into cellulosomes, but we believe that our screen will effectively identify strains with compatible enzymes – even if some of them are not complexed – for the generation of highly active strains.
- One reviewer is concerned about the low ethanol titer and the long fermentation time shown in a graph we presented. This result was normal for the low load of enzyme cocktail used in the particular experiment. This result itself does not suggest any limitation in the capacity for enzyme expression. We take the approach of maximizing enzyme synergy, as opposed to quantity. Therefore, we are well-positioned to get the most out of yeast.
- Our method facilitates the identification of synergistic sets of enzymes for saccharification. The downstream applications can be generation of yeast strains or inclusion of the identified enzymes into a cellulase cocktail. The latter approach is unaffected by potential problems in yeast as an organism for consolidated bioprocessing. We believe our technology to be a versatile discovery tool that has high potential for commercialization.

- We had a very constructive discussion with the reviewers on the synergy between enzymes on the yeast surface and enzymes within the commercial cocktail. We will promote this idea further and pursue collaborations with enzyme suppliers to discern which classes of enzymes would be more cost effective when expressed in yeast, as opposed to added to an enzyme cocktail.
- We appreciate the advice of one reviewer on applying our technology to other challenges in the field. Synergistic interactions in genetics are by definition surprising effects, or effects that are unexpected given the effects of single mutations, or cellulase constructs in our case. Because each synergistic interaction has the potential to make saccharification drastically more efficient, it is challenging for us to give up our current purpose. At the same time, we would like to leverage the successful demonstration from our current effort to form additional collaborations with experts to expand into a number of metabolic engineering projects.

SYNTEC: SYNTHETIC BIOLOGY FOR TAILORED ENZYME COCKTAILS

(WBS#: 2.5.3.201)

Recipient:	Novozymes, Inc.
Presenter:	Sarah Teter
DOE Funding FY14:	$665,230
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,834,770
Project Dates:	10/1/2013 - 9/30/2015

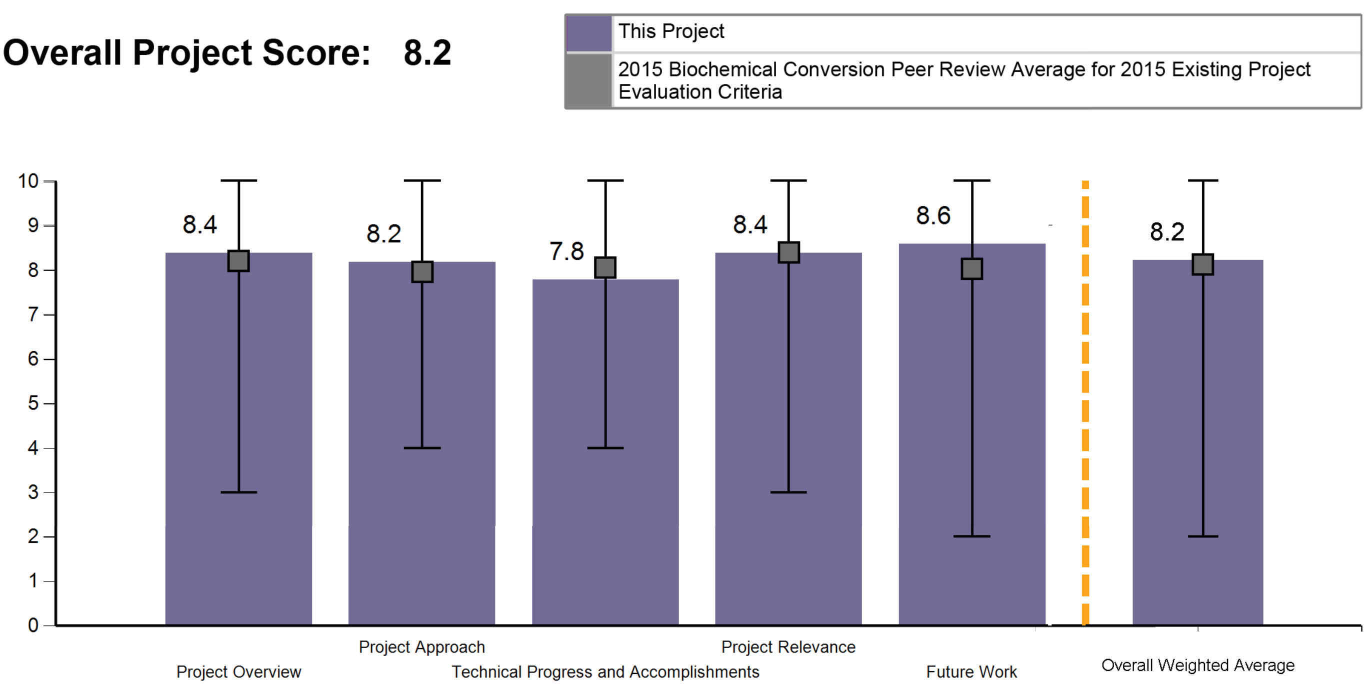
Project Description

Novozymes is interested in accelerating technologies that allow for rapid selection of enzymes for industrial application. SynTec delivers a screening platform for assessment of glycosyl hydrolase and auxiliary enzyme modules as potential parts for cellulose degrading cocktails. Because effective deconstruction of biomass requires synergistic action of numerous catalytic activities, the project team developed a combinatorial screening method that probes the combined hydrolytic potential of an array of candidate enzyme modules. Leveraging selected dockerin and cohesion sourced from cellulosomes allowed the project team to overcome a challenge of engineering a thermostable, self-assembling protein complex. By automating and streamlining protein isolation from expression broths, and normalizing enzyme dose, the project team overcame slow screening steps of purification and quantification. This allows faster learning cycles from gene selection to output of encoded hydrolytic potential. SynTec screening is being used to deliver a tailored enzyme cocktail for AFEX™-PCS (ammonia fiber expansion pretreated corn stover) without costly pH adjustment. Optimal performance of the benchmark cocktail Cellic® CTec3 requires acidification to pH 5. After nine months of screening, the project thus far has delivered greater than three-fold dose reduction relative to CTec3 in the absence of slurry acidification. The project further aims to deliver an enzyme composition which exceeds CTec3 performance at its optimal pH.

Overall Impressions

- Overall, this is a good project. It provides fast ways to investigate improvements focused on a specific pretreatment and the needs of that process for enzyme

Overall Project Score: 8.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

saccharification. The choice of AFEX, which must need more hemicellulase activity than other pretreatments, was an excellent subject on which to try these techniques.

- Three-fold reduction in enzyme loading is very significant. Nice research and the potential impact to industry is significant.
- The project has shown great advancement in both screening and dose reduction, with potential for continued improvement. The potential to target individual feedstocks and/or pretreatment processes can have a tremendous impact on industry.
- This project has developed and validated a novel approach to rapid screening and development of enzyme combinations, enabling rapid development of enzymes for different feedstocks, pretreatments or process conditions.
- Novozymes is developing optimized enzyme cocktails for various pretreatments and feedstocks. This is very valuable work since not all processes will require the same enzyme activities.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

DESIGN, CONSTRUCTION, AND IMPLEMENTATION OF NOVEL BIOFUEL PRODUCTION CAPABILITIES IN FILAMENTOUS FUNGI - SYNBIO

(WBS#: 2.5.3.202)

Recipient:	PNNL
Presenter:	Kenneth Bruno
DOE Funding FY14:	$1,452,661
DOE Funding FY13:	$360,366
DOE Funding FY10-12:	$0
Planned Funding:	$589,584
Project Dates:	10/1/2013 - 9/30/2017

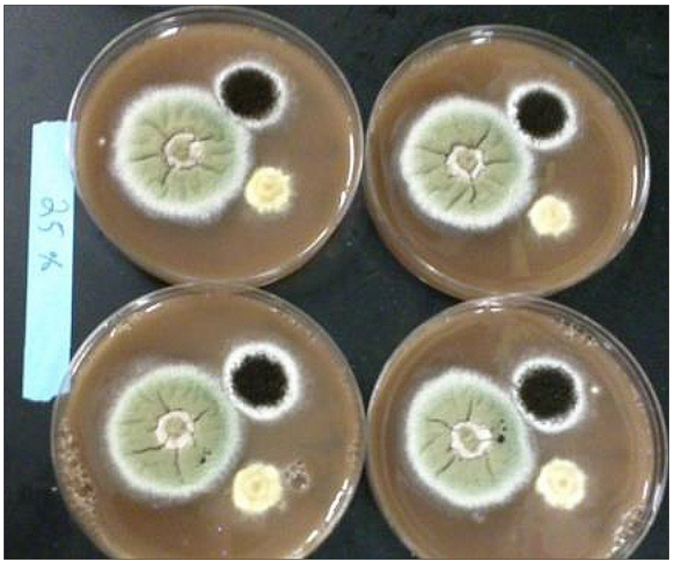
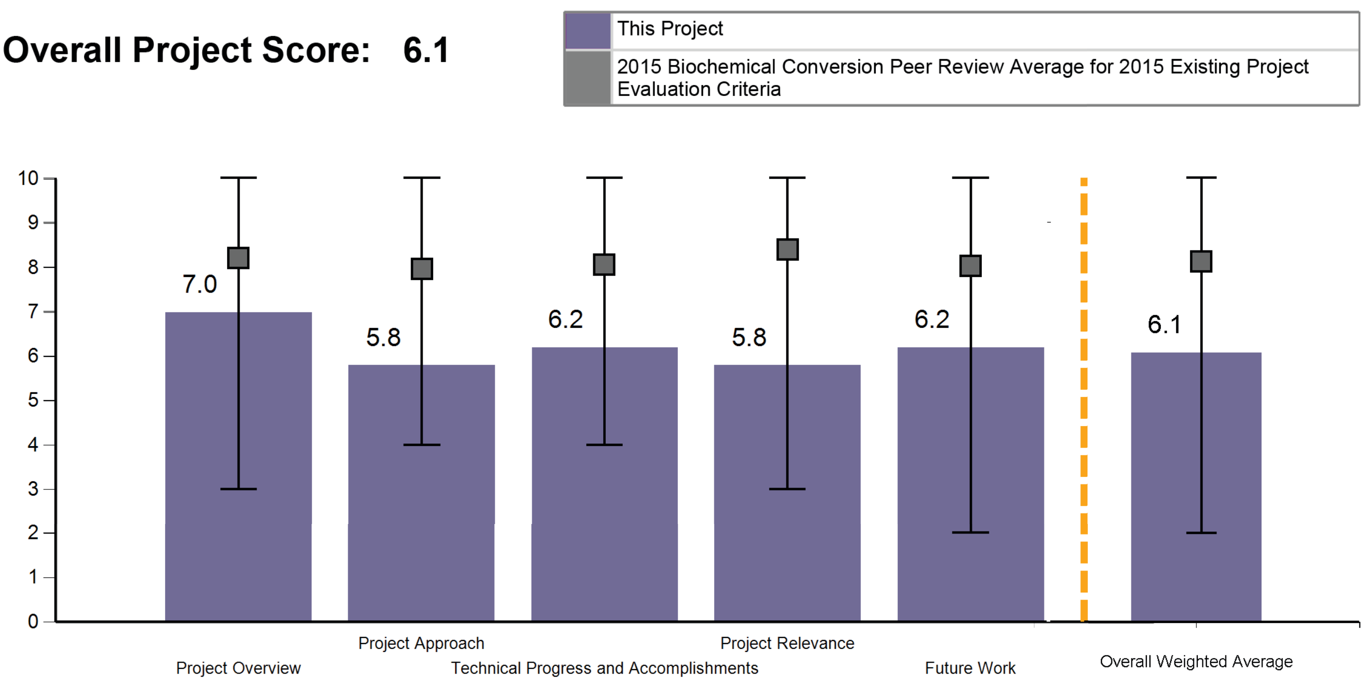


Photo Courtesy of PNNL

Project Description

Fungi are the primary source of enzymes used in conversion of plant material to sugars including starch hydrolysis for traditional ethanol production and, more recently, enzyme preparations that are used to obtain sugars from lignocellulosic biomass. Technological advances in molecular genetic manipulations of filamentous fungi have provided us with the tools to manipulate the genome of these organisms with remarkable facility. Scientists now have the ability to mathematically model, genetically manipulate, and globally characterize production compounds of interest in fungi. The next step in taking advantage of these important systems is to develop exchangeable functional modules that will allow for application of the principles of synthetic biology within filamentous fungi.

Overall Project Score: 6.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Members of the project team have identified a novel class of enzymes in fungi for the synthesis of hydrocarbon compounds. Project objectives include developing a strain that can produce the target compound on pretreated corn stover (PCS); utilizing 30-liter bioreactors to analyze production and provide the information to metabolic model; genetically manipulating an organism to improve production; achieving a target titer of 500 mg/liter on PCS within two years; and discovering additional novel compounds with desirable traits for downstream processing.

Overall Impressions

- No convincing arguments that working in fungi is superior for the commodity fuels and chemicals that BETO is interested in. There are many issues with utilizing fungi in production. Yes, citric acid is produced with fungi and penicillin, but I suspect that there are few other ways to make them. That is not true for the commodity fuels. It is hard to see what this project contributes.
- This work covers a novel pathway that is not being researched in the national laboratories. I would like to see more focus on specific products.
- This project seems to exist because of the presence of expertise and not because of an industrial/commercial need. Applying synthetic biology to filamentous fungi is novel, but one must ask why it is novel and not fill a niche for the sake of filling it. Low titers at the end of a two-year project, an organism that consumes the target compound, and long lag times prior to sugar utilization raise questions as to whether there could ever be commercial application, not just how far it is away.
- Some progress was made toward increasing titer. It is unclear how effectively economic constraints are used to guide and constrain R&D. Selection of a target molecule and MEK (a protein) inducer may not be economically viable.
- Although this work is scientifically interesting, it is hard to tell what the ultimate goal is. The researchers are focused on a molecule that has unknown (and undefined) opportunities. In addition, they observed that the organism produces a lot of another unidentified material that also has unknown properties and opportunities. There appear to be too many unknowns.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

DESIGN AND OPTIMIZATION OF BIOFUEL PRODUCTION WITH BIOSENSOR-GUIDED SYNTHETIC EVOLUTION

(WBS#: 2.5.3.203)

Recipient:	Lygos, Inc.
Presenter:	Eric Steen
DOE Funding FY14:	$516,552
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,188,810
Project Dates:	10/1/2013 - 9/30/2015

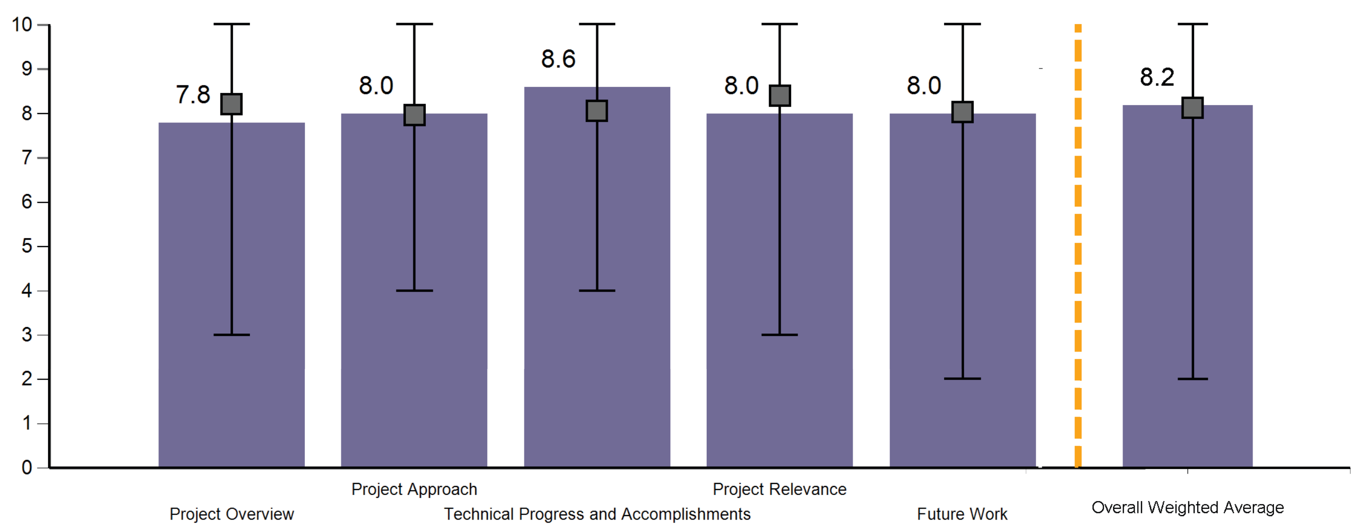
Photo Courtesy of Lygos, Inc.

Project Description

The project goal is to develop an integrated approach to biochemical pathway optimization for production of malonic acid and demonstrate a path toward commercially relevant fermentation metrics. The ability to engineer micro-organisms like yeast and E. coli for biofuel production relies upon knowledge of that individual organism's metabolic pathways. Our grasp of an organism's metabolic processes that are directly related to producing specific biofuels like ethanol, butanol, biodiesel, and other short-chain alcohols is limited to the enzymes directly responsible for converting sugar or cellulose into biofuel product in addition to a limited number of "indirect" pathways. This understanding is extremely limited and potentially represents only 10% of the total metabolic pathways that define how an organism survives. The data produced from this effort will refine an existing model of metabolism, therefore resulting in an increased understanding and ability to design. In order to better understand how to mitigate potentially harmful release into the environment, The project team also proposes to perform release simula-

Overall Project Score: 8.2

(purple)	This Project
(gray)	2015 Biochemical Conversion Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

tions in controlled, contained bio-reactors. The expected benefits of this work includes the ability to more thoughtfully engineer microbes to efficiently convert plant-derived material into biofuel product, resulting in decreased dependence on petroleum and a more sustainable source of energy. Secondary benefits include increased domestic jobs and demand for farming fallow lands.

Overall Impressions

- The project is a good example of product development and development of tools for other products. It fits well with DOE's desire for alternative products.
- Successful and cost-effective production of biocatalysts that produce chemicals, such as malonic acid as a platform molecule, are promising. The market is 60,000 tons per year.
- This is an interesting project that seems to be focused on novelty in multiple aspects (e.g., pursuing a target molecule that no other known molecule has produced, running a high-throughput screening tool). Integration with a TEA to drive the research is appreciated, and has provided interesting results to date. The project is a good use of resources, and although it would be good to see the screening tool commercialized, the failure to do so because of resource allocation indicates a high level of dedication to the project.
- The prject takes an innovative approach to strain engineering and significant progress towards developing a robust biochemical production organism.
- Lygos has spent significant time selecting a high value molecule to develop a bioconversion process around. It has also developed a unique screening system that can be used to evaluate variants. This is an excellent program that will help BETO achieve its short- and long-range goals.

PI Response to Reviewer Comments

- Lygos thanks the reviewers, DOE, and the NREL validation team for their participation in the public review and continued feedback and guidance during the project. The Lygos team is confident that the work we are continuing to perform with the support of this DOE grant will lead to the development of a commercially viable bio-malonic acid production process and facility, while laying a foundation for rapidly designing, constructing, testing, and optimizing biocatalysts. We are grateful to receive positive feedback from reviewers that further supports this view.

SYNTHETIC DESIGN OF MICROORGANISMS FOR LIGNIN FUEL

(WBS#: 2.5.3.205)

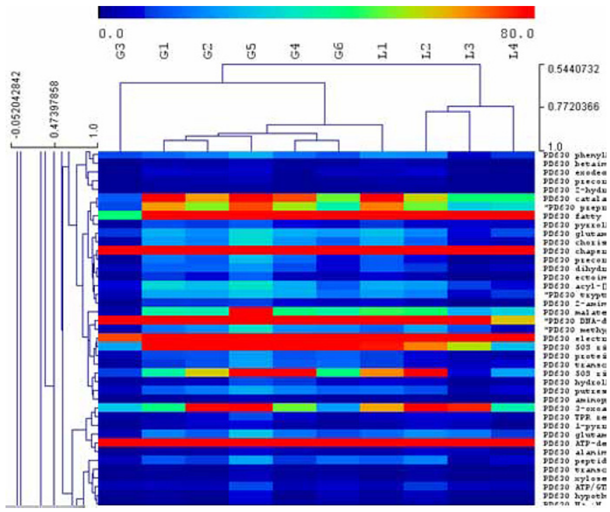


Image Courtesy of Texas Agri-Life Research

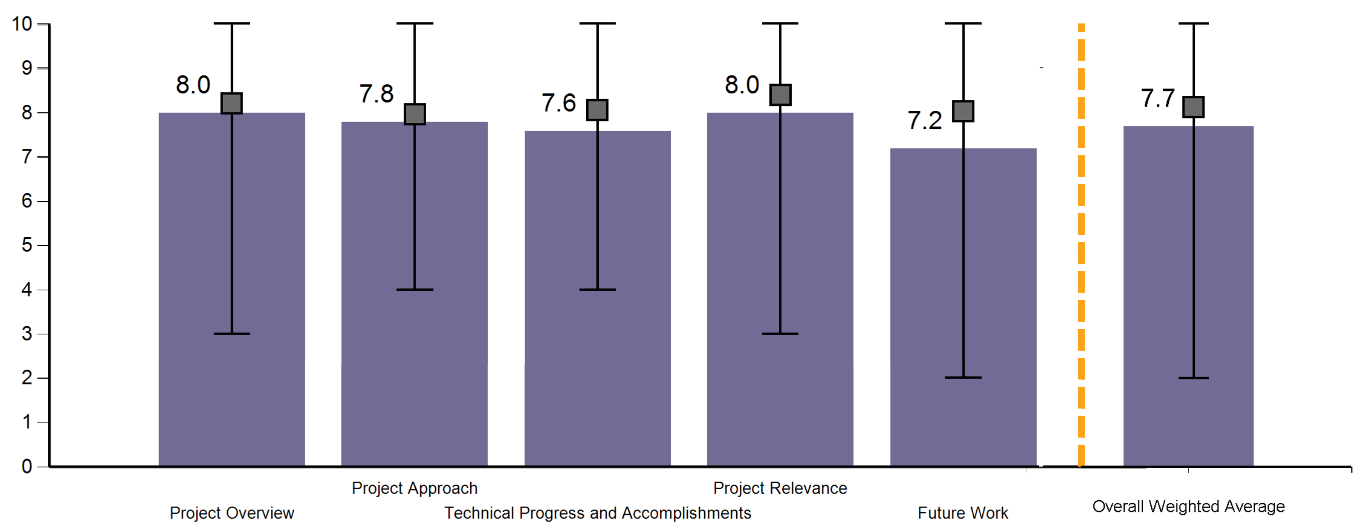
Recipient:	Texas Agri-Life Research
Presenter:	Joshua Yuan
DOE Funding FY14:	$676,582
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,723,692
Project Dates:	10/1/2013 - 9/30/2015

Project Description

This project employs a synthetic biology approach to address one of the most challenging issues in lignocellulosic biofuel production: the use of lignin for fungible fuels. Despite significant advances in processing carbohydrate in lignocellulosics, the utilization of lignin for fungible fuels or chemicals has yet to be achieved. At best, lignin is utilized as a low-value thermal resource for powering the associated manufacturing processes. However, modern biorefineries for cellulosic ethanol have ~60% of excess lignin. Thermal conversion has been investigated to transform the waste lignin stream into fuels, yet the technology is still complicated by heterogenous oxygenation compounds and the need for fuel upgrading. This project brings together a team representing the state-of-the-art to develop a novel platform for biological conversion of lignin into lipid for biodiesel production. The project objectives include: (1) synthetic design of secretion systems and functional modules in RHA1 to enable effective lignin depolymerization; (2) modification and

Overall Project Score: 7.7

This Project	
2015 Biochemical Conversion Peer Review Average for 2015 Existing Project Evaluation Criteria	



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

integration of functional modules to improve carbon flux from aromatic compound catabolism to lipid production; (3) design of genetic circuits to balance lignin depolymerization and derivative conversion for higher conversion efficiency; and (4) optimizing the fermentation of lignin to lipids using synthetic and wild type strains.

Overall Impressions

- This is a good project with a good approach and results for lignin degradation. The project has collaboration with ADM, which provided the biorefinery slurry, so lignin is industrially relevant.
- Lignin to fuels/chemicals is highly relevant to the industry.
- This project seems at first to have poor results, but when one realizes the work that has been done with kraft lignin, things look a lot better. The use of externally added laccases is not new (e.g., pulp and paper industry of mid-90s), but it is good to see potential integration of laccase production with lipid-producing organisms.
- The project has made great progress on a number of fronts, from lignin depolymerization to strain engineering. However, the scope of activities and possibilities remains very broad. I recommend the project look to down select the options and focus work on the most technically and economically feasible approaches.
- A consolidated lignin process of using a single organism to depolymerize lignin and convert lignin-derived monomers into a valuable product (in this case lipid) is extremely challenging, yet, if successful, the payback is big.

PI Response to Reviewer Comments

- We appreciate the comments regarding “great” progresses and relevance. We agree with the first reviewer that the consolidated lignin processing (CLP) is a challenging task. For this reason, we also proposed to combine lignin fragmentation with bioconversion in the process optimization. This serves as an alternative approach for CLP to mitigate the risk. In addition, we agree with the reviewer that the scope of activities may be down-selected. We have requested a one year no-cost extension so that we could achieve the aggressive target of 5 to 10 g/L lipid titer. At this stage, we are investigating different options to increase lignin processibility, engineer microorganisms, and optimize the bioprocess. We have already began to focus on certain promising perspectives and will further down-select the options based on the outcome for lignin and process characterization. Dr. Ragauskas’ group at the University of Tennessee is now carrying out extensive lignin and process characterization for the team, which will provide the guideline to further down select the directions.

ENZYME ENGINEERING AND OPTIMIZATION

(WBS#: 2.5.4.100)

Recipient:	NREL
Presenter:	Michael Himmel
DOE Funding FY14:	$1,752,851
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$5,703,554
Project Dates:	10/1/2014 - 9/30/2017

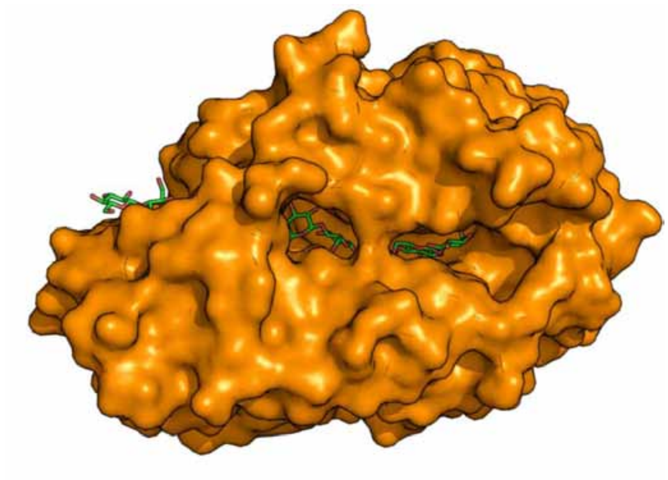
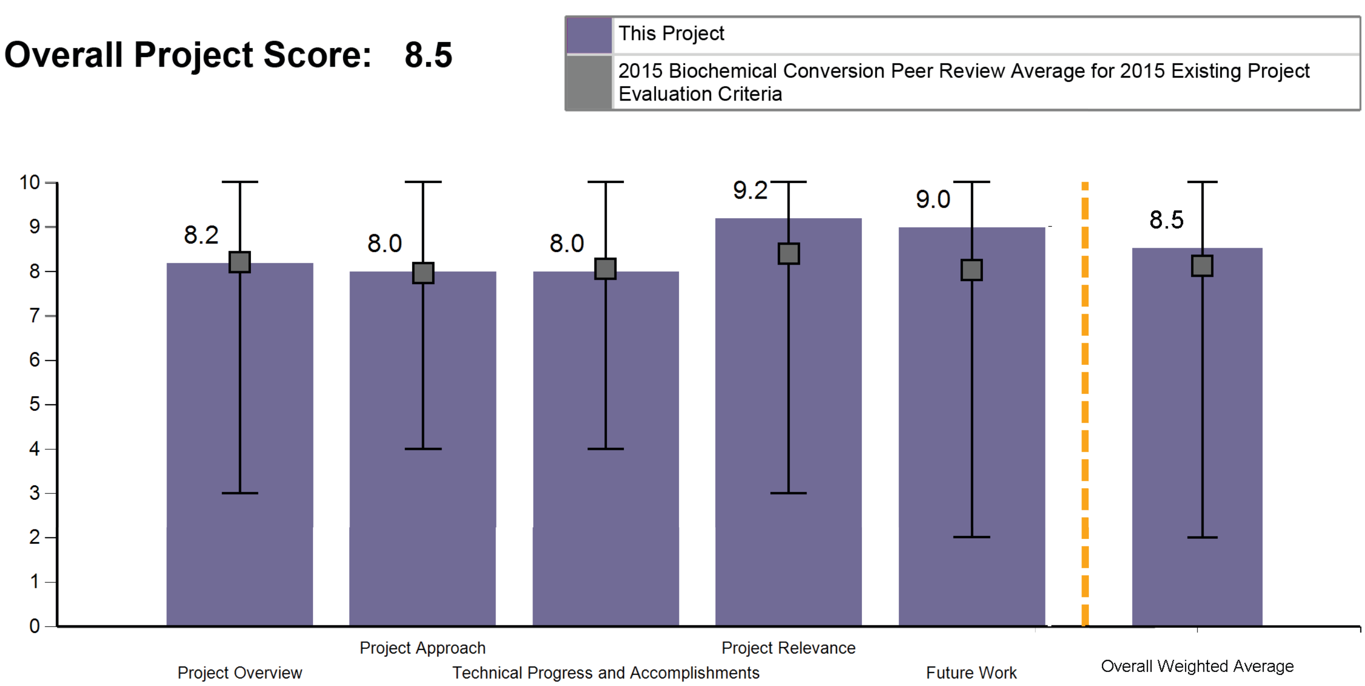


Image Courtesy of NREL

Project Description

The goal of this project is to ensure that cellulase enzyme loadings can be reduced to BETO's 2017 target of 10 mg/g cellulose using modern enzyme engineering and cocktail formulation optimization strategies. Given that cost-effective biomass conversion to sugars is a common theme for many conversion processes, the overall bioenergy industry also benefits from this work. The project team is using a knowledge-based approach, which links protein structure to performance. The team has pioneered the close coordination of computational analysis and experimental validation for cellulase improvement and have achieved positive results (1.25 to 1.6 fold improvement in Cel7A performance). The team has successfully demonstrated the ability to model cellulase action, designed structural features likely to impact performance, built targeted mutations, and showed improved performance on pretreated biomass. The team has also demonstrated the utility of the high temperature hold biomass conversion scheme using cocktails of caldiphilic bacterial cellulases. The early stages of selection of glycosylation



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

and P. funiculosum subdomain mutations in T. reesei Cel7A, suggested for future work in FY13, are being accomplished in FY15, with successful outcomes. Active site mutations and mutations suggested by newly initiated HTP yeast screening will be accomplished in FY15-16. Work to express newly discovered, highly active bacterial cellulases in T. reesei will be accomplished in FY15-17.

Overall Impressions

- This is as reasonable an approach as possible when trying to stay current with industry and be relevant. The challenge is keeping relevant with a commercial industry. However, NREL, with all of its expertise, experience and closeness to the materials has made a big contribution in this field over the years. Keep up the good work.
- Lower enzyme loading and cost is an important goal. Huge effect on profitability in biochemical conversion facility.
- This project could benefit greatly from a discussion of the work completed over the last 15 years and how it relates to progress as measured by a TEA.
- This project continues to develop strategic insights and developments to improve the performance and cost of cellulases. The project is well connected with other BETO projects and applying innovative strategies. While the project clearly uses techno-economic analysis, the focus is very heavy on improving the biochemical activity of the enzymes. I would recommend that the project put more focus on evaluating and improving the production economics of the new enzymes.
- This is an extremely successful program with a lot of promise to improve cellulase enzyme performance and thereby decrease enzyme cost to the overall process. At some point, there should be some emphasis on reactor and process design to reduce enzyme loading and improve system performance.

PI Response to Reviewer Comments

- Thank you for your comments. We have intentionally stayed away from commercial sector endeavors, such as large-scale enzyme production technologies and economics. Rather, we enable industry by tackling the difficult task of improving the key enzyme components in cellulase cocktails using rational design.

LOW-ENERGY MAGNETIC FIELD SEPARATION USING MAGNETIC NANOSTRUCTURED ABSORBENTS

(WBS#: 2.5.5.100)

Recipient:	ANL
Presenter:	Phil Laible
DOE Funding FY14:	$253,389
DOE Funding FY13:	$182,995
DOE Funding FY10-12:	$146,870
Planned Funding:	$966,746
Project Dates:	10/1/2011 - 9/30/2017

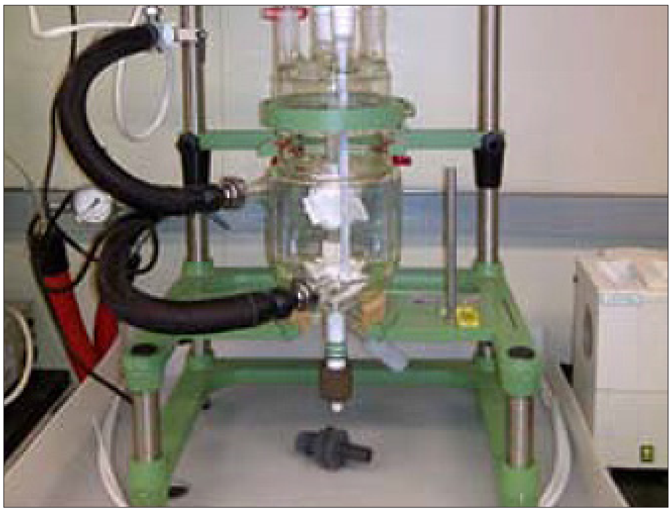
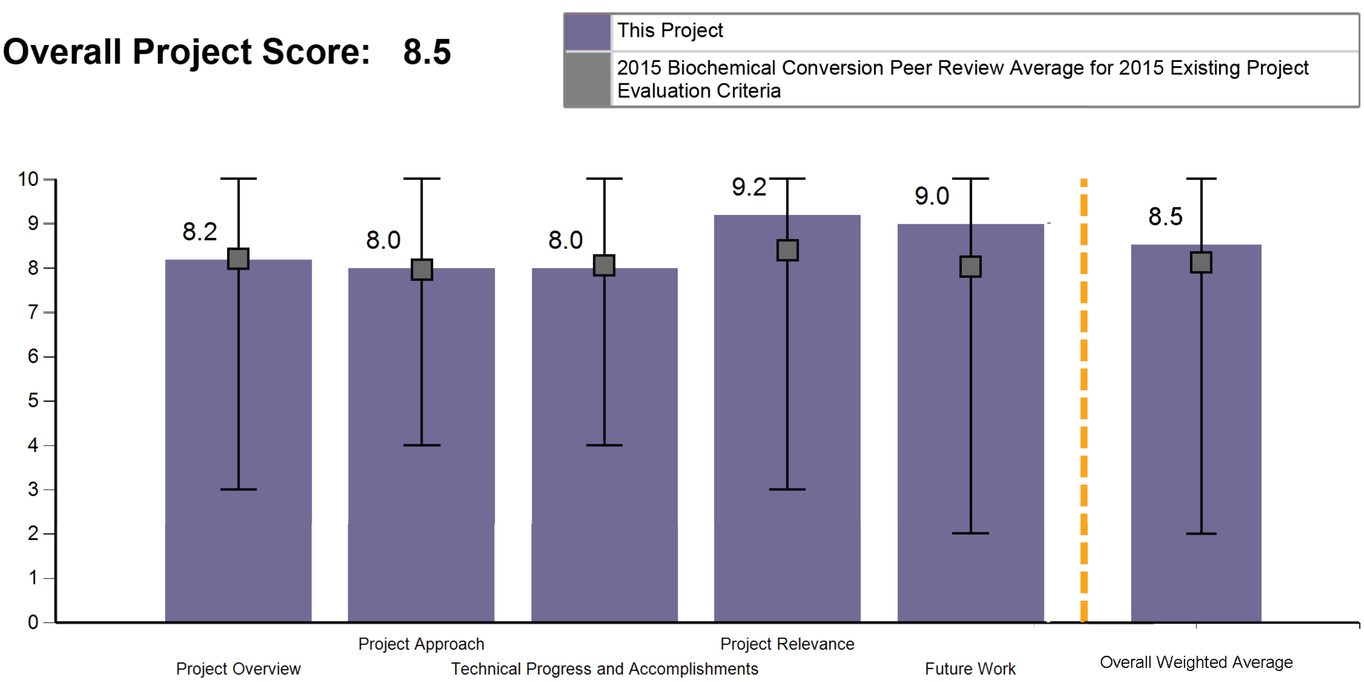


Photo Courtesy of ANL

Project Description

Energy-efficient, magnetic-field technology is being explored to improve process economics for separations of next-generation fuels from fermentation broths. Nanostructured adsorbents (NA) are produced utilizing heterogeneous vapor-phase polymerization and successfully adsorb target hydrocarbons. Tailored NA surface treatments enable adsorption of a range of long-chain isoprenols with high affinity and efficiency. The capacity of the NA for hydrocarbon far exceeds their weight. Hybrid magnetic and low-pressure, mechanical compression routinely releases 80% of the hydrocarbons adsorbed during a cycle. At the laboratory scale, NA have proven stable and reusable for tens of cycles. Little, if any, NA is lost during each cycle. Current efforts focus on synthesis and desorption processes that scale appropriately, allowing for further improvement of extraction/desorption efficiencies and success of recycling. Future NA technological advancements will focus upon improving adsorption

Overall Project Score: 8.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

specificity. As compared to current, commonly practiced solvent extraction and distillation methods, the costs associated with this novel approach can be much lower, especially as multi-cycle operations are extended as the technology matures. Applications for this process-intensified approach are greatest for fermentation practices where products are exported into the culture medium and product inhibition is exhibited at low titer.

Overall Impressions

- This is a good project and it offers an economical alternative to some complex recovery schemes for products from fermentations.
- The advancement of nano particle technology and reduction in overall production costs really lends itself to the industry. This is truly an innovative technology.
- This is a fascinating project that is very novel. Separations efficiencies of 80-85% are potentially within commercialization range (separation of product from nanomaterial). As odd as the technology sounds, it has great potential. Some questions that should be addressed include adsorption efficiency at low titers, inhibition concerns, and the impact that losses due to attrition may have on any particular process that uses the technology. It would be good to see collaboration with some of the near-commercial projects within the portfolio, both for real-world testing and potential acceleration of commercial projects.
- This project represents a novel separations technology with potentially broad applicability to a number of different biomass conversion applications. Techno-economic analysis was effectively used to ensure both technical and economic feasibility. The project plan is well structured to fully evaluate this technology. If successful, this separations technology would provide a great alternative to traditional separations.
- This is an extremely relevant program since impurities play a large role in both conversion of biomass, as well as downstream recovery. The described method may provide solutions to dilute product streams that contain a large amount of impurities.

PI Response to Reviewer Comments

- Absorption efficiency at low titer is potentially where this technology will have its biggest impact. Future experiments will include both higher and lower product titers. There may be separate issues associated with both regimes. In regard to "inhibition concerns," inhibition of growth by nanoparticle aggregates will be addressed in FY16 and the results will be critical for the realization of separations-integrated bioreactors. Modifications to surface treatments and linker chemistries will be used to minimize effects, if observed. The idea to collaborate with near-commercial projects within BETO's biochemical conversion portfolio will be considered for the end of FY16 and there will be activities that consume a good portion of the efforts in FY17.

LBNL ABPDU

(WBS#: 2.6.1.100)

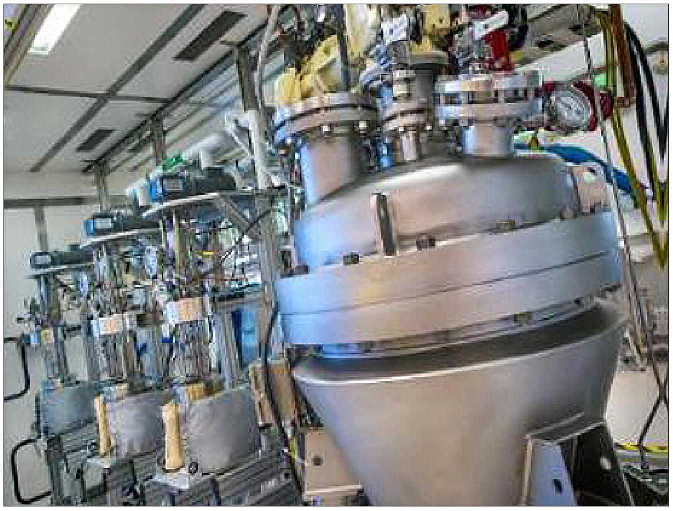


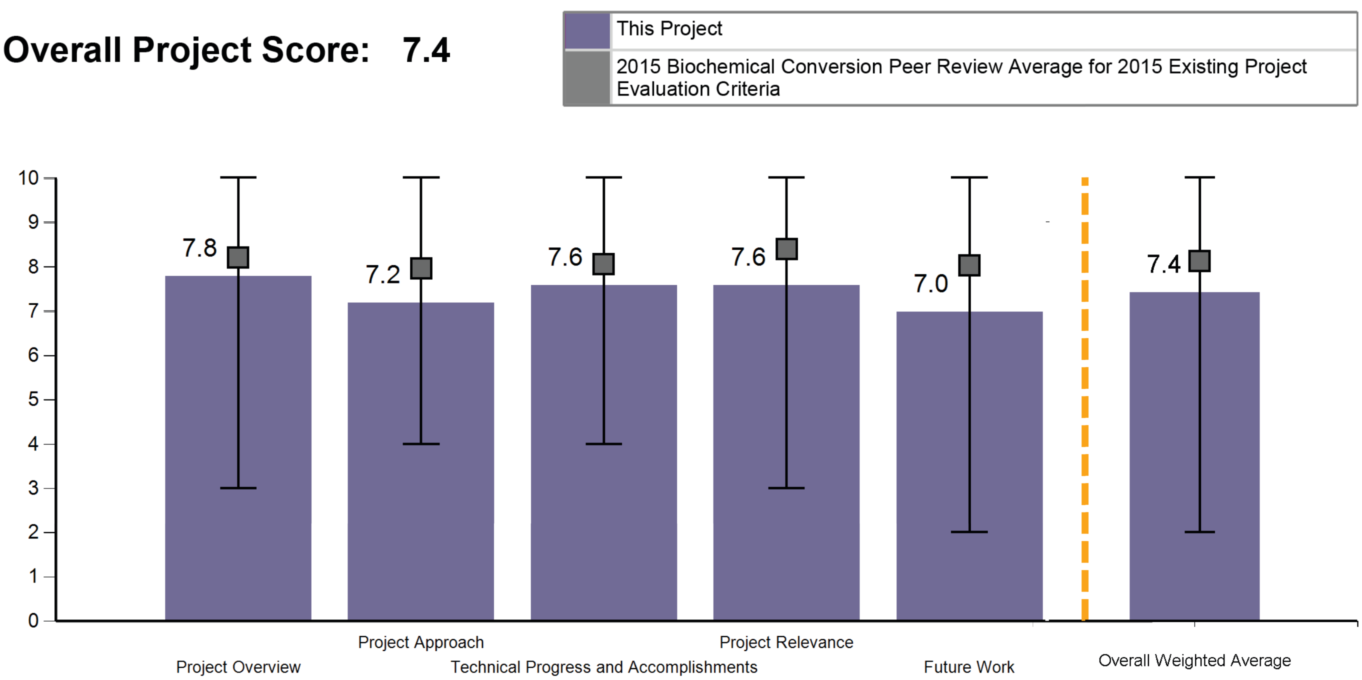
Photo Courtesy of LBNL

Recipient:	LBNL
Presenter:	Todd Pray
DOE Funding FY14:	$3,883,229
DOE Funding FY13:	$3,872,612
DOE Funding FY10-12:	$22,565,298
Planned Funding:	$10,404,212
Project Dates:	10/1/2010 - 9/30/2015

Project Description

The project goals are to build a process demonstration unit to support BETO's mission in addressing key barriers to biofuel and bio-economy development, and partner with researchers from industry, the national laboratories, and academia to optimize and scale technologies to enable bio-based chemicals, materials, and fuels commercialization. The Advanced Biofuels Process Demonstration Unit (ABPDU) is a state-of-the-art facility at Lawrence Berkeley National Laboratory (LBNL), funded by the American Recovery and Reinvestment Act (ARRA) and available since 2012 to industry, national laboratories, and academic institutions to demonstrate at 2 to 300 liters scale advanced biofuels production processes and biomass deconstruction technologies. Key technical challenges to be addressed and the approach include: (1) adapting equipment to client/sponsor requirements – focus on understanding industry needs and updating/upgrading hardware and software capabilities with the LBNL Engineering Division to stay current; and (2) maintaining process readiness across several technical disciplines under (and in between) tight project timelines – focus on cross-training and proactive project management and aggressive uptime metrics.

Overall Project Score: 7.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- Providing a flexible bench scale facility for smaller startups to develop their processes is an important niche spot in this industry. Developing a client base to become financially independent of DOE is important.
- The ABPDU is a terrific resource that has clearly improved since the last peer review. Although significant progress has been made toward self-sufficiency, it is important that project leadership focus on methods to grow industrial application and move away from BETO funding rapidly. The plan to maintain cutting-edge status by continuously upgrading is admirable; be sure to focus on upgrading in a direction that attracts industry.
- The ABPDU represents a state-of-the-art, flexible small pilot-scale facility. The project has facilitated a number of studies for others and appears positioned to increase collaborative work. As most small entities could not afford to develop such a capability on their own, this facility plays a vital role in scale up and validation of biomass conversion activities.
- The ABPDU needs to become self-sustaining in the very near term.

PI Response to Reviewer Comments

- We are pleased that most of the reviewers' comments recognize the value of our flexible bench- and pilot-scale bioprocess development and demonstration facility at the ABPDU. Of particular note is the progress we have made with our industrial partners. Following earlier input and feedback from BETO, we have been extremely focused on developing more of these industry relationships across different feedstocks, processes, and biofuel and bio-product segments. It will continue to be a top priority for the ABPDU staff to expand these relationships using competitively awarded projects as well as WFO- and CRADA-associated sponsorship, thus increasing our non-BETO funding.
- The types of flexible, rapid turnaround capabilities of the ABPDU are highly valued and considered vital by our partners, many of whom are located near us in the high-tech, small company-rich environment of the San Francisco Bay Area. Lawrence Berkeley National Laboratory management has provided a significantly reduced G&A overhead cost structure to help us in this regard so that we can expand our important contributions to the biofuels and bioproducts community.
- As the ABPDU continues to mature, and as our results are communicated in the scientific community, we expect to be able to even further increase our utilization and expedite testing and scale-up on behalf of BETO and our partners. We will continue to work toward improvements in this area and solicit best practices from our BETO and industry partners and other national laboratories.

BIOCHEMICAL VALIDATION ACTIVITIES

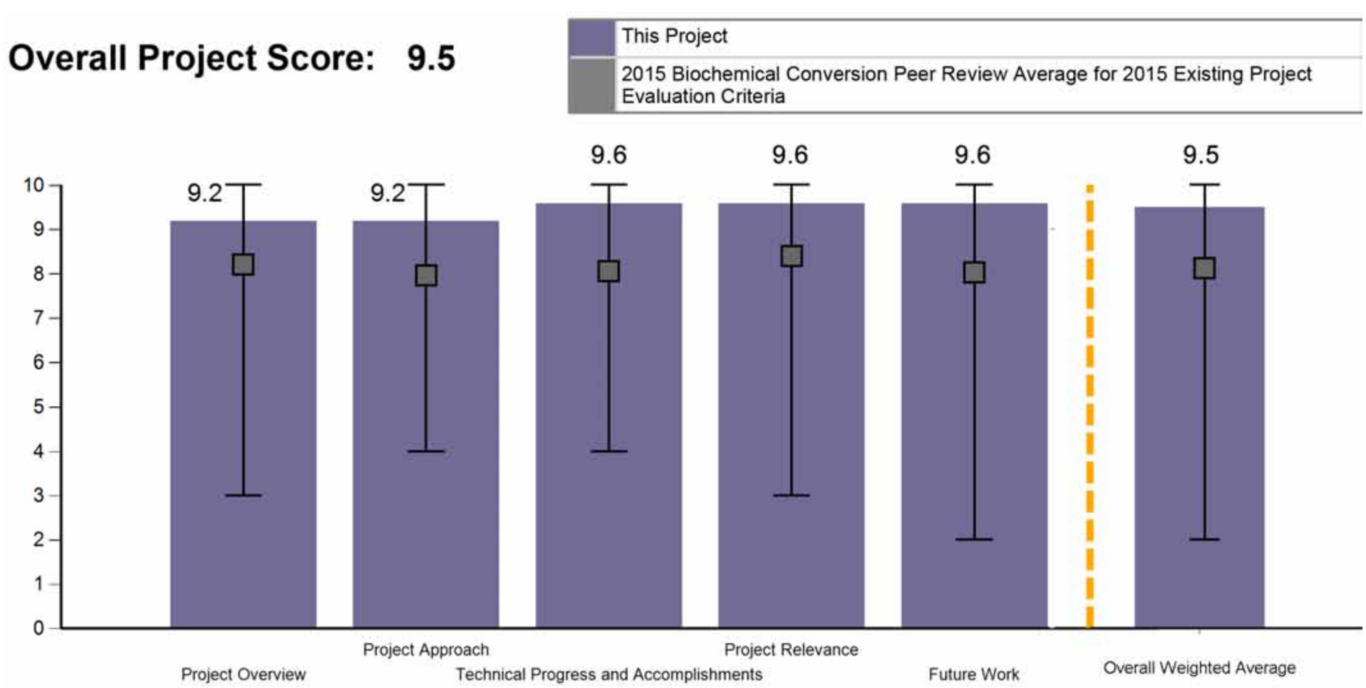
(WBS#: 2.6.1.102)

Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Jim McMillan
DOE Funding FY14:	$24,214
DOE Funding FY13:	$79,731
DOE Funding FY10-12:	$0
Planned Funding:	$628,070
Project Dates:	10/1/2010 - 9/30/2015

Project Description

The Biochemical Process Improvements Validation project demonstrates technical performance results generated by all five projects awarded under the Funding Opportunity Announcement (FOA), DE-FOA-0000337, "Integrated Process Improvements for Biochemical Conversion of Biomass Sugars from Pretreatment to Substitutes for Petroleum-based Feedstocks, Products and Fuels." For each project, a validation team conducts site visits to assess the reasonableness of reported experimental performance and techno-economic cost estimates in accordance with the pre-established Validation Plan, with results documented in confidential reports to DOE. Initial validations are carried out to verify or revise originally proposed benchmark performance and cost levels, and thereby establish the baseline against which future project performance and cost improvements are evaluated. Intermediate validations are conducted before each project's mid-award stage gate review to assess progress toward established intermediate performance and cost targets. For projects passing their stage gate, a final validation is performed to



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

confirm progress relative to final performance and cost targets. In all cases, the overall validation process adheres to strict confidentiality and non-disclosure agreements. The Synthetic Biology Validation project similarly validates 3 of the 5 projects awarded under DOE FOA, DE-FOA-0000719, “Innovative Biosynthetic Pathways to Advanced Biofuels” by assessing and documenting starting point and final performance of these projects.

Overall Impressions

- The results are found to be satisfactory, which is great. NREL should consider writing a description of the concepts of how this should be done, just in case there is a change of personnel or a lull in the frequency that DOE needs this service. A great methodology has been developed and DOE should make sure that it is not lost.
- This is a highly relevant and important project.
- This is one of those projects that absolutely must remain within the portfolio. Not only does it help drive DOE-funded projects toward success, but information that comes from the validations that can be shared (or generalized and shared) goes a long way to supporting the industry as a whole and individual, non-DOE-funded research projects. The relentless drive to duplicate results provides not only rigor within the project, but meaningful lessons learned that can be shared. Separation of individuals working on validation work from contract work being performed at the national laboratories shows professionalism, as well.
- This is a strategic project and it is well planned and executed. The project is delivering valuable results with a relatively small budget. This validation activity provides a consistent baseline of performance for key technology areas. I recommend this approach be expanded to other areas, particularly with a look toward early-stage technology projects.
- This is a very important activity since it ensures that the information in the original proposal is accurate and correct. It also allows DOE to monitor progress throughout the project.

PI Response to Reviewer Comments

- We appreciate the peer reviewers’ efforts to assess and review these validation projects. We are pleased that the review panel sees value in these project validation tasks, which, though different from direct R&D, serve a useful quality assurance function for DOE-funded (cost-shared) projects (i.e., for the subset of projects that include this validation component).
- Project information is currently documented in multiple reports spanning over five years. In particular, the reports documenting the validation process (which partially informs the project award negotiations), as well as the end-of-year summary reports provided to DOE that include discussion of lessons learned, together contain all of the requisite information. It would useful to consolidate all of this information into a single report.

BIOCHEMICAL HIGH-THROUGHPUT CHARACTERIZATION

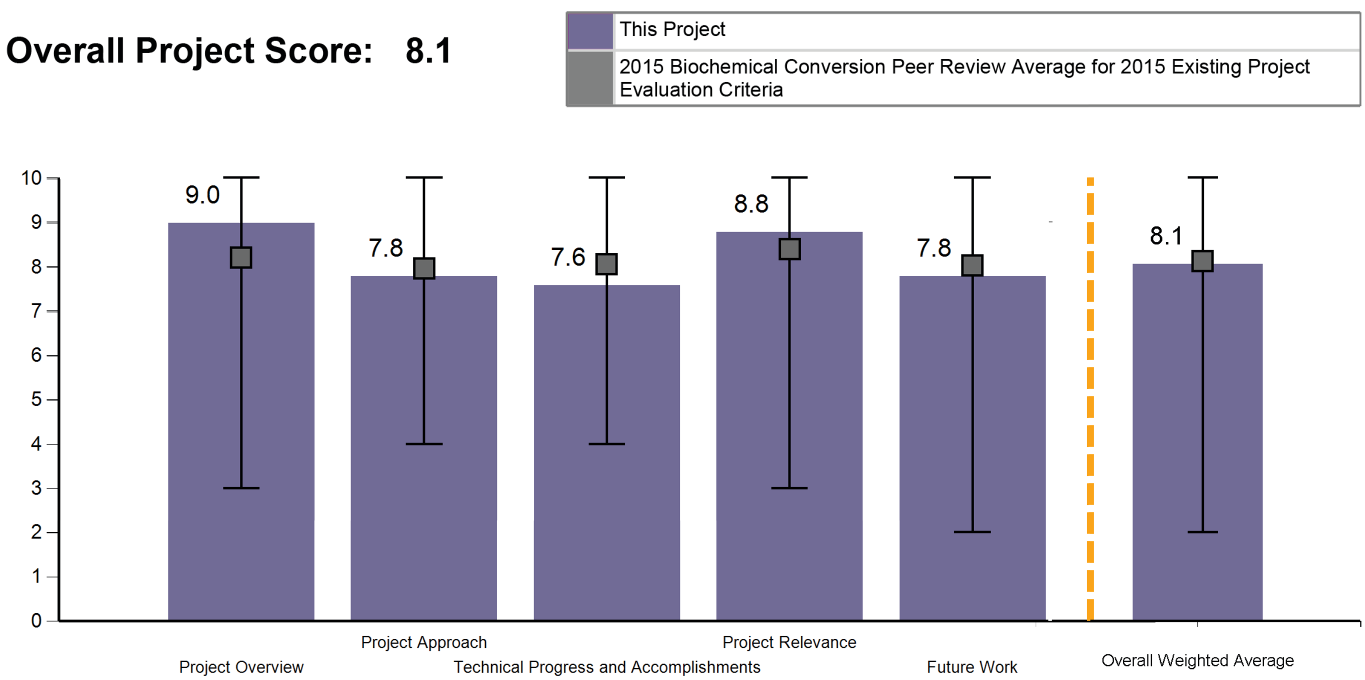
(WBS#: 2.6.2.106)

Recipient:	INL
Presenter:	Gary Gresham
DOE Funding FY14:	$214,785
DOE Funding FY13:	$1,106
DOE Funding FY10-12:	$368,915
Planned Funding:	$285,215
Project Dates:	10/1/2010 - 9/30/2015

Photo Courtesy of INL

Project Description

The objective of the High Throughput Characterization (HtC) project is the automated high-throughput comminution of biomass samples in preparation for analytical characterization. This effort supports development of feedstock specifications/grades for optimized dynamic blendstocks that meet cost, quality, and conversion targets. Every sample that enters the Biomass Characterization Lab or exchange point characterization requires some level of comminution and sample preparation. Sample comminution impacts all aspects of research within the Feedstock Platform and entails a large investment in time and human resources. The comminution process has become a bottleneck to developing large robust data sets of feedstock attribute data. The goal for the coming year is to develop a demonstration-scale robotic work cell for grinding that can enhance speed, consistency, reliability and throughput of the comminution process. The system will utilize a set of automated conveyors for input and



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

output queues with a robotic arm to process the samples from the input queue, through an automated feeder and Wiley mill grinder, and back to the output system. The resulting system will advance the state of the art for sample preparation, streamlining rapid characterization protocols to provide robust and timely data sets that will enhance the understanding of feedstock attributes for researchers, industry, and policy makers.

Overall Impressions

- This is a useful project for BETO and it can contribute to the very important function of rapid analysis that BETO has led the way for industry. The project team needs to quantify the milestones better and make sure that the project includes a final milestone for introducing a robot that will be reasonably-priced for a standard industrial lab that can afford a NIR instrument, for example.
- This is really relevant research. There are a lot of challenges to automating this process, but it is worth the effort.
- The team has obviously considered many of the issues to be addressed and has leveraged several key resources for the project. I would encourage them to look for ways to utilize the existing robot very simply, with the intention of specifying a much less expensive robot for commercial application. Also, it is good that so much consideration is being given to how this will be rolled out into industry. It would be disappointing if this wound up supporting INL work only. The fact that the project offers 24/7 operation with safety issues eliminated is a big plus.
- High throughput biomass characterization would be strategic development for the BETO mission, enabling collection of larger, more consistent data sets on biomass. The project is well developed and shows great promise to deliver a key technology to the community. Quantitative metrics for turnaround time, sample recovery, cost/sample, etc., would be helpful to determine if the investment in automation will be worth it.
- This is excellent work and shows great progress in automating sample preparation, which will greatly reduce time and money for biomass characterization.

PI Response to Reviewer Comments

- This project, budgeted for $500K/year for three years, just started in FY15. It will develop an automated system for the comminution and preparation of biomass samples. This effort is necessary because of the substantial limitation of sample throughput and the significant number of biomass samples expected in the coming years to support dynamic blending and resource evaluations.
- The current project goals are focused on improving throughput, reducing overall analysis costs, and building large and robust biomass feedstock quality attribute data sets. These data sets will be used to understand variability and bound specifications to allow blendstock formulation, reduce risk within the logistical supply chain, and support development of feedstock specifications/grades and quality control options for transaction-point valorization. Most current rapid-screening and analysis methods require the biomass sample to be ground and homogenized. The high throughput comminution, rapid-screening and analysis have near-term benefits and long-term applications. In the near term, the analytical data provides the foundation for all the feedstock blending options, and provides the data that supports the state-of-technology approaches, establishing specifications and modeling. Long-term applications can be directly applied to area resource evaluations and transaction-point characterization, which will require some level of comminution.
- The baseline grinder used to develop these methods is the Wiley Model 4 mill, although other more efficient options are being investigated in collaboration with Eberbach Corporation and Forest Concepts. Currently, manual grinding requires roughly 1 hour

of technician time per sample for 5 gallons of material, and can take longer depending on the initial and final format, and type of biomass. The throughput target for this sample preparation system is between 6 and 10 samples/hour over a 24-hour period (a 16-fold increase at minimum). It is anticipated that with the future characterization needs for testing blended feedstock options, dynamic blending, area resource evaluations, and development of feedstock specification and grades, 2,500 to 5,000 samples will require comminution in a single month. This would require sample throughput to increase from 8-10 samples a day to 75 to over 150 samples a day.

- The ability to process large numbers of feedstock resources will provide robust data sets for the Least Cost Formulation model (which will include quality in FY15), allowing industry, financial investors and researchers to take full advantage of the billion ton resources that are available, and provide blend options for specific areas and feedstock resources. It is anticipated that the high throughput methodology will support process control options within depots, rapid analysis and screening at conversion refineries, and transaction-point characterization options.
- The robot hardware to be utilized in this project has been used extensively on other work at the Idaho National Laboratory. The software and hardware used to interface the robot with equipment in a robotic work cell was heavily leveraged to enable a rapid start-up of this project, saving several months of development time over what would be required with a new robot system.
- To better address the needs to verify the consistency of the output, work scope includes performing statistical analysis to demonstrate that automated grinding delivers samples that are equivalent to the manually ground samples. The efficacy of intra-sample cleaning methodologies will be determined, as well as the potential impact that increased mill throughput, enabled by augmentation, may have on particle morphology. The project will also include a statistical analysis of the overall average turn-around and throughput of the system under actual processing conditions with the 6 and 10 samples/hour target metric.

PROCESS IMPROVEMENTS TO BIOMASS PRETREATMENT FOR FUELS AND CHEMICALS

(WBS#: 2.2.3.200)

Photo Courtesy of MBI

Recipient:	Michigan Biotechnology Institute (MBI)
Presenter:	Farzaneh Teymouri
DOE Funding FY14:	$1,020,046
DOE Funding FY13:	$1,798,304
DOE Funding FY10-12:	$816,831
Planned Funding:	$3,676,944
Project Dates:	10/1/2010 - 9/30/2015

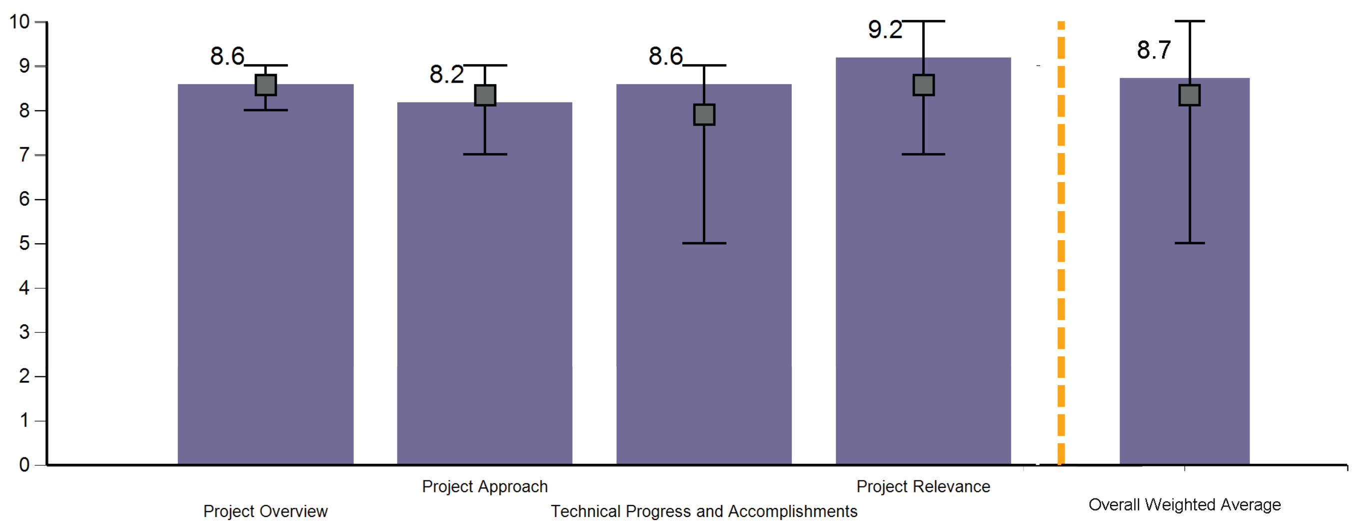
Project Description

MBI, a 501c(3) company focusing on de-risking and scaling up bio-based technologies, has teamed up with Michigan State University and the Idaho National Laboratory to develop and demonstrate process improvements to the ammonia fiber expansion (AFEX) pretreatment process. The logistical hurdles of biomass handling are well known, and the regional depot concept is a promising alternative to centralized collection. In depot concept, small, distributed bioprocessing operations collect, preprocess, and densify biomass before shipping to a centralized refinery. AFEX has unique features among pretreatments that would make it desirable as a pretreatment prior to densification at the depot scale. MBI has designed a novel approach to AFEX that can be scaled down economically to the depot scale at lower capital cost compared to the traditional design of AFEX. Thus, the purpose of this project is to develop, scale-up, demon-

Overall Project Score: 8.7

This Project

2015 Biochemical Conversion Peer Review Average for 2015 Sun-setting Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

strate, and improve this novel design. The key challenges are the recovery of ammonia, consistent and complete pretreatment performance, and the overall throughput of the reactor. In this project, a 1-ton/day facility was installed and the following key performance factors were demonstrated: >94% ammonia recovery, >75% sugar yields at high solid loading, and complete utilization of the sugars for ethanol production at 2,500 liters scale. The economic model shows a 46% reduction in AFEX capital cost at the 100-ton/day scale compared to the traditional design of AFEX.

Overall Impressions

- This is a great project and hopefully the commercial mechanical design for getting the biomass in and out is sound. It has great potential to support a first-of-a-kind single facility for animal feed. That would be a great way to prove out the solids handling and to work out any remaining issues with ammonia recovery.
- This is interesting work. I would like to see collaboration with an independent integrated biorefinery process.
- This is an important project because it is one of the only known ways to transport pretreated material. Good progress has been made toward the project's critical success factors (only 1 has not been met and it is close to being achieved). The TEA discussion shows consideration of commercial application and comparison to other technologies. It will be good to see this technology continue to move toward commercial use.
- This was an excellent presentation with a well-defined project plan and progress towards goals. AFEX pretreatment coupled with densification depots represents a very novel approach that could significantly improve the logistics and costs of feedstock supply.
- This is a very well done work and relevant. AFEX pretreatment is probably the only pretreatment process that can be used to densify and store biomass prior to hydrolysis and conversion. The challenge will be to scale-up an end-to-end biomass to fuels (ethanol) process using AFEX pretreatment.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

DEVELOPMENT OF AN INTEGRATED BIOFUEL AND CHEMICAL REFINERY

(WBS#: 2.3.2.200)

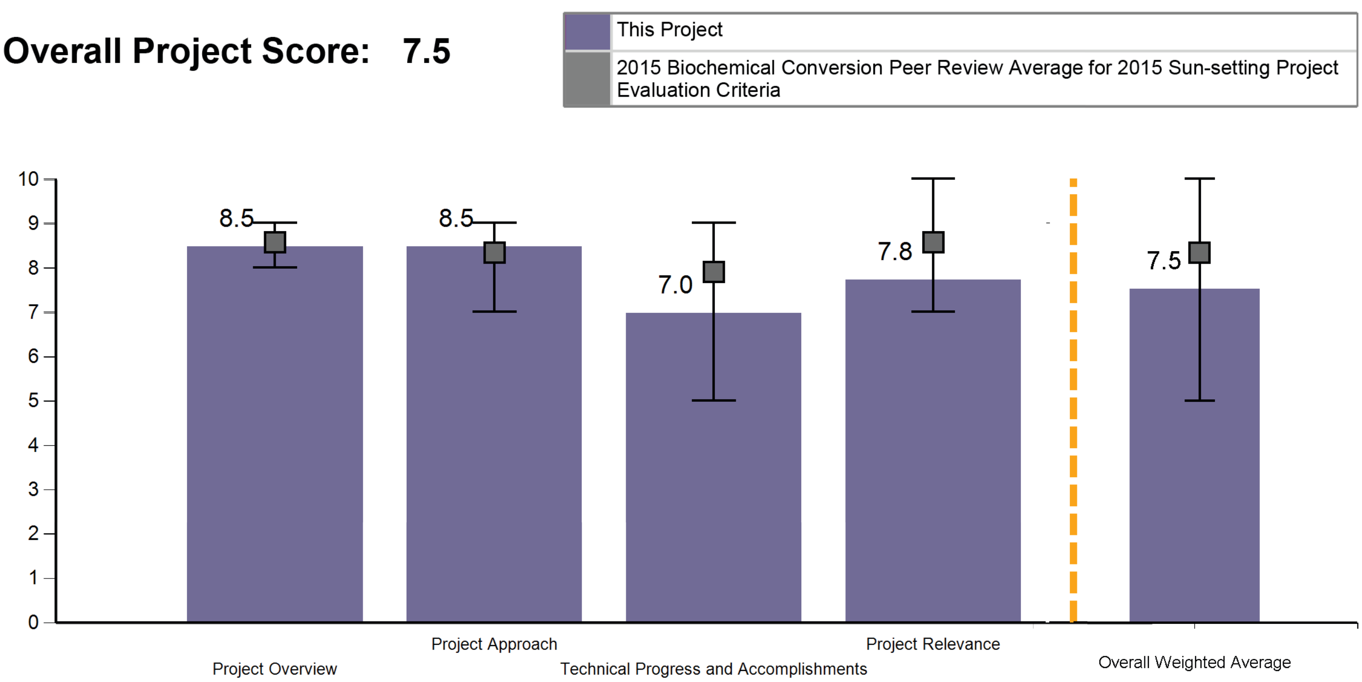
Photo Courtesy of Genomatica

Recipient:	Genomatica
Presenter:	John Trawick
DOE Funding FY14:	$1,809,189
DOE Funding FY13:	$1,006,505
DOE Funding FY10-12:	$1,006,505
Planned Funding:	$760,392
Project Dates:	10/1/2011 - 9/30/2015

Project Description

This project will demonstrate the commercial readiness for production of the industrial chemical, 1,4-butanediol (BDO), from biomass by engineered E. coli. Targets were BDO titer, rate, and yield (TRY) and growth in lignocellulosic hydrolysates (Hz). A range of hydrolysates was used to assess limitations in a biomass-to-BDO process. Via adaptive evolution methods, whole-genome sequencing, and introduction of identified target genes, strains co-utilizing C5/C6 sugars were made. The composition of Hz versus TRY led to a modified Hz composition. This was used in partnership with the DOE to redirect the project to focus on: (1) several biomass Hz from new suppliers; (2) Hz specification due to the characteristics of the Genomatica BDO process; (3) a gene cassette to engineer any BDO producing strain for biomass; and (4) modified BDO recovery to more economically recover BDO at industry specifications. BDO TRY and growth of the E. coli strains were predictable based on Hz compo-

Overall Project Score: 7.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

sition from several suppliers. This defined metrics for biomass Hz composition to achieve BDO TRY along with internal TEA to evaluate the economic potential of each modification to strain, Hz feed, and process. An improved biomass-to-BDO production strain reached BDO T-R in a 30 L fermentation above original objectives. Yield approached the proposed Y and modifications to BDO recovery were demonstrated. Genomatica is now in the position of having a biomass-to-BDO process that can be commercialized.

Overall Impressions

- I don't think the project really accomplished the objective, because the dilute acid systems did not work well.
- I would have liked to have seen TEA/LCA analyses. Interesting work and the improvement in titer based on strain development is very impressive.
- It is good to see a near commercial-ready project; success stories benefit every project in the portfolio. Some concern that there was not much information shared publicly (e.g., lessons learned) that could help the industry as a whole move forward. It should be possible to help drive additional innovation to market faster that would not be considered competition. This opportunity should be taken to support BETO.
- Project has delivered an impressive improvement on BDO production by E. coli from biomass sugars. Performance, and presumably economics, is highly dependent on the pretreatment and conditioning of the biomass sugars. The details of the pretreatments and techno-economic analysis were not presented, making it impossible to determine if the project has delivered improved economics.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

THERMOCHEMICAL CONVERSION

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Thermochemical Conversion Technology Area is one of seven key technology areas reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of 43 projects were reviewed by six external experts from industry and academia. This review represents a total U.S. Department of Energy (DOE) investment of approximately $57 million (FY 2013-FY 2014), which equates to around 14% of the BETO portfolio covered at the 2015 Peer Review. During the review, the Principal Investigator (PI) for each project was given approximately 30 to 45 minutes to deliver a presentation and respond to questions from the Review Panel. Projects were evaluated and scored on the following criteria: project overview, project approach, technical progress and accomplishments over two years, relevance to BETO goals, and future plans.[1]

BETO designated Dr. Nichole Fitzgerald as the Thermochemical Conversion Technology Area Review Lead. In this capacity, Dr. Fitzgerald was responsible for all aspects of review planning and implementation. Overview information on the Thermochemical Conversion Technology Area, along with full project scoring results, summary comments, analysis, PI response, Review Panel Summary Report, and BETO Programmatic Response can be found in the following sections.

THERMOCHEMICAL CONVERSION

OVERVIEW

The focus of the Thermochemical Conversion Technology Area is to develop commercially viable technologies for converting biomass feedstocks into energy-dense, fungible, liquid transportation fuels, as well as bioproducts or chemical intermediates and biopower. Generally, thermochemical conversion technologies involve pathways that utilize bio-oil and gaseous intermediates to produce products including finished fuels; fuel precursors; high-quality intermediates such as sugars, syngas, or stabilized bio-oils; and high-value, bio-based chemicals that enable fuels production.

Currently, the Thermochemical Conversion Technology Area funds activities that fit under seven broad groupings for overcoming key technical challenges and barriers:

Analysis and Sustainability: To understand the impact of technologies by evaluating environmental sustainability metrics and improving sustainability of each feasible bio-oil pathway; assessing techno-economic feasibility and measuring progress toward technical performance targets; conducting life-cycle analysis; and informing current state of technology updates, thereby verifying the accuracy of modeled cost projections.

Feedstock Interface Activities: To understand the impact of feedstock quality on conversion efficiency and economics; research aims to stabilize and efficiently transport and handle biomass, as well as economically preprocess biomass to the required specification to enable process optimization.

Deconstruction Processes: To produce useful intermediates from biomass; robust and cost-effective biomass

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

thermal conversion processes are under development to help the industry fully realize the benefits of an integrated biorefinery. These processes can convert a variety of biomass materials to suitable clean and high-quality intermediates for subsequent conversion to biofuels, biochemical, or biopower.

Upgrading Processes: To convert intermediates to fuels and chemicals; once a crude bio-oil or syngas is produced, technologies for cleanup, conditioning, and/or stabilization are needed for upgrading to a finished fuel co-product.

Integration and Intensification: To optimize for systems-level performance.

Conversion Enabling Technologies: To apply new knowledge and tools to innovate beyond current conversion technologies (materials research, computational studies towards reaction mechanisms); the goal is to develop new technologies that either improve known conversion processes or lead to the development of new conversion processes.

Validation: To demonstrate technical, sustainability, and economic improvements in an integrated process setting; integration and scale-up efforts are at the bench and pilot scale and generate data that are used to assess progress against technical and cost targets, as well as environmental sustainability metrics. The operational data are also used to model nth plant costs and technical projections for each thermochemical conversion pathway.

THERMOCHEMICAL CONVERSION TECHNOLOGY AREA REVIEW PANEL

The following external experts served as reviewers for the Thermochemical Conversion Technology Area during the 2015 Project Peer Review.

THERMOCHEMICAL CONVERSION	
REVIEWERS	
Don Stevens (Lead Reviewer)	Cascade Science and Technology Research
Dan Burciaga	TRI
George Huff	BP
George Parks	Retired, ConocoPhillips
John Persichetti	Colorado School of Mines
Richard Quann	ExxonMobil

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.

Project Scoring Information: The final score charts depict the overall weighted score for each project in each technology area. Titles for each project and the performers are also provided in the scoring charts.

Review Panel Summary Report: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.

BETO Programmatic Response: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.

Project Reports:

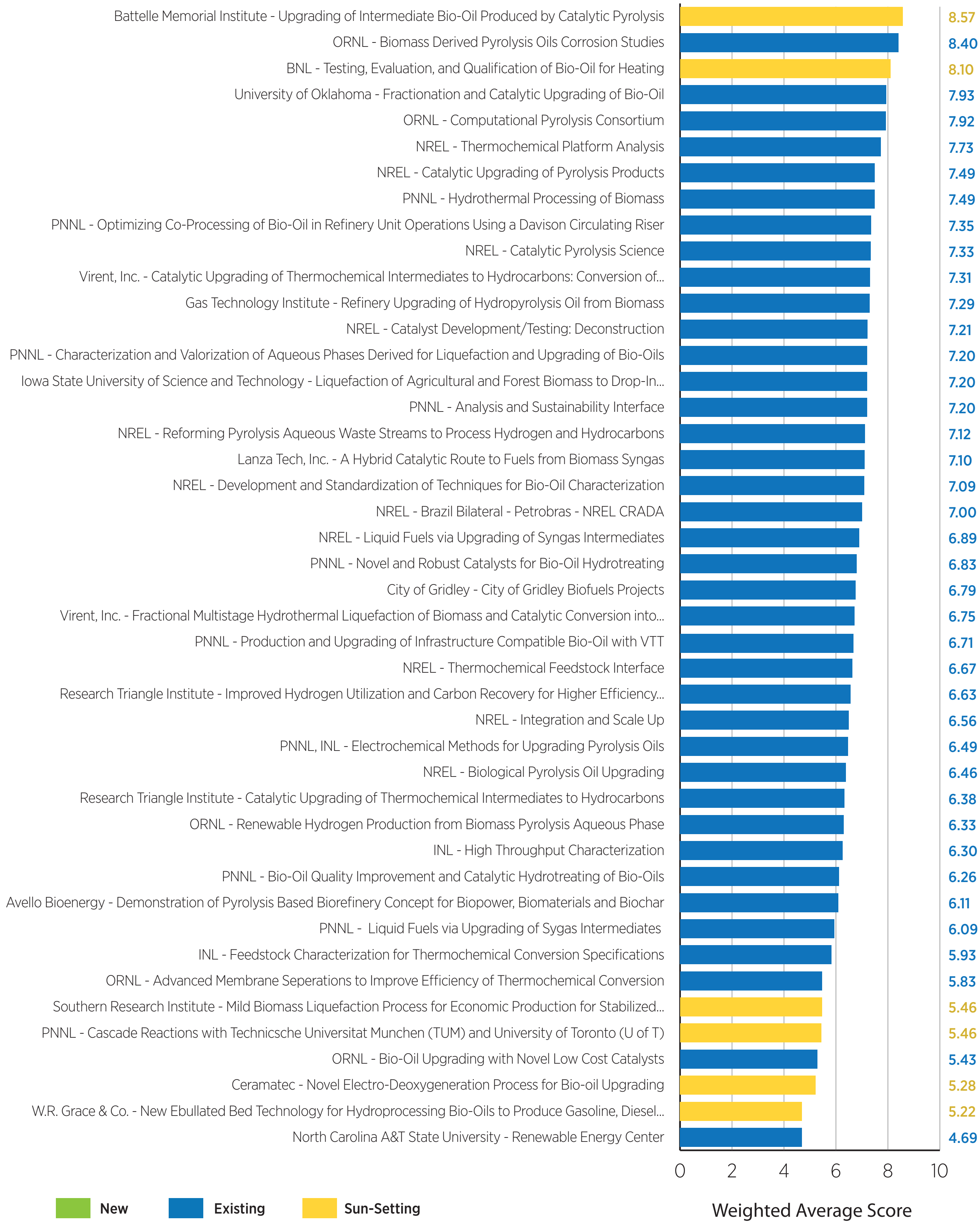
- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space allotted.
- **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers charts depict the range of scores for each evaluation criteria within each technology area.
- **Reviewer comments** are presented as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks and, in most cases, did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.
- **PI responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases, provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the Review Panel.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Thermochemical Conversion Technology Area.

THERMOCHEMICAL CONVERSION TECHNOLOGY AREA SCORING



REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum? Why?

Nearly all of the Thermochemical Conversion Technology Area projects are making reasonable technical progress and have potential to help meet this area's goals for drop-in transportation fuels. Projects that were conducted during 2013-2015 made incremental, rather than breakthrough, progress toward those goals. Reasons for this were not discussed in detail, but may relate to the fact that the thermochemical conversion pathways have been significantly defined by prior efforts.

Strengths

High-ranking projects share several common characteristics. These projects bring together a large number of relevant partners from a variety of fields to effectively leverage the strengths of each on "bigger picture issues." The partnerships typically include national laboratories and research institutes, industries, and sometimes universities. The top-rated projects also provide strong leadership to coordinate the efforts of these partners. Projects organized as formal consortia, or which effectively function as consortia, have been particularly productive. The Computational Pyrolysis Consortium and the work on bio-oil corrosion at Oak Ridge National Laboratory (ORNL) are two examples.

Top-rated projects also tend to be more focused on "solving problems," rather than simply studying them. The strong projects better understand how their work is relevant to the BETO goals and typically have better-developed technical metrics to measure their success. The pyrolysis demonstration at Battelle Memorial Institute is a good example.

Several pyrolysis demonstrations at reasonable scales have successfully operated for extended periods (1,000+ hours). The ability to operate for extended periods is crucial for establishing the viability of concepts and also for identifying barriers that must be addressed.

National laboratory performers have been effective in bringing together industry in support of BETO goals. The laboratories have extensive scientific/engineering expertise and innovative capabilities, which industry can leverage to advance the commercial state of the art. Both the number of laboratory/industry interactions and the effectiveness of those interactions appear to be increasing.

Weaknesses

Across the Thermochemical Conversion Technology Area, many projects were unable to, or did not identify, the key technical parameters and metrics needed to measure their success. Goals tended to be generic, such as "improve" or "optimize" performance of a process component, but most projects did not have specific, measurable technical targets tied to improving process economics. In the absence of clear technical goals and an understanding of process impact, projects tend to be unfocused and less relevant to BETO. All performers need to have strong, metrified technical targets, a clear understanding of potential economic impacts if technical targets are met, and clear decision points to help guide their research. Additional discussion is provided in the "Recommendations" section of this document.

The strong programmatic focus on Design Report cost targets often appeared to prevent project leaders from seeing the big picture. Researchers frequently cited the design case target costs, but had not established clear technical measures of success relevant to their specific projects. Most presenters did not or could not explain how their work related to BETO's cost goals. Also, in some cases, it was not clear that the high-level technical targets identified in the design case cost goals were the ones most relevant to the work.

The weakest performers also have several characteristics in common. Weak performers tend to be isolated and lack strong partnerships to provide perspective beyond their own limited self-interests. Several "incubator" and other new-start projects have not undertaken sufficient planning to understand how their approach will impact significant barriers to commercial implementation, even if the work is technically successful. These projects typically have weak technical performance targets with little or no consideration of potential economic impacts. In some cases, such as those where significant amounts of electricity would be used, the projects have little understanding of the overall energy efficiency or potential life-cycle analysis (LCA) impacts from their approach. Some weak projects are also trying to do too much, diluting their impact. These projects need to focus on achieving a higher impact in fewer areas.

The Thermochemical Conversion Technology Area needs to place more emphasis on solving problems rather than studying them. For example, there are numerous experimental projects studying catalysts, but it is not clear whether the Platform is effectively using existing industry-based expertise to help guide this work. In some cases, existing commercial catalysts may be appropriate. In other cases, relevant industrial catalyst expertise, offered by symposia such as The Catalyst Group or others, may be available to help focus research, but is not being used at present.

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Are there any projects that stand out as meeting (or not meeting) this criterion? Is the government's focus appropriate in light of private sector investments?

The projects, taken as a whole, have potential to continue advancing the state of the technology. The Thermochemical Conversion Technology Area has identified an appropriate number of conversion pathways, and the research continues to be satisfactory. Some projects either have active industry partners or they are led by industry, and those partnerships are helping advance the commercial state of the art.

While this technology area continues to make good incremental progress toward its goals, the portfolio includes few projects that have the potential for significant breakthroughs that would dramatically alter and advance the commercial state of the technology. The reviewers recommend that BETO increase the number of projects that have the potential for significant breakthroughs. Closer coordination of the BETO program with ARPA-E and related efforts could assist in identifying and evaluating higher-risk projects with the potential for substantial impact. Further discussion is included in the Recommendations section of this report.

RELEVANCE

3 Are the projects well aligned with what is needed by industry for successful commercialization of an advanced bioenergy industry? How can the impact of BETO on the emerging industry be amplified?

Project Relevance to BETO Goals

Overall, the research projects are relevant to BETO's mission. They are providing important information on a variety of thermal conversion pathways. These pathways include various pyrolysis approaches, direct liquefaction approaches, and a smaller effort on gasification product synthesis.

Top performers display the best understanding of the relevance of their projects. They can explain their crucial technical targets for success and how those relate to success. The use of high-level barriers from the Multi-Year Program Plan (MYPP) is not adding significant relevance to projects. While BETO benefits from having an understanding of the higher-level technical challenges, the projects need clearly defined technical targets with metrics. During this review, project leaders referred to the MYPP barriers without showing technical targets specifically relevant to their work.

Project Relevance to Industry

Overall, the projects are relevant to industry, and some have industry participants that actively participate in the work. The direct in-cash and in-kind cost sharing of industry participants demonstrates the value of the work in helping shape their future plans. Industry/national laboratory collaborations typically help make the research more relevant to both partners and BETO.

With BETO's current focus on transportation fuels, projects across this Platform still lack sufficient understanding of how their bio-oils and upgraded products relate to refinery operations and requirements. The characteristics of even significantly upgraded bio-oils may create issues for refineries, and these issues must be addressed. The need for all projects to gain a better understanding of the refinery interface was noted in 2011 and 2013 and has improved somewhat. Continued improvement related to the refining industry interface is still needed.

In addition to transportation fuels, the Thermochemical Conversion Technology Area should also consider other potentially important uses for partially upgraded products, such as industrial turbine fuels, heating oils, and others. Using partially deoxygenated fuels could potentially reduce costs and improve energy balances for technologies compatible with lower-quality fuels. As indicated in prior reviews, it is important for DOE to consider replacing not only transportation fuels, but also the many components of the "whole barrel," including chemicals and other products produced from oil.

Projects Meeting/Not Meeting Relevance Criterion

High Relevance: The ORNL corrosion research produces data that is highly relevant to the entire pyrolysis community. The studies use actual components from multiple conversion systems to provide technical data on corrosion from bio-oils. The project is also solving higher-level issues, such as determining whether or not there is a direct correlation between corrosion and the traditional total acid number (TAN) measurement used in the petroleum industry.

Low Relevance: Some of the new Annual Operating Plan (AOP) "incubator" projects are less relevant to the Thermochemical Conversion Program because they have unclear technical targets or are unlikely to have commercial impact even if technically successful.

INNOVATION

4 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The projects in the Thermochemical Conversion Technology Area are generally addressing the broad problems and high-level barriers established by BETO. This work involves a combination of incremental/practical projects and some innovative approaches. Projects involving innovative approaches (e.g., LanzaTech) typically involve more risk because they are innovative. Among the 44 projects reviewed, most were viewed to be making incremental progress rather than achieving breakthrough innovation.

Although BETO has initiated an AOP "incubator" and competitive solicitations specifically designed to increase innovation, many of the projects in this category received low rankings. These low scores were due to unclear technical goals or daunting challenges to commercial implementation, even if initial technical targets were met. BETO should further refine the AOP selection process to better identify concepts that are both innovative and likely to be commercially implemented if technical goals are met.

Going forward, the reviewers strongly recommend that BETO fund additional innovative research projects with potential to achieve significant breakthroughs to advance the commercial state of technology. This suggestion is described in greater detail in the Recommendations section.

5 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more BETO could do to orient technologies toward successful commercialization? Are there projects that stand out as positive or negative examples of this orientation? Why?

At present, research funding has been allotted in a reasonable, balanced manner across various levels of the technology pipeline (technology readiness levels or TRLs). Fundamental research is focused on underlying issues, such as corrosion catalyst behavior. Bench- and lab-scale research is providing important information on topics including bio-oil upgrading. Moderate-scale facilities are now capable of producing tens of gallons of hydrocarbon products, which is important for the refinery interface. Early-stage industry pilot plants and demos, such as those at Battelle Memorial Institute or RTI, are demonstrating that these technologies can be operated continuously for extended periods.

Moving into 2016 and beyond, it will be important for BETO to maintain this balance of research activities. Most larger-scale, industry-led projects are ending in the next 12-18 months. As these projects end, the Platform will increasingly become a laboratory-oriented program where most projects are at the lower levels of the technology readiness pipeline. The BETO program needs to proactively maintain a strong, diverse set of performers working at a variety of technology readiness levels.

GAPS

6 Are there any gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals? Are there any areas in the existing portfolio that need more or less emphasis?

The current Thermochemical Conversion Technology Area provides a reasonably comprehensive approach to producing transportation fuels from biomass. Suggestions for further strengthening this area are provided below:

Gaps in Technology Area Portfolio

Catalyst performance and its impact on reactor plugging and fouling, particularly in relation to the thermal stability of bio-oil, continue to be *one of the most significant, overarching issues for the Thermochemical Conversion Technology Area*. While BETO is currently conducting research on this topic, most researchers are still reporting ongoing problems that reduce catalyst efficiencies and lifetimes. Additional, highly coordinated efforts in this area will be crucial for programmatic success. Our strong recommendation to fund additional experimental catalysis/fouling research as a consortium or other highly coordinated effort is described in the Recommendations section.

BETO should focus additional research on integrating into the existing, broad fuel system. Current projects have a strong focus on replacing gasoline, jet fuel, turbine fuels, and diesel. This focus may be too narrow and distant in terms of commercial success. There is a need to include projects that can achieve success in the near-term, such as projects on products, chemicals, heating oil, and similar opportunities.

There is currently too much focus on the use of hydrogen for removing oxygen from biomass. It would be useful to spend increased effort on new chemistry to eliminate oxygen by condensation and other approaches to eliminate oxygen.

The current BETO gasification efforts deal with catalytic conversion of clean syngas to fuels. Globally, there is extensive clean-syngas-to-fuels research using other carbon sources, such as natural gas or coal. The need for BETO to conduct research in this area is not apparent, and the reviewers believe that conversion of clean biomass syngas to fuels is not a reasonable biomass-related function. Instead, the reviewers recommend that gasification research should focus on the impurities encountered in characteristic biomass syngas; research should investigate how to handle these impurities during fuels production. BETO may also want to obtain input from the existing industry to determine research needs going forward.

Other Areas BETO should Fund or Address to Meet Programmatic Goals

Technical Issues: Reviewers identified several technical areas where funding is needed to provide important information:

- Gather toxicity data for future MSDS sheets. The current projects provide a good source of information.
- Improve removal of inorganics in pyrolysis.
- Improve biomass feeding systems. Biofuels technologies will not be successful if the feed systems fail.
- Examine separations. This is a continuing challenge for all technology pathways.

Capital/Equipment Utilization Issues: Reviewers noted that several projects have larger-scale equipment, but were uncertain if BETO investments in that equipment will allow its effective use. For example, some demo units had operated only a few hours over the past several months. Similarly, it was unclear if laboratory equipment, such as the Davison Circulating Riser (DCR) or others, would be sufficiently funded in the future to effectively operate the equipment. While the DOE system does not always categorize this equipment as "capital," it is important that it is effectively used. The reviewers recommend improved BETO planning to determine what equipment sizes are needed and how funding will be provided over time to ensure that the equipment is utilized at full capacity.

Techno-economic Analysis (TEA) Issues: The Reviewers suggest some changes in the TEA/LCA analyses for this and other technology areas. BETO has applied consistent high-level TEA/LCA analyses to the Thermochemical Conversion Technology Area, and reviewers support this action. The implementation of analysis also appears to have improved from prior reviews in 2011 and 2013. Further improvements are needed, as discussed below:

- Individual project economics are more consistent than in prior years, but there are still significant inconsistencies. A simple, rapid turn-around model, probably with modules, would be useful. Reviewers cited "H2A," the model used by the DOE Hydrogen Program, as an example, but others may be more suitable. This recommendation was also made in 2013.
- There is a need for independent, third-party evaluation of all TEA/LCA analyses prepared by any organization that is conducting related research. The independent effort would validate the consistency and appropriateness of the various studies and help confirm that the most appropriate technical goals are being selected for study.
- At present, there are too many independent ASPEN-based models, each of which costs time and money to produce and are likely to be suboptimal. A repository where the best-in-class could be easily retrieved and utilized would be beneficial.
- More analysis on pioneer plant facilities is needed to provide information to early adopters of the technologies. Such analyses would also provide BETO with information on how to help overcome barriers for the initial facilities. The focus in Nth plants will be limited in value unless the first several are built.

7 What synergies exist between projects within this technology area? Is there more that BETO could do to take advantage of these synergies?

SYNERGIES

Many effective synergies exist between the projects in the Thermochemical Conversion Technology Area. BETO consortia are successfully bringing highly qualified people and facilities together and producing excellent outcomes.

Interactions between the Feedstocks and Thermochemical Conversion Technology areas have increased in frequency and effectiveness. Those interactions were repeatedly noted by individual projects, well beyond the limits of specific "interface" activities. The improved understanding by both groups is beneficial.

Several projects showed excellent synergies with international partners that bring the value of an international perspective to BETO (VTT-Finland, Brazil, etc.). BETO benefits strongly from understanding the global perspective on biofuels and leveraging international expertise.

Synergies between the ongoing projects is generally strong, but could potentially be further improved. As discussed previously, BETO should establish additional consortia-type efforts around experimental catalysis and, potentially, other topics to better leverage the expertise already available. Further efforts to simplify mechanisms that enable industry to better use national laboratory expertise would also be useful.

8 Does this program appear to be appropriately leveraging breakthroughs from the DOE Office of Science, ARPA-E, the National Science Foundation, and/or other DOE Offices or federal agencies?

Based on the information presented, reviewers do not perceive BETO as effectively leveraging breakthroughs at other federal agencies. It is unclear whether the reviewers' perceptions arise from an absence of information provided at the review, or whether, more significantly, there is a lack of actual and effective coordination with these programs. In either case, the linkages between these agencies were not described. Individual reviewers are aware of some efforts to coordinate federal programs, such as the Biomass Research and Development Initiative (BRDI) Board.

Two agency efforts in particular, ARPA-E and the military renewable fuels programs, have played an important role in bringing innovative ideas forward and improving fuels utilization. We recommend that BETO establish clear connections with both programs to assist in identifying innovative ideas with breakthrough potential and to assist with implementation of renewable fuels.

RECOMMENDATIONS

9 What are the top three most important recommendations that would strengthen the portfolio in the near- to medium-term?

The Review Panel proposes the following three recommendations:

1. **Establish an "Experimental Catalysis Consortium" and perhaps others:** Based on the success of existing BETO consortia, our first recommendation is to establish a highly coordinated "Experimental Catalysis Consortium." Numerous presentations on experimental catalyst studies reported difficulties, such as fouling, plugging, and thermal stability. However, individual projects were less focused on solving these higher-level issues and more focused on studying laboratory-specific catalyst issues within individual reaction pathways/stovepipes. A strongly coordinated effort is needed to focus the breadth of expertise available on the *overarching plugging, fouling, and thermal stability issues* impacting experimental catalytic conversion studies. The computational catalysis consortium is a good model for a separate effort on experimental catalysis, but other strongly coordinated approaches, such as a "Center of Excellence" approach, could also be effective. In addition to the strong need for the experimental catalysis consortium, BETO would also benefit from much closer coordination of research or consortia on aqueous organics in waste streams. The current efforts related to characterization, treatment, and valorization are important, but there is no coordination among performers and there appears to be some overlap.

2. **Establish clear, specific technical and economic targets for all projects to measure success:** Our second recommendation is to establish strong, metrified technical goals for each project. The technical goals should be tied to potential economic improvements. These targets are needed to help focus research on key technical barriers and measure progress toward success. The reviewers would like to see information, such as: "*The current best-in-class catalyst lasts for six months before replacement. This contributes $0.XX to the cost of a final product (gasoline or diesel). Our work aims to increase that lifetime to 12 months, lowering catalyst replacement cost to $0.YY.*" Successful development of these tar-

gets will improve the effectiveness of projects and their relevance to BETO. BETO may benefit from an "independent engineer" program to assist with this goal. The independent engineers could work with the researchers either before or immediately after their project was funded to develop clear targets and make sure that the projects' economic and sustainability impacts were considered. The effort would be less intensive and expensive than provided for the BETO Demonstration and Market Transformation program, but could provide overall guidance and consistency.

3. **Increase the number of innovative projects with potential for significant breakthroughs:** Our third recommendation is to expand the number of innovative projects that could potentially make significant breakthroughs in advancing the state-of-the-art. Incremental progress alone will not enable the program to meet the federal government's national goals for large quantities of renewable fuels, and significant breakthroughs are still needed. ARPA-E programs foster innovative ideas, but the connections between BETO and that program were not explained. Better coordination with ARPA-E, as well as military renewable fuels programs, may help identify and advance promising innovative concepts.

In moving forward, BETO will also benefit from strengthening the selection process for innovative projects in its AOP "incubator" program and its competitive solicitations. Proposals selected for funding should not only be innovative, but must also have reasonable probability of commercial implementation if technical goals are met.

BETO PROGRAMMATIC RESPONSE

IMPACTS

The Thermochemical Conversion Technology Area team would like to thank all six reviewers for their time and appreciates the dialogue that resulted from the review process. As discussed in the Conversion R&D Overview section of this report, the Thermochemical Conversion and Biochemical Conversion Technology Areas were combined into a single Conversion R&D Area for FY2015. While the project period for this review included time before this merger, the Thermochemical Conversion Technology Area team hopes that some reviewer concerns about impacts and focus on Design Reports will be addressed by this change.

As of March 2015, the Office has published design case models detailing eight potential pathways to biofuel production (four focused on thermochemical pathways, two on biochemical pathways, and two on algae pathways). Many of the projects that presented in the Thermochemical Conversion Technology Area are working on aspects of these design case models, including several of the incubator-style projects that reviewers noted "were rated low because they were unlikely to advance the commercial state of the technology (low relevance to BETO)."

While the design cases focus on specific conversion technologies, the ultimate goal is to develop technologies along several pathways to address the broad range of physical and chemical characteristics of various feedstocks and to reduce the risk that any specific technology could fail to reach commercial viability. This is referred to as the pathways approach. The pathways approach aims to diversify R&D, in recognition that industry will ultimately decide which pathways are the most viable, and to enable progress in one technology so that it can affect multiple, different pathways.

The design case pathways allow BETO to focus R&D funds on areas that contribute the most to production cost reductions. The pathways also enable the program to show progress from year to year in a relevant metric (MFSP). Pathways are meant to be representative, utilizing modular pieces that can be combined in various ways to reach finished fuels and products. As the pathways approach becomes more developed, it should be more apparent how different projects fit into the portfolio as a whole, and overall reliance on using the 2017 and 2022 cost goals as primary measures of project success will be reduced.

The goal of these incubator-style projects, which may not always lead to guaranteed successes, is to examine different modular pieces of potential pathways. BETO recognizes that different pathways involve technologies at various levels of development, and some have advanced further than others.

More information on the pathways approach can be found in BETO's Multi-Year Program Plan (MYPP) available at: *http://www.energy.gov/eere/bioenergy*.

INNOVATION

The Review Panel comments on innovation were summarized in the recommendations section below.

GAPS

Catalyst Performance: Reviewers identified a number of gaps in the Thermochemical Conversion Technology Area, but highlighted one project, "catalyst performance and its impact on reactor plugging and fouling, particularly in relation to the thermal stability of bio-oil," as perhaps the most significant. In response to this gap, Thermochemical Conversion has begun the process of creating a set of Catalysis Working Groups to address these issues in FY2016. This effort is described further in the Recommendations section below.

Hydrogenation: Reviewers felt that "current research may over-emphasize hydrogenation approaches to remove oxygen from bio-oil." While the Thermochemical Conversion Technology Area recognizes that hydrogen is a precious commodity, especially in the petroleum refinery, they also understand that renewable carbon is similarly precious when producing renewable fuels, and will continue to work on reducing hydrogen demand, where possible.

Drop-in Fuels and Products: Reviewers expressed concern that the vast majority of projects were focused on fuel production to help meet the 2017 and 2022 cost targets. The Thermochemical Conversion Technology Area recognizes the importance of additional opportunities including drop-in fuels and bioproducts. BETO as a whole is in the process of expanding its project portfolio to include more of these opportunities going forward, for example, the Vehicles Optima initiative.

TEA/LCA Analyses: The reviewers made additional suggestions about improving the use of TEA/LCA analyses within the Thermochemical Conversion Technology Area. They stressed the need for independent, third-party evaluation of all TEA/LCA analyses, which is an existing standard.

External reviewers for the 2013 Fast Pyrolysis and Upgrading Design Case included representatives from Zeton, Iowa State University, Harris Group, CanmetENERGY/ Canadian Bioenergy Association, UOP, and VTT.

External reviewers for the 2014 Whole Algae Hydrothermal Liquefaction Design Case included representatives from SAIC, Genifuel, Cornell University, Reliance Industries LTD, Algenol, University of Georgia, Southern Research Institute, Sapphire Energy, and UOP.

SYNERGIES

The Review Panel expressed some concern that the Thermochemical Conversion area was not working closely with other DOE programs, such as the Office of Science and ARPA-E. Several current portfolio projects were initiated by ARPA-E, including the following:

- Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons from Research Triangle Institute; and
- Refinery Upgrading of Hydropyrolysis Oils from Biomass from the Gas Technology Institute.

Additionally, the Ohio State University project awardee selected in the recent FY2014 Incubator FOA also has ARPA-E heritage.

In addition to current portfolio projects, BETO communicates regularly with ARPA-E to share information on relevant projects, especially those from the ARPA-E PETRO (Plants Engineered to Replace Oil) biomass-based fuels and Electrofuels Programs. BETO also shares upcoming announcements, communications, and talking points about related initiatives, such as the REMOTE (Reducing Emissions using Methanotrophic Organisms for Transportation Energy) Program. The intent of these communications is to help both programs operate in a complementary way and increase the relevance of related projects.

BETO maintains similar conversations with the Office of Science, especially with the Office of Biological and Environmental Research (BER) and the Office of Basic Energy Sciences (BES), Chemical Sciences, Geosciences and Biosciences Division. The Thermochemical Conversion Area will make every effort to continue these communications going forward.

RECOMMENDATIONS

There were three major recommendations set forth by the Review Panel:

1. **Establish an "Experimental Catalysis Consortium" and perhaps others:** Based on this recommendation and information received from PIs during the review process, the Thermochemical Conversion Technology Area has taken steps to develop a set of Catalysis Working Groups in FY2016. Working Groups will consist of PIs from multiple laboratories working on similar catalysis projects and will encourage those PIs to share information on challenges and successes that they have experienced in their work. The Working Group structure will consist of both small and large group meetings and an annual or biannual in-person meeting. If initial meetings are successful, the Working Groups may expand to include additional relevant industry projects. Additional work is being done to establish a multi-laboratory Separations Consortium for FY2016-2017 and, depending on available funding and success of these efforts, other consortia may be considered in the future.
2. **Establish clear, specific technical and economic targets for all projects to measure success:** This is an area that Thermochemical Conversion Technology Area continues to emphasize for all projects when establishing milestones, and one that has been specifically targeted for improvement for FY2016. Projects have been instructed to consider more specific goals and targets and to link their milestones to factors that will have an emphasis on the state of the art. The reviewer-suggested language is a helpful guideline. *(This contributes $0.XX to the cost of a final product—gasoline or diesel. Our work aims to increase that lifetime to 12 months, lowering catalyst replacement cost to $0.YY.)*
3. **Increase the number of innovative projects with potential for significant breakthroughs:** As mentioned above, several upcoming competitive projects have heritage with the ARPA-E program, or are being funded through the FY2015 Incubator funding opportunity. These projects are specifically selected based on their potential to generate breakthrough approaches and technologies. While the Thermochemical Conversion Technology Area team understands the importance of funding projects that are advancing the state of the art or that have the potential for significant breakthroughs, they also feel that it is important to fund a variety of projects across multiple TRLs. In order to ensure a well-rounded portfolio that continues to see success over a long period of time, some funding needs to be devoted to less advanced and higher-risk ideas that may not always lead to success. Thermochemical Conversion Technology Area team recognizes that some of the ideas that were presented at the Project Review may no longer represent a viable path forward for BETO. Subsequently, the Office has reached out to PIs to communicate reviewer comments with the intent of restructuring projects

to achieve a higher impact. BETO's Thermochemical Conversion Technology Area team thanks the Review Panel for all their time and effort, which has made conversations like this possible.

ANALYSIS AND SUSTAINABILITY INTERFACE

(WBS#: 2.1.0.301)

Recipient:	PNNL
Presenter:	Sue Jones
DOE Funding FY14:	$494,241
DOE Funding FY13:	$464,229
DOE Funding FY10-12:	$774,143
Planned Funding:	$2,567,703
Project Dates:	10/1/2010 - 9/30/2017

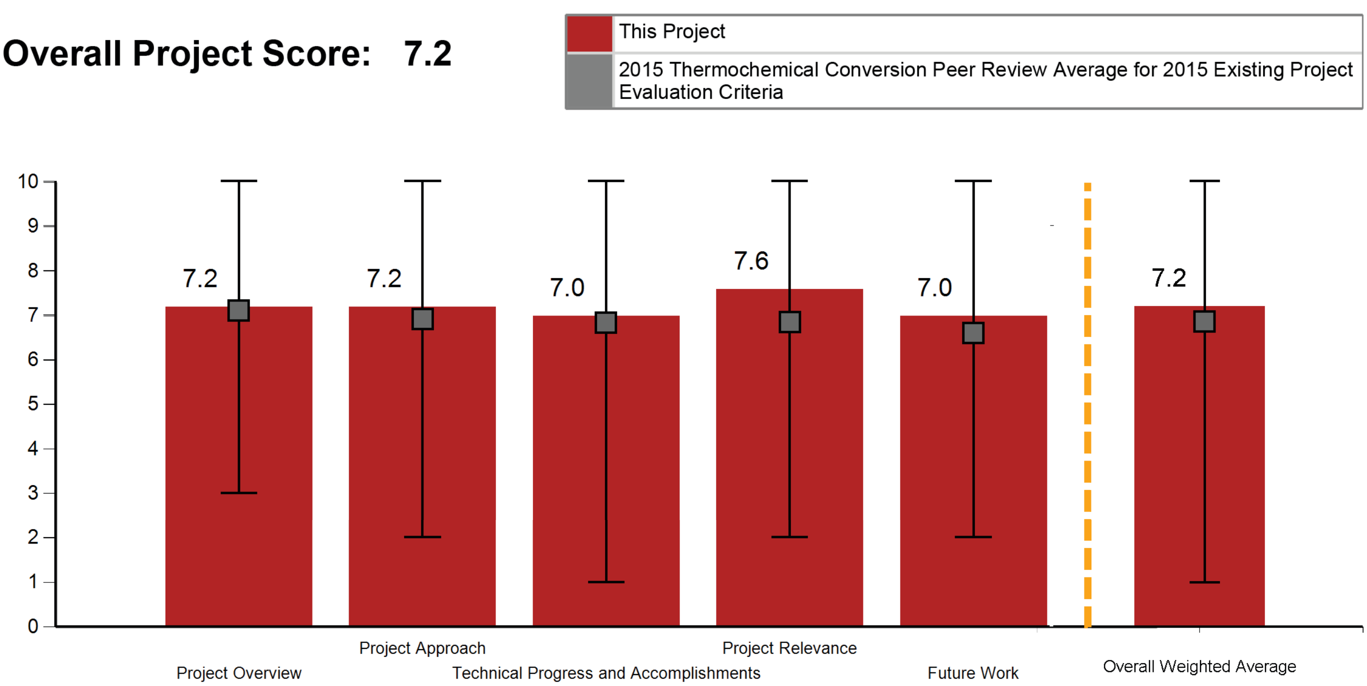
Project Description

This project provides technical, economic and sustainability analysis efforts for BETO. Specific tasks include annual state of technology (SOT) updates for the Fast Pyrolysis and Upgrading to Hydrocarbons pathway, leading to a goal of $3.00/gge on a modeled cost mature technology basis. Additional tasks include development of techno-economic and sustainability analyses for new thermochemical related conceptual design cases for direct and indirect liquefaction and performing other types of analyses, as requested. The overall goal of the multi-laboratory analysis tasks is to provide high quality analysis for the Conversion Platforms in support of the BETO's technical and economic targets. Key to this project is the collaboration between this project and the researchers. Both qualitative and quantitative analyses are generated to assist in determining targeted research aimed at reducing cost and sustainability impacts.

Overall Impressions

- This project provides much needed economic analysis to standardize the metrics that projects are evaluated by.
- This project is making good progress and provides useful insights to researchers about where opportunities exists to reduce costs. There is good coordination with related analyses at other national laboratories.
- Like other DOE Design Cases dealing with Nth plants, this one does not provide economics relevant to early adopters for the first several plants where

Overall Project Score: 7.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

costs will be much higher. First plants will require much greater capital and contingency expenditures, for example, and the present analyses do not adequately address these. DOE should consider other types of analyses to assist with early commercial adoption of emerging technologies.

- This project has done great work looking beyond GHG, such as water. It made a good attempt at striving for detail in OSBL (such as hydrogen production, wastewater). This is typically the weak link and requires site-specific information and the experience of an EPC contractor. ISBL falls out with Aspen and costing techniques, although most likely based on Gulf Coast economics – thus, be careful. The project team needs to make sure that everyone within the national laboratory system that is using Aspen costing is calibrated. A TEA user group would be helpful to correlate assumptions and physical properties, which may already exist. Can the Aspen tool be developed in a way that it can be readily applied (and not abused) in the hands of the researcher? *[OSBL: Outside Battery Limits; ISBL: Inside Battery Limits; EPC: Engineer-Procure-Construct]*
- The work is well planned and executed. It would benefit from the inclusion or creation of simple spreadsheet-based tools that could be distributed to researchers, allowing them to quickly assess the impact of their work and set firm targets for performance improvements.
- This project demonstrates good progress and clear reporting. As an "interfacing" activity, it should also drive toward achieving 2017 objectives, and not just an approach to see how it turns out.

PI Response to Reviewer Comments:

- Thank you for your review. We agree that standard assumptions and methods are vital with regard to analysis. BETO meets monthly with the national laboratories in a regularly scheduled meeting to ensure that design cases, MYPP updates, and overall assumptions are aligned. Aspen and related software does tend to require experience to make it useful and consideration should be given to how best to make these methods and results more generally available for use by all stakeholders. While Nth plant assumptions are useful for tracking the effects of research improvements, we agree that it does not address first-of-a-kind plants. That is being addressed, for example, with NREL's Biomass Scenarios Model.
- We also agree that merely modeling the research results at the end of each year is insufficient in terms of assisting research directions. Hence, a key aspect of this project is the ongoing dialogue between the researchers and the analysts throughout the year, meeting several times per month. New experimental results are incorporated into the models, and the analysts provide feedback to the researchers on the resulting cost impacts as well, providing cost reduction scenarios that are used to plan future experiments.

THERMOCHEMICAL PLATFORM ANALYSIS

(WBS#: 2.1.0.302)

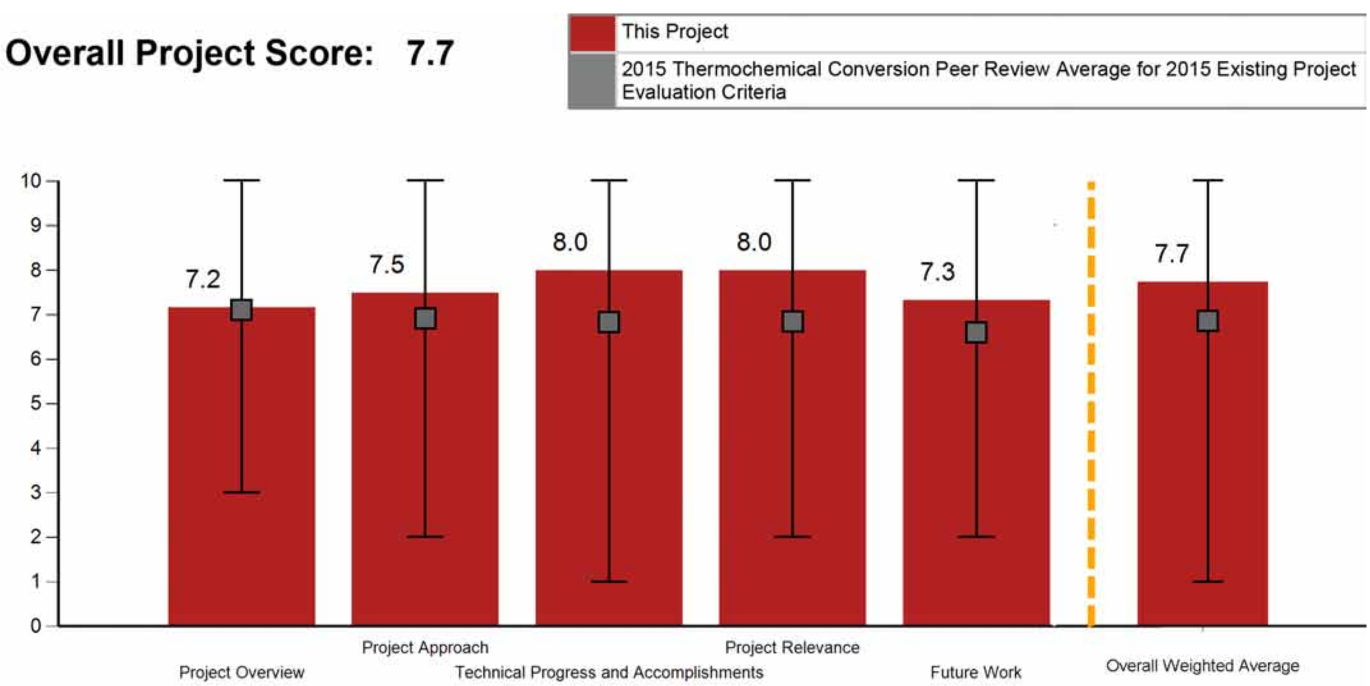
Recipient:	NREL
Presenter:	Abhijit Dutta
DOE Funding FY14:	$1,170,206
DOE Funding FY13:	$1,016,845
DOE Funding FY10-12:	$2,593,837
Planned Funding:	$6,460,804
Project Dates:	10/1/2010 - 9/30/2017

Project Description

The purpose of this project is to develop process and techno-economic analysis (TEA) models for conceptual biorefinery configurations to represent biomass-to-fuels research efforts and integrate the R&D results to track the state of technology toward meeting BETO 2022 cost targets and sustainability goals for hydrocarbon transportation fuels. The TEA-related work under this task includes developing design cases and reports to establish targets and identify barriers, quantifying the impacts of research progress on cost and sustainability metrics, integrating kinetic and thermodynamic models to increase predictive capabilities of process models, engaging in as-needed, quick-turnaround analysis, and developing SOT assessments for pathways outside of core BETO conversion R&D. Until FY12, the primary objective of this task was supporting the platform in advancing the SOT and demonstrating the production of cost-competitive ethanol from biomass via gasification and mixed alcohol synthesis. Following the successful FY12 demonstration, the task focus has shifted to cost reduction of biomass to hydrocarbon fuels processes. The current hydrocarbon pathways include fast pyrolysis with in-situ/ex-situ vapor upgrading and production of high-octane gasoline blendstock via gasification. This project serves to maximize the value of analysis capabilities for core BETO-funded conversion research at NREL, PNNL, and other BETO-funded efforts.

Overall Impressions

- Excellent, high quality work. Why doesn't industry know about it or use it? Need more outreach, presentations, etc.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- This project is making good progress and provides useful insights to researchers about where opportunities exist to reduce costs. There is good coordination with related analyses at other laboratories.
- Like other DOE Design Cases dealing with Nth plants, this one does not provide economics relevant to early adopters for the first several plants where costs will be much higher. First plants will require much greater capital and contingency expenditures, for example, and the present analyses do not adequately address these. DOE should consider other types of analyses to assist with early commercial adoption of emerging technologies
- TEA is an important area, and this project implies the work across the national laboratories is tightly joined up. This strong collaboration sometimes does not come across from the presentations given by individual projects. ISBL is easier to get from Aspen modeling—assume that the costs presented are U.S. Gulf Coast. OSBL is very difficult as it is often very site specific. The group should work closely with an EPC contractor to stay calibrated, given that cost estimating with the Aspen approach is only good within 25% at best. It is easy at this high level to "over model." Results should be used to provide directional guidance, as they often are. But, they are far less exact than often presented.
- This work has been well executed and appears to be utilized by researchers to guide and target research.

PI Response to Reviewer Comments

- Thank you for your helpful feedback and guidance. We recognize the uncertainties associated with estimating capital costs for emerging technologies. We will continue to work with engineering firms to develop high-quality capital cost estimates within the limits of our available funding and budgets. We will also continue to leverage published and quoted cost data for commercially available processes and equipment.
- We understand that first-generation, pioneer plants will be much higher cost relative to those for a mature industry as projected by our analysis. We maintain the capability for assessing pioneer plant costs and will continue to offer the capability to BETO as requested.
- As mentioned in other responses, we make efforts to present our work and make many of our tools available in the public domain. We also welcome and seek collaborative projects with industry partners.

FEEDSTOCK CHARACTERIZATION FOR THERMOCHEMICAL CONVERSION SPECIFICATIONS

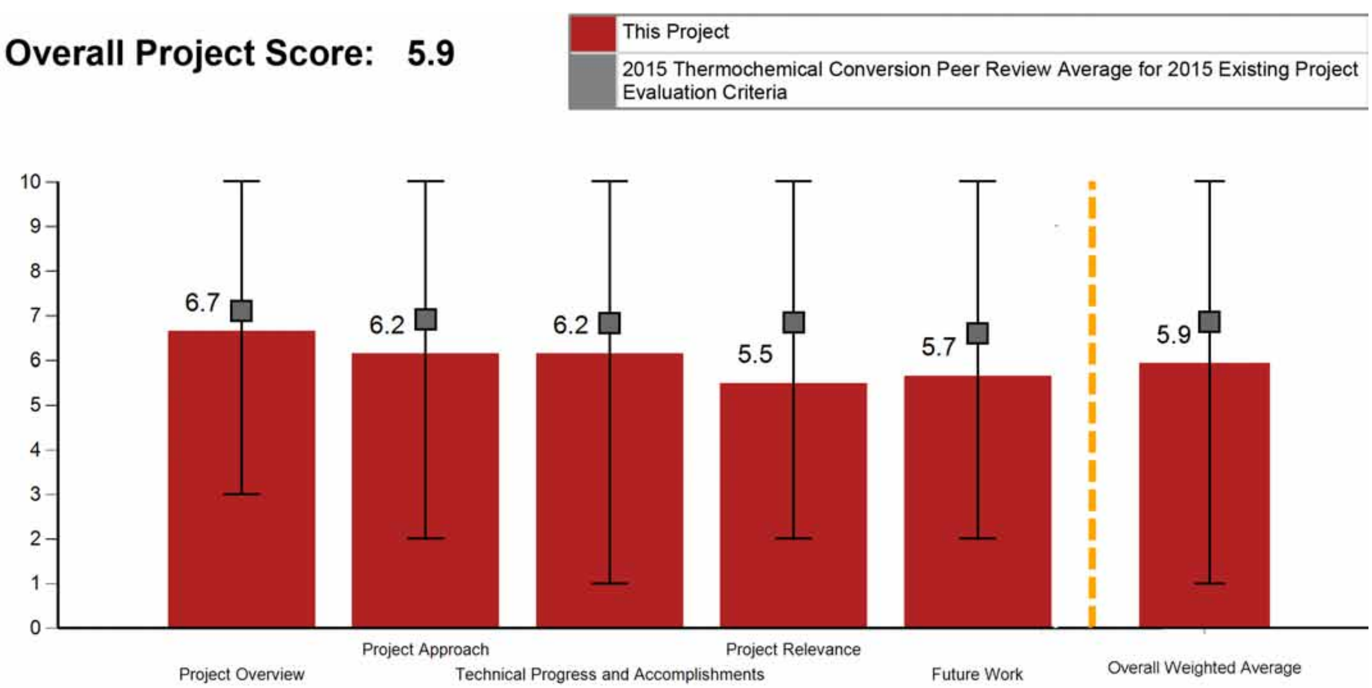
(WBS#: 2.2.1.301)

Recipient:	INL
Presenter:	Tyler Westover
DOE Funding FY14:	$960,565
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$89,435
Project Dates:	10/1/2013 - 9/30/2017

Photo Courtesy of INL

Project Description

The purpose of this project is to link supply chain expertise and capabilities at INL with corresponding conversion research at NREL and PNNL, so that feedstock specifications and conversion sensitivities can be established. This work involves determining the range and variability of key feedstock properties, such as ash content/composition, moisture, heating value, and oxygen content; evaluating the effectiveness and cost of pretreatment options to control key properties; and measuring the impact of such properties on the yield and quality of conversion products. The ultimate goal is to develop predictive supply and conversion models that are needed to enable least-cost formulations to be determined real time at a local level depending upon available resources. Key aspects of the project include: (1) developing rapid analytical screening tools for parameters that affect conversion reactions; (2) building a shared inventory of realistic, well-characterized, field-run samples; (3) assessing preconversion technologies; (4) performing conversion and upgrading tests to determine the impact of key feedstock properties; and



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

(5) developing predictive models for supply and conversion operations. Near-term future work will focus on select feedstocks and blends to perform comprehensive conversion and upgrading experiments from which predictive multivariate conversion models will be built.

Overall Impressions:

- I have never understood why this technology was assembled when there are so many industry leaders doing it better. This is an example of where an industrial consortium would have yielded tried and true results for a fraction of the cost.
- The project is making progress, but the differences between this and the NREL/PNNL task on thermochemical feedstock interface are unclear. To avoid a perception of overlap, DOE may want to combine these tasks and have them adopt an industry-based group to provide insight.
- The project is focusing on rapid analysis and pretreatment methods. This seems like an important element for developing a market to allow consumers to diversify feedstock use and understand the impact on their process. Work needs to understand reproducibility, which is part of the plan. Also, there is likely a lot of existing data that could be mined.
- The project is working in three significantly different areas to address issues. It is not clear how these approaches to characterization and ash removal impact the overall economics of conversion.
- The project results may be very useful, but the presentation and relationship with other similar projects make it difficult to separate what is specifically being derived herein. Projects that are tightly related and conducted by the same institutions should offer a coordinated presentation to address the integration and relationship of efforts.

PI Response to Reviewer Comments

- Data in the literature is often conflicting and almost never complete. This work has shown that yields from hydtrotreatment are very different from that of pyrolysis; consequently, both processes must be considered together. Combined tests showing results from fast pyrolysis and oil upgrading are virtually non-existent in the literature. When both conversion steps are combined, our results indicate that the relative importance of feedstock properties, such as content and composition of inorganics, changes from what has been published in the literature to date.
- Efforts at INL, NREL, and PNNL in the Thermochemical/Feedstock Interface are closely coordinated. Research plans are harmonized during each planning cycle, and results are shared between national laboratories throughout the year and are used to develop the next year's plans. This ensures that we make effective use of each lab's unique facilities and expertise while preventing duplication of efforts. Moving forward, the three projects will be formally reviewed as one for the purposes of the Merit Review process and likely for future Peer Reviews.
- The total cost of ash on conversion is not yet determined because it involves many effects, including unwanted participation in conversion reactions, catalyst poisoning, and downstream filter problems. This project collaborates with Logistics projects to develop TEAs of the processes to estimate the economics of feedstock supply, preprocessing, and conversion.
- DOE balances funding through FOAs, industrial consortiums, and efforts by national laboratories to move research forward while also maintaining capabilities so that tests can be repeated, modified, or advanced as needed. By investing in capabilities at the national laboratories, DOE ensures that annual SOT reports can be developed and delivered with consistent supporting data and assumptions.

HIGH THROUGHPUT CHARACTERIZATION

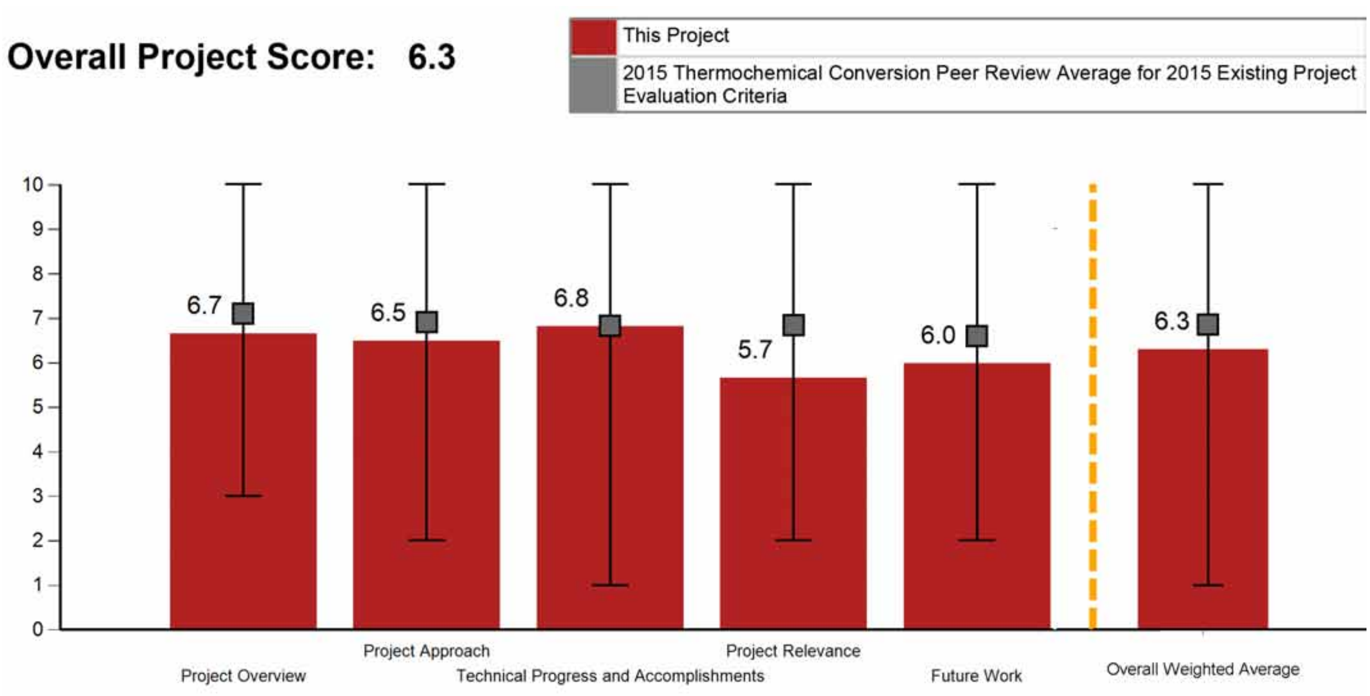
(WBS#: 2.2.1.303)

Recipient:	INL
Presenter:	Gary Gresham
DOE Funding FY14:	$226,665
DOE Funding FY13:	$432,843
DOE Funding FY10-12:	$714,686
Planned Funding:	$250,806
Project Dates:	10/1/2010 - 9/30/2017

Photo Courtesy of INL

Project Description

The objective of the High Throughput Characterization (HtC) project is the automated high-throughput comminution of biomass samples in preparation for analytical characterization. This effort supports development of feedstock specifications and grades for optimized dynamic blendstocks that meet cost, quality, and conversion targets. Every sample that enters the Biomass Characterization Lab or exchange point characterization requires some level of comminution and sample preparation. Sample comminution impacts all aspects of research within the Feedstock Platform and entails a large investment in time and human resources. The comminution process has become a bottleneck to developing large robust data sets of feedstock attribute data. The goal for the coming year is to develop a demonstration-scale robotic workcell for grinding that can enhance speed, consistency, reliability and throughput of the comminution process. The system will utilize a set of automated conveyors for input and



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

output queues with a robotic arm to process the samples from the input queue, through an automated feeder and Wiley mill grinder, and back to the output system. The resulting system will advance the state of the art for sample preparation, streamlining rapid characterization protocols to provide robust and timely data sets that will enhance the understanding of feedstock attributes for researchers, industry, and policy makers.

Overall Impressions

- Utility of the project is completed, with the first 50% of project funds spent. Trying to figure a way to make a free robot work will cost many times more than the budget allows.
- The review presentation did not quantify how any more samples would actually be analyzed compared to the present state of the art. Clear, quantifiable goals are needed to ensure the project is relevant.
- The project speeds up sample analysis and provides large amounts of data, but it needs to work out impact if the project is successful, e.g., how much will throughput increase?
- This project is a routine implementation of automated sample preparation that has been common in industry for over 25 years. It could result in significant savings in labor and reductions in sample preparation time if the sample load continues and grows.
- The approach may be good from a purely technical perspective, but the number of samples evaluated may be distracting from addressing other, more informative analysis. When using an automated sample preparation approach, a statistical analysis of the approach should be included. This is what will be required when moved into an industrial setting.

PI Response to Reviewer Comments

- The current project goals are primarily focused on improving throughput, reducing overall analysis costs, and building large and robust biomass feedstock quality attribute data sets. These data sets will be used to reduce risk within the logistical supply chain; understand variability and bound specifications to allow blendstock formulation; and support development of feedstock specifications and grades, and quality control options for transaction-point valorization. Most current rapid-screening and analysis methods require the biomass sample to be ground and homogenized. It is important to note that high throughput comminution and rapid-screening and analysis have both near-term benefits and long-term applications. In the near term, the analytical data provides the foundation for all the feedstock blending options, provides the data that supports the state of technology reports and development of specifications and modeling, as discussed. Long-term applications can be directly applied to area resource evaluations and transaction-point characterization.
- The baseline grinder used to develop these methods was the Wiley Mill, although other, more efficient options are being investigated in collaboration with Eberbach Corporation and Forest Concepts. Currently, manual grinding requires roughly 1 hour of technician time per sample for 5 gallons of material, and can take longer depending on the initial and final format, and type of biomass. The throughput target for this sample preparation system is between 6 and 10 samples per hour over a 24-hour period, which is at minimum a 16-fold increase (e.g., 9 samples/day to 144 samples/day). It is anticipated that with the future characterization needs for testing blended feedstock options, dynamic blending, area resource evaluations, and development of

feedstock specification and grades, 2,500 to 5,000 samples will be required in a single month. This would require sample throughput to increase from 8 to10 samples a day, to 75 to 150 samples a day, or more. The overall throughput of the grinding and sample preparation system will be greatly improved, because the system will be capable of continuous operation, and the robotic system will be capable of servicing multiple grinding units.

- The ability to process large numbers of feedstock resources will provide robust data sets for the Least Cost Formulation model (which will include quality in FY15), allowing industry, financial investors and researchers to take full advantage of the billion ton resources that are available, and provide blend options for specific areas and feedstock resources. It is anticipated that the high throughput methodology will support process control options within depots, rapid analysis and screening at conversion refineries, and transaction-point characterization options.
- The robot hardware to be utilized on this project has been used extensively on other work at the Idaho National Laboratory. The software and hardware used to interface the robot with equipment in a robotic workcell was heavily leveraged to enable a rapid start-up of this project, saving several months of development time compared to what would be required with a new robot system.
- To better address the needs to verify the consistency of the output, work scope includes performing statistical analysis to demonstrate that automated grinding delivers samples that are equivalent to the manually ground samples. The efficacy of intra-sample cleaning methodologies will be determined, as well as the potential impact that increased mill throughput, enabled by augmentation, may have on particle morphology. The project will also include a statistical analysis of the overall average turn-around and throughput of the system under actual processing conditions.

THERMOCHEMICAL FEEDSTOCK INTERFACE

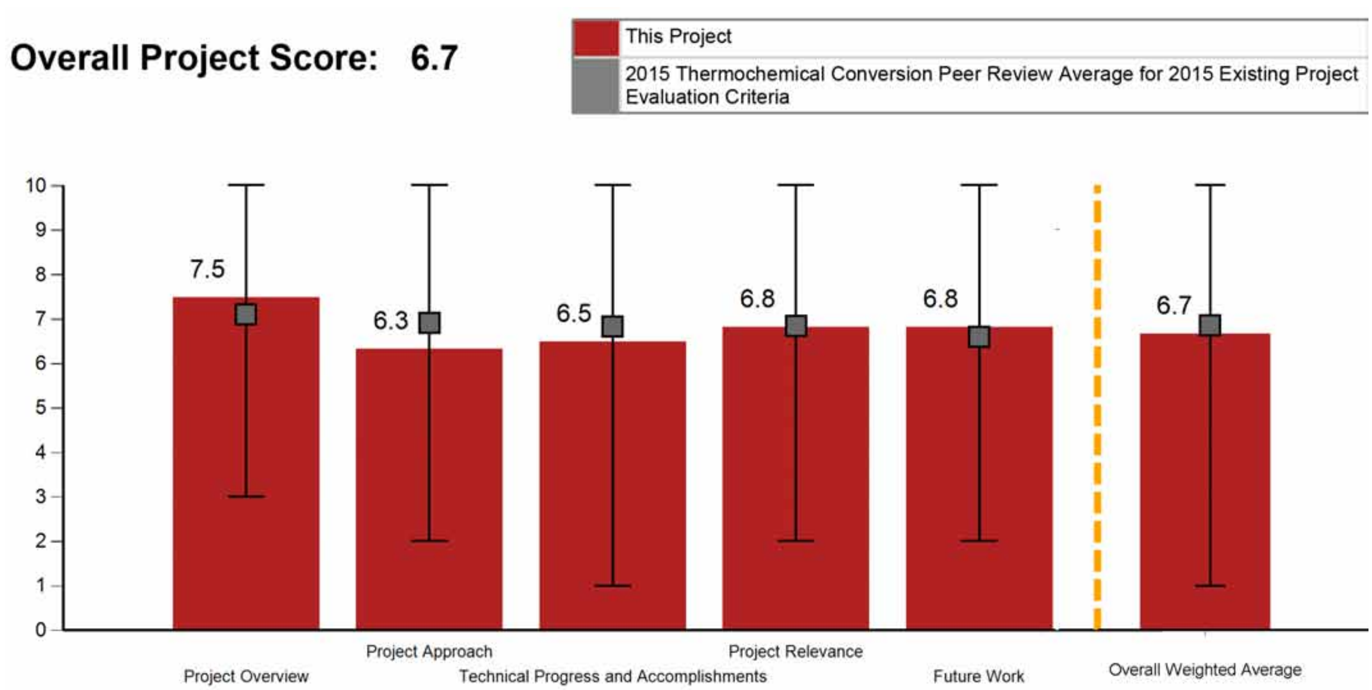
(WBS#: 2.2.1.304, 2.2.1.305)

Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Danny Carpenter
DOE Funding FY14:	$1,543,177
DOE Funding FY13:	$1,269,604
DOE Funding FY10-12:	$907,877
Planned Funding:	$2,306,836
Project Dates:	10/1/2010 - 9/30/2017

Project Description

Cost-competitive production of domestic biofuels on a national scale will likely require inclusion of low-cost and diverse biomass types into the supply chain. However, the impact of feedstock on product yield, composition, and overall conversion efficiency is poorly understood. Working with INL for high-impact feedstock selection and pre-conversion strategies, the NREL and PNNL Thermochemical Feedstock Interface projects evaluate the effects of feedstock on direct liquefaction technologies (fast pyrolysis/hydrotreating, in-situ/ex-situ vapor upgrading, hydrothermal liquefaction). The near-term objective is to establish in-feed specifications that ensure BETO's FY17 conversion cost target of $2.47/gge is met for bio-oil upgrading with an $80/dry ton blended feedstock. Among this project's key achievements in FY14 was an integrated study of the fast pyrolysis/hydrotreating pathway using six feedstocks and two blends. The feedstock was found to have distinct effects on multiple parts of the process, including bio-oil yield/composition, hydrotreating yield, hydrogen consumption, selectivity to fuel products, and overall conversion cost ($2.50-$4.10/gge). While



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

investigating how the very broad range of potential feedstocks and their natural variability will affect multiple conversion technologies remains a challenge, this is the type of process-relevant data that will help a biofuel industry co-optimize biomass resource development and conversion technologies at a lowered overall risk.

Overall Impressions

- The idea of building a database of feedstocks with fundamental information is very good.
- The work in this project is closely related to the INL Thermochemical Feedstock Interface project. To avoid the perception of overlap and duplication of effort, DOE may want to combine these projects into a single, integrated project.
- Relating feedstock properties to performance is key, as is determining how to economically blend different feedstocks. The project needs to make a final connection with producing a quality fuel. Quality data is important for tight material balanced results. Also, this project needs to be formally linked together with the two INL feedstock projects (presented by Tyler Westover and Gary Gresham).
- This work is exploring significant feedstock issues, but would benefit by expansion to include processing variables. To be relevant in the long run, the work should focus on cost-effective existing techniques rather than new and often exotic characterization tools.
- This is the key program collecting process data, and it probably should be expanded.

PI Response to Reviewer Comments

- Several quality indicators are assessed for the hydrocarbon fuel blendstocks produced in this project, such as simulated distillation, water content, total acid number, CHNS/O, viscosity, density, inorganic content, and heating value. Additionally, efforts are underway in separate Analysis projects to develop advanced biofuels blending models to estimate the value of biomass-derived blendstocks to refineries. We will coordinate with these projects to ensure that fuel quality data are relevant.
- Although reviewed separately this year, the Feedstock Interface projects at INL, NREL, and PNNL are very closely coordinated. Research plans are harmonized during each planning cycle, and results are shared between the national laboratories throughout the year and are used to develop the next year's plans. This ensures that we make effective use of each lab's unique facilities and expertise while preventing duplication of efforts. Moving forward, the three projects will be formally reviewed as one for the purposes of the three-year Merit Review process and for future Peer Reviews.
- Initial performance tests were conducted using several feedstocks under the same processing and catalyst conditions. Work will now shift to investigating and optimizing process conditions, especially for blended feedstocks that meet DOE cost targets. While process development (catalyst and reactor design, for example) is not in the scope of this project, a major objective is to identify potential issues, such as poor performance or contaminants from low-cost feedstocks, at an early stage as processes are developed and optimized to avoid feedstock-related problems during scale-up.

HYDROTHERMAL PROCESSING OF BIOMASS

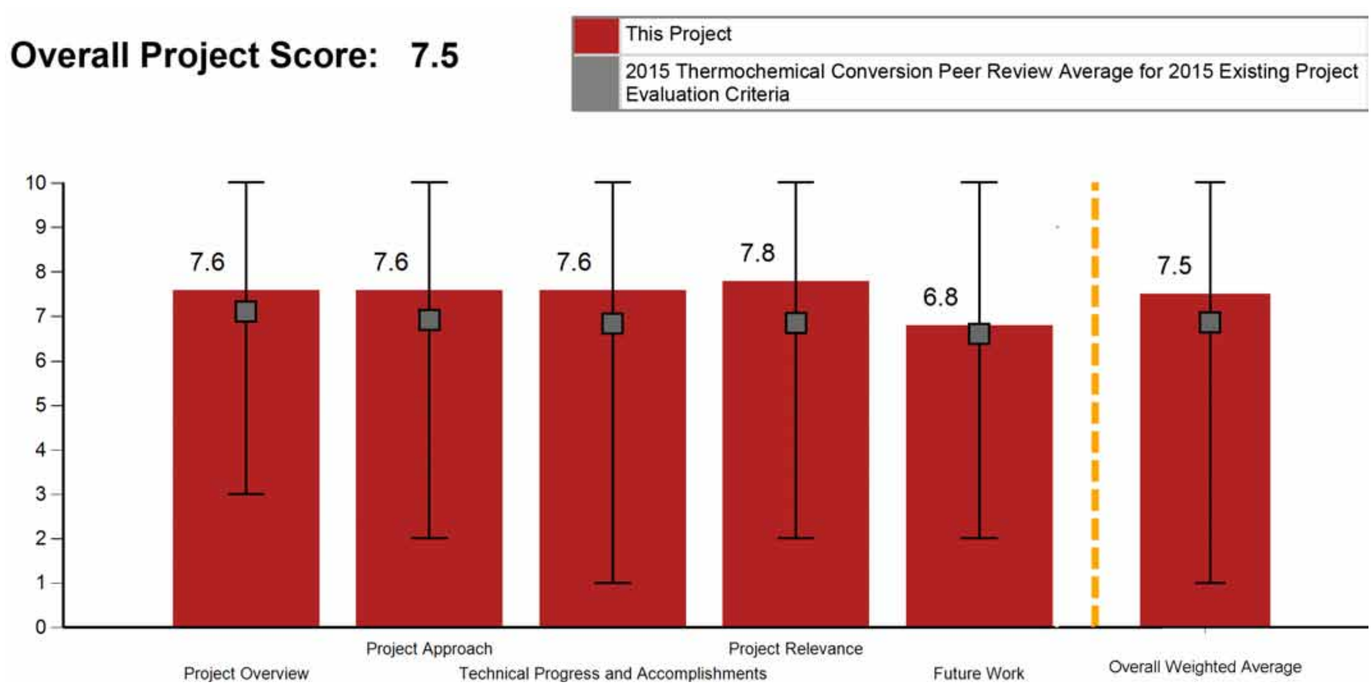
(WBS#: 2.2.2.301, 2.4.1.303)

Photo Courtesy of PNNL

Recipient:	PNNL
Presenter:	Richard Hallen
DOE Funding FY14:	$1,252,885
DOE Funding FY13:	$2,258,340
DOE Funding FY10-12:	$1,619,372
Planned Funding:	$9,176,505
Project Dates:	10/1/2010 - 9/30/2017

Project Description

This project is working to advance the state of hydrothermal liquefaction technology (HTL), improve overall process performance and economics, and determine the value and best pathway to market for the product. The HTL technology has unique and compelling attributes for the production of biocrude from woody, agricultural, and waste feedstocks. This effort will advance the technical readiness/modality of HTL through leveraging existing capabilities, programs, key relationships and the recent HTL developments under national consortiums (NABC and NAABB) and Work for Other (WFO) agreements. The R&D efforts have been focused on the highest priority challenges identified in internal and independent TEAs and design evaluations. HTL has shown attractive attributes for producing a biocrude, which is thermally stable, low in oxygen (c.a. 10%) and can be upgraded in a single staged hydrotreater. PNNL has been engaged in various scales of HTL testing starting with batch reactors in the 1970s. The major advances started in 2008 with the development of lab and bench-scale continuous flow reactor systems. Very few research organizations have the capabilities and expe-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

rience level to conduct continuous HTL testing. PNNL has successfully demonstrated continuous HTL processing with a wide range of whole feedstocks, including wood, corn stover, algae, and other wet feedstocks. Research from bench-scale testing was used for development of two pilot-scale facilities by industrial partners.

Overall Impressions

- HTL conversion seems to be the exclusive focus when a major concern is the separation of useful product from water and contaminants that is likely to be the key issue.
- Transitioned from batch to continuous system. Need to demonstrate long-term operation, in both hydrothermal and upgrading reactors. What becomes of the wastewater and the organic contained within? What about the pH adjuster?
- The project has potential interest, but needs to use techno-economic analysis to set measurable targets and goals.
- This project is off to a good start and shows good initial project management and execution.

PI Response to Reviewer Comments

- Thank you for your comments and questions. PNNL has made significant engineering improvements with regard to the continuous HTL processing of biomass feedstocks. The engineering improvements to the HTL system have provided stable operation over longer operating periods. For biocrude upgrading, catalyst stability has been demonstrated for over 200 hours using a single-stage catalyst bed. TEAs have shown that upgrading HTL biocrude provides significant reduction in final fuel costs compared to fast pyrolysis.
- Depending somewhat on the feedstock composition, HTL will generally convert the majority of the organic carbon to a phase separating biocrude. However, a significant amount of carbon is converted to low molecular weight; water soluble compounds, and research on conversion or treatments of these compounds, is ongoing. A relatively new project within BETO is examining recovery of value from aqueous by-products, "Characterization and Valorization of Aqueous Phases Derived from Liquefaction and Upgrading of Bio-oils," and we are providing this project HTL samples for their work.
- For HTL of wood and dry agricultural wastes, the addition of some amount of sodium carbonate has been required to buffer pH. However, other feedstocks, such as algae, do not require pH adjustment. It is expected that other wet wastes feedstocks may not require pH adjustment, but the testing is just starting for these feedstocks.
- TEAs are being used by the HTL team to set measurable goals and targets. Near-term research is focused on generating the data needed to complete the TEA for the new feedstocks. The TEAs are used to identify the most attractive feedstocks, and the key areas to focus the R&D for economic viability of HTL.
- One key area for HTL cost reduction identified by the TEA is improved separations. We are exploring various technologies for continuous separations, including water/oil separation at higher temperature and pressure. Intellectual property has also been developed on an improved water/oil separation for HTL biocrude and BETO supported the patent preparation/filing for the new process.

LIQUEFACTION OF AGRICULTURAL AND FOREST BIOMASS TO "DROP-IN" HYDROCARBON BIOFUELS

(WBS#: 2.2.2.401)

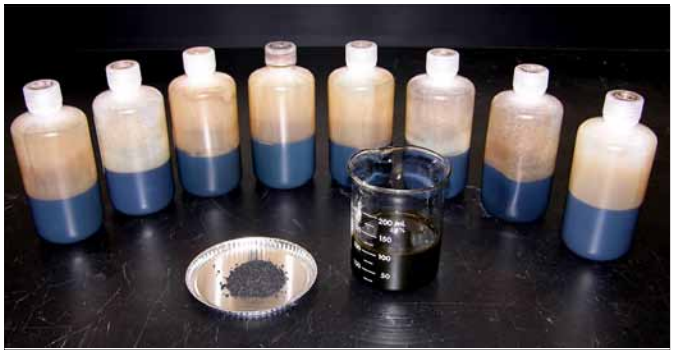


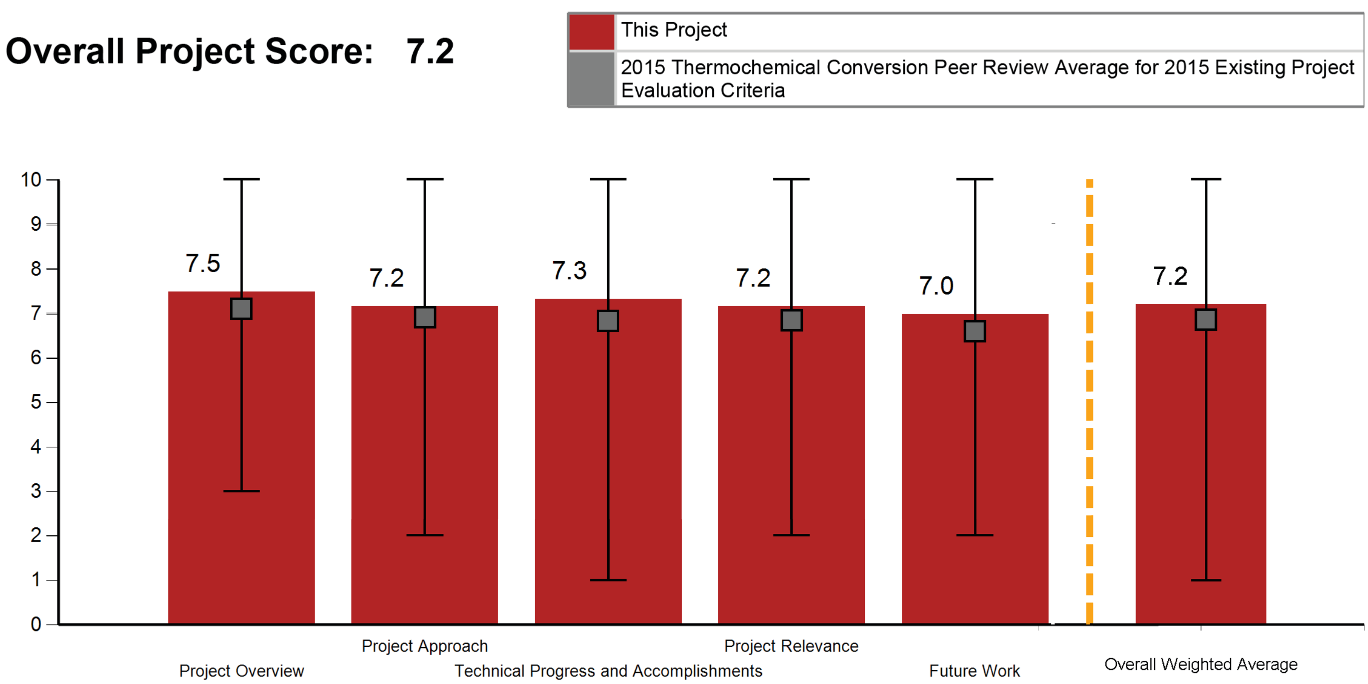
Photo Courtesy of ISU

Recipient:	Iowa State University (ISU) of Science and Technology
Presenter:	Ryan Smith
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$3,500,000
Project Dates:	1/1/2013 - 12/31/2015

Project Description

Iowa State University and Chevron Technology Ventures (CTV) are collaborating to demonstrate solvent liquefaction as a pathway to produce low cost drop-in hydrocarbon transportation fuels. A 1 kg/hr continuous liquefaction unit built by Catchlight Energy, a joint venture between Chevron and Weyerhaeuser, has been redesigned and rebuilt at ISU to demonstrate continuous production of stable bio-oil from forest biomass. A liquid cut will also be recovered and directly recycled for use as a solvent in the liquefaction reaction. This unit will also demonstrate continuous solids removal. The bio-oil will be hydroprocessed to refinery-compatible biocrude and fuel blendstocks. Optimal hydroprocessing conditions will be developed by CTV. Continuous production and recovery of bio-oil and solvent, direct solvent recycle, solids removal and hydroprocessing of resulting bio-oil are critical in demonstrating the commercial viability of solvent liquefaction for the production of drop-in hydrocarbon transportation fuels. The results of the pilot plant and hydroprocessing tests

Overall Project Score: 7.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

will be used to conduct a techno-economic analysis and develop a preliminary process design for a demonstration plant. A three-year study to examine response of wildlife and plant communities to biomass removal and intercropping of native switchgrass within pine stands is nearly complete. Major negative impacts on water quality, biodiversity or soil productivity have not been observed.

Overall Impressions

- This is good fundamental work, but the question of separation of product from water and contaminants is still the issue.
- This is an interesting solvent-based approach, which produces a stabilized bio-oil for upgrading to hydrocarbons. The potential of this concept to have impact should be clearer in 2016 when the project is complete.
- The project moves a promising technology of solvent liquefaction toward commercialization by demonstrating continuous operation with solvent recycle and solids removal. The project needs to determine how much makeup solvent with similar hydrogen donation properties would be required, and needs to consider the fate of wastewater. Other projects in the BETO program show fouling/plugging with bio-oils during hydrotreatment with 25% oxygen (so this may be too high). Long-term operation of the upgrader is an important part of the demonstration.
- The effectiveness of solvent-assisted liquefaction is a worthwhile new approach to try.

PI Response to Reviewer Comments

- The hydrotreating aspect of the project is a key deliverable, and previous proprietary studies suggest that 25% oxygen is sufficient for upgrading. Provisions for independent insertion of makeup solvent were accounted for in the initial design. Extensive care was taken in both design and selection of components to provide detailed mass balance information around the system as a whole in order to answer questions around solvent consumption. Wastewater is isolated from the system in two distinct locations as fairly pure product fractions. These materials will be evaluated for both mass closure and speciation in order to consider wastewater treatment strategies in the proposed techno-economic analysis.

BIO-OIL UPGRADING WITH NOVEL LOW COST CATALYSTS

(WBS#: 2.3.1.301)

Recipient:	ORNL
Presenter:	Jae-Soon Choi
DOE Funding FY14:	$456,557
DOE Funding FY13:	$463,764
DOE Funding FY10-12:	$0
Planned Funding:	$579,678
Project Dates:	10/1/2012 - 9/30/2017

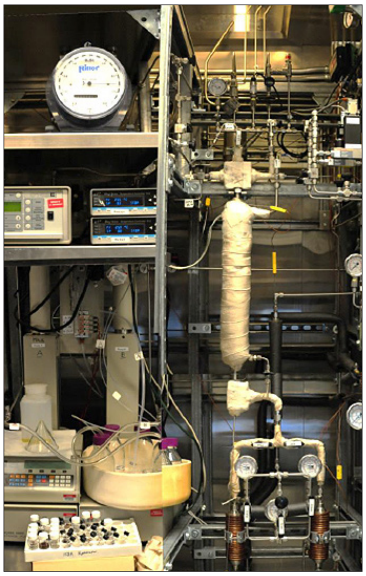
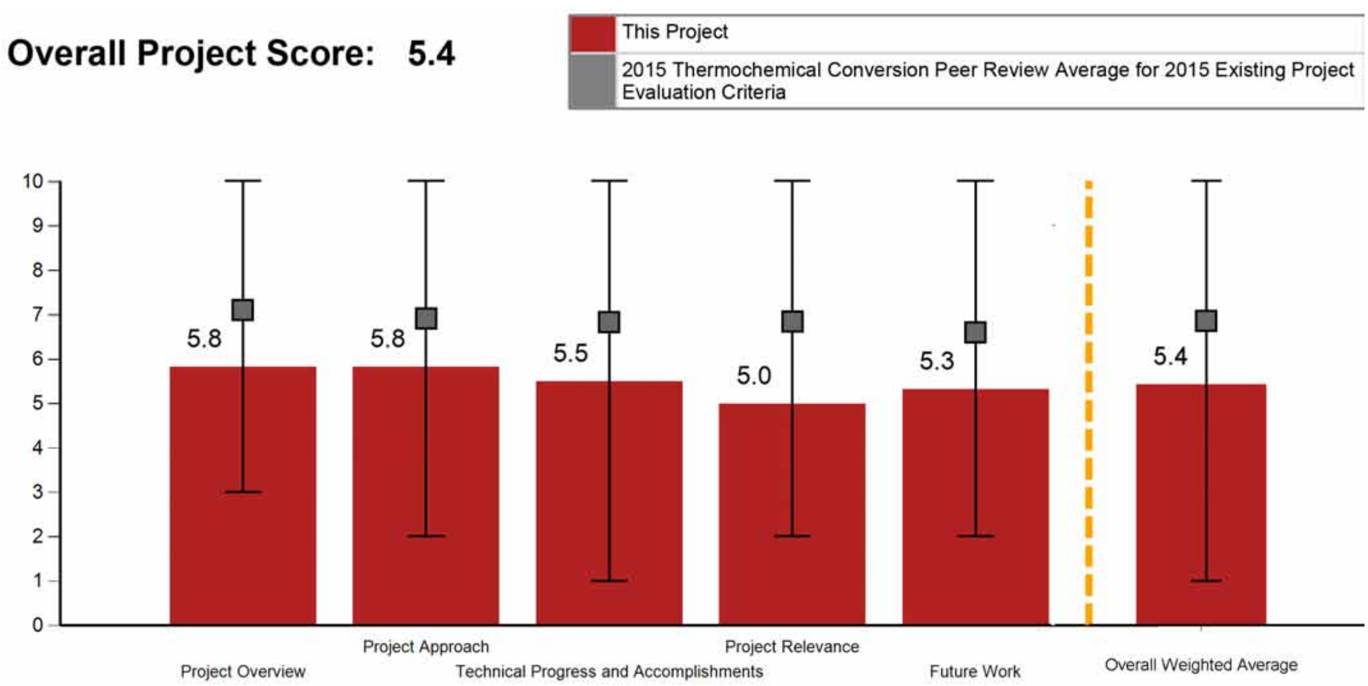


Photo Courtesy of ORNL

Project Description

The project purpose is to develop novel catalysts effective for bio-oil hydroprocessing that are less expensive and more durable than the state of technology. Our approach is to engineer catalysts based on transition-metal carbides which are low-cost materials and do not require sulfiding agents in the feed. The catalyst development is guided by detailed synthesis and characterization study at ORNL and real bio-oil testing and techno-economic analysis at PNNL. To achieve the FY17 conversion cost target, BETO identified the high cost and limited durability of catalysts as critical barriers to address. Challenges to be overcome for project success include limited knowledge and industry experience available on carbide application to bio-oil hydroprocessing. The project team has developed a method to prepare shaped bulk carbide catalysts. A range of Molybdenum (Mo), Wanadium (W), and Niobium (Nb) carbides were synthesized, characterized and evaluated with model compounds, which led to a down-selection of Mo carbides for in-depth study and optimization. Select Mo carbides were tested in two-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

stage hydroprocessing of real bio-oil and initial TEA comparison to baseline catalysts was made. Results showed that carbides possess several properties, which could lead to significant conversion cost-saving; i.e., no precious metal, less hydrogen consumption, less carbon as CO_2, and regenerability. Future work will be focused on designing effective regeneration strategies and enhancing catalyst activity.

Overall Impressions

- Short-term catalyst tests are not very useful. Contaminants are often present in small amounts and build up.
- The proposed catalysts are scientifically interesting, but initial results are about the same as baseline catalysts from others. The project does not have clearly established metrics for what the performance needs to be or how that will be achieved.
- Even with a different support, the project still has a problem with coking and fouling. The new support has not eliminated the problem. The biggest problem is the catalyst life, not regeneration. Is plugging homogeneous or heterogeneous? The project needs to connect with other work funded by BETO suggests that inorganic content may be a huge source of deactivation in addition to carbonaceous residues.
- This project appears to be solving a problem that may not exist. Workers need to clearly show an advantage over existing catalysts.
- The research effort is lost in technical scientific details and needs to move toward catalyst development with longer-term commercialization potential – that direction is not apparent at this time.

PI Response to Reviewer Comments

- We thank the reviewers for their insightful comments, which we will consider carefully for our future work.
- This project has shown that carbide catalysts are robust in bio-oil hydroprocessing, which involves high-temperature water. The novel catalysts, therefore, appear to have potential to solve one of the critical challenges the existing catalysts face; i.e., limited hydrothermal stability. It is also encouraging to see that the carbide catalyst in its infancy can perform at least as well as the state of technology in real bio-oil upgrading.
- Catalyst fouling/plugging remains a single most important technical barrier to achieving the project goal, which is significant reduction in bio-oil conversion cost. The carbonaceous deposits leading to catalyst fouling can resemble coke. Another type of foulant we often observe is more akin to a phenol formaldehyde resin chemistry, more of a homogenous chemistry issue. We will continue collaborating with other BETO efforts and partners to understand this chemistry and roles of biomass-specific fouling agents. The gained insights will guide us to develop effective deactivation mitigation and regeneration strategies.
- We will track via techno-economic analysis our progress toward developing catalysts, which are less expensive, more durable, and more easily regenerable than the state of technology.

BIO-OIL QUALITY IMPROVEMENT AND CATALYTIC HYDROTREATING OF BIO-OILS

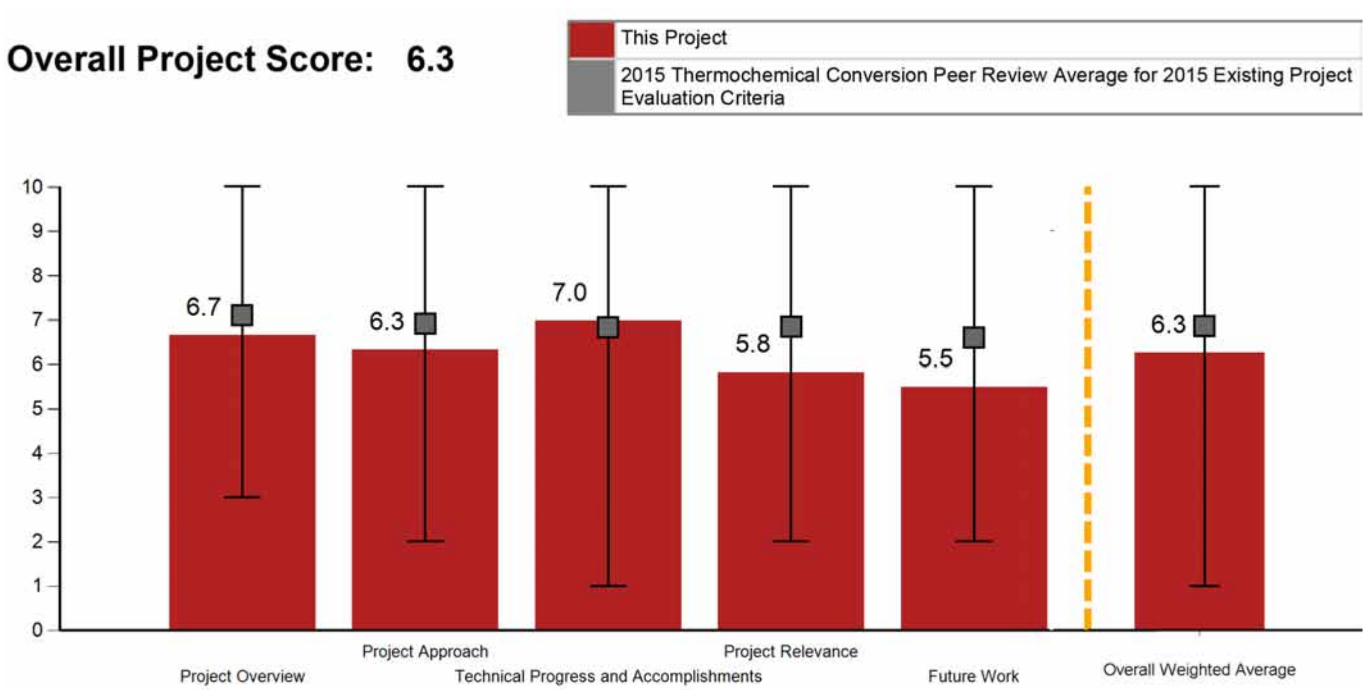
(WBS#: 2.3.1.302)

Recipient:	PNNL
Presenter:	Mariefel Olarte
DOE Funding FY14:	$975,216
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$5,684,784
Project Dates:	10/1/2013 - 9/30/2017

Photo Courtesy of PNNL

Project Description

The project objective is to advance the technology for liquid transportation fuel from biomass via fast pyrolysis and catalytic upgrading to overcome existing barriers to commercialization by driving the technology toward the FY17 targets established in the MYPP through targeted research. Despite excellent improvements in the state of technology, bio-oil refining has a significant maturity gap compared to the 70-year history of petroleum refining. While biomass pyrolysis to a liquid bio-oil is well understood, it is not a direct replacement for petroleum at any point in the spectrum of petroleum refining. Catalytic refining of bio-oil makes it compatible with petroleum refining, demonstrating a unique potential for producing biomass-derived liquid transportation fuels. Still, some unique challenges need to be overcome. Catalyst lifetime as long as 60 days has been demonstrated, where only a few years ago, five days was considered successful. Sustained improvements in catalyst lifetime



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

and reductions in cost drivers will make this pathway economically compelling. The key areas of development are: (1) catalyst development; (2) quality improvements of the intermediates and products; (3) novel process development; and, (4) demonstration at scale. The project also interfaces with four other supporting BETO efforts, including the techno-economic analysis task, the feedstock interface task, the bio-oil analysis task, and the fundamental catalysis consortium.

Overall Impressions

- The project is making very good progress in the area of catalytic upgrading of liquid bio-oils.
- Need to address scale-up issues, mass transfer, heat transfer, and gas-liquid distribution. Reactor exotherms appear to be an issue that need to be addressed, both experimentally to get good quality data and industrially to be able to safely operate. Also, need to get beyond pricing on a gasoline gallon equivalent (gge) basis by using heat values. Need to look at the fuel quality.
- This ambitious project needs clear quantitative measures of success.
- This is another example of developing a technology that will be ready for technology transfer in the next few years, showing good promise at this stage in the project life.

PI Response to Reviewer Comments

- Excellent comments throughout. As reviewers advise, we have been focusing more on squaring our results with modeling to capture the issues of mass transfer, scale, and heat transfer to capture the process in a way that it can be both understood and scaled. We agree with the reviewers; product quality is now in focus, particularly as we are moving toward scale that can reliably generate the sample fuels needed for product-specific analyses.

NOVEL AND ROBUST CATALYSTS FOR BIO-OIL HYDROTREATING

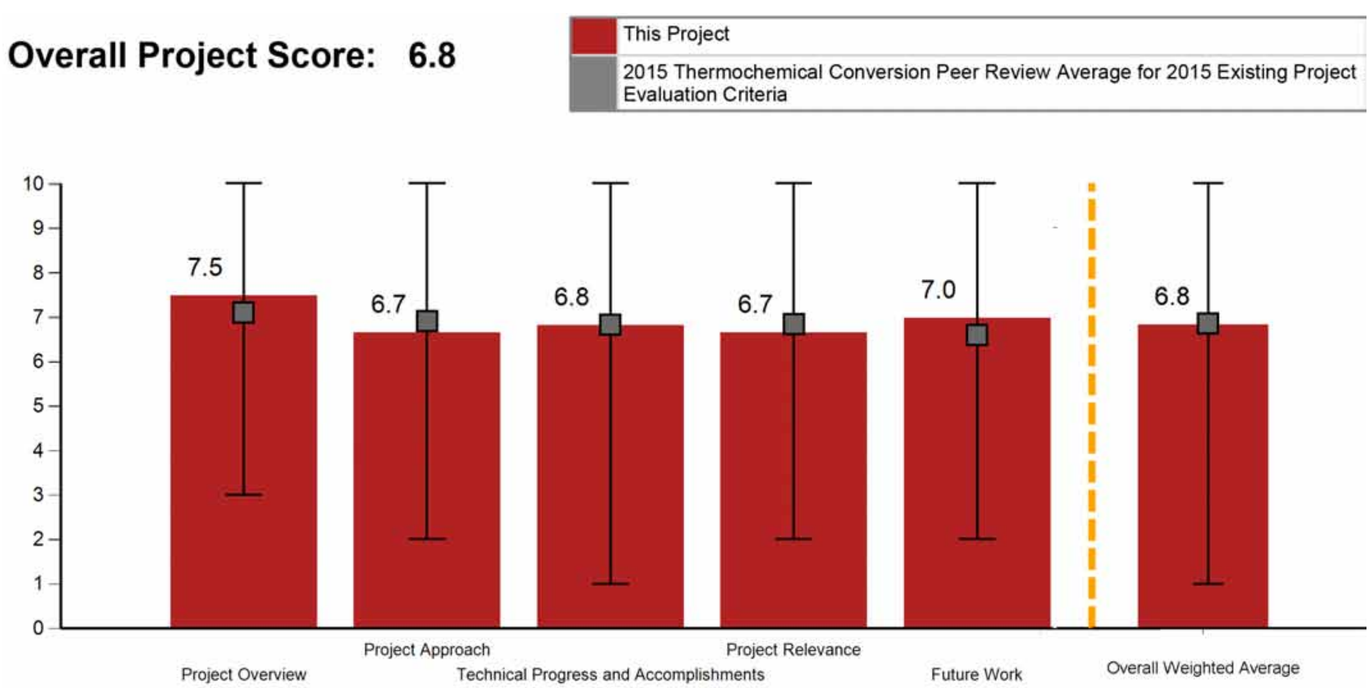
(WBS#: 2.3.1.303)

Photo Courtesy of PNNL

Recipient:	PNNL
Presenter:	Corinne Drennan
DOE Funding FY14:	$206,406
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,573,594
Project Dates:	10/1/2013 - 9/30/2017

Project Description

The purpose of this project is to lower the cost associated with bio-oil hydrotreating catalysts by addressing catalyst deactivation issues through advancing the understanding of bio-oil hydrotreating chemistry and developing new generation catalysts with improved lifetime and functionality over conventional systems. This project is to further improve the non-sulfide catalyst line previously developed in Pacific Northwest National Laboratory for a two-step process for bio-oil hydrotreating. This project ties directly to upgrading process goals and targets of BETO and supports its cost goals. The successful project will have developed new generation bio-oil hydrotreating catalysts with lower bio-oil production cost associated with catalysts and improved the understanding of bio-oil hydrotreating chemistry to narrow the knowledge gap in bio-oil upgrading processes. The major potential challenges include deactivation of non-sulfide metal catalysts by sulfur poisons in bio-oil, balancing catalyst performance requirements and catalyst production cost, and complexity of bio-oil resulting in difficulties for correlating with performance. Since February 2014, this project has developed catalysts with extensively varied



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components; conducted catalyst synthesis, detailed characterization, and bio-oil hydrotreating testing; and established correlations between metal identity, solid acid, and the performance of hydrotreating catalysts.

Overall Impressions

- I don't understand how the DOE catalyst projects are finding that there are inorganics in biomass. The fact that they exist in sometimes huge quantities should inform the projects before they start. No wonder they see short lives.
- The project is making good progress toward goals that are relevant to BETO.
- Inorganics are an issue in catalyst deactivation. How best this issue should be addressed? How are the inorganics distributed on the catalyst? Perhaps a top bed support material to remove and protect the catalyst might help. Would a bimodal support be better with the large pores used to collect the inorganics? It still feels like there are more unknowns than knowns.
- The project needs to justify its reason for not using sulfided catalysts; especially when the replacement catalysts it proposes are easily poisoned by sulfur in the feedstock. The assumed shortcomings of sulfided catalysts are never established.
- The work quality at this time seems to be on track for supporting the BETO 2017 objectives.

PI Response to Reviewer Comments

- We greatly appreciate the comments and suggestions from the reviewers. We are fully aware of the complexity of bio-oil and also identified the major attributes of bio-oil that affect the stability of their hydrotreating, such as contaminants and active species, and the corresponding deactivation mechanism of bio-oil hydrotreating catalysts (i.e., catalyst poisoning by contaminants and catalyst fouling by condensation product of active species). We and other labs working on the related projects are also fully aware that the existence of inorganics and extensive research results have been obtained as relates to the properties of inorganics in bio-oil and its effects on bio-oil properties and upgrading. Several approaches have been developed to reduce the inorganics in bio-oils, including hot-vapor-filtration during fast pyrolysis (NREL and PNNL) and bio-oil cleaning by ion-exchange (Battelle and PNNL). This project specifically understands the consequence of the deep removal of inorganics from bio-oil by ion-exchange in the two-step hydrotreating process and the catalyst deactivation mode related to the inorganics. We will utilize TEA to evaluate the cost of the bio-oil cleaning process and therefore identify most promising opportunities.
- Non-sulfide reduced metal catalysts are essential for the current multi-step process including stabilization followed by hydrodeoxygenation (HDO) for bio-oil hydrotreating. In particular, the stabilization step by hydrogenation relies on the high hydrogenation activity of reduced metal catalysts, primarily the precious metal catalysts, at a relative low reaction temperature (80-180 °C), which is beyond the capacity of sulfide catalysts presently available. The sulfide catalysts designed for hydrotreating of the refined petroleum products are functioning well on the HDO step at a higher temperature (350-420 °C). However, this occurs at the disadvantage of catalyst deactivation, high reaction temperature requirement, extra sulfur addition to bio-oil, and difficulty of catalyst regeneration by coke removal. As a result, the limited catalyst lifetime has been identified as a bottleneck of the bio-oil upgrading process.
- Research on the developing alternative catalysts specifically designed for bio-oil hydrotreating, including the reduced metal bifunctional catalysts in this project, is greatly helpful for the success of the biomass to fuels via bio-oil technologies. The major advantages of the bifunctional catalysts over the high temperature HDO catalysts include better

activity, lower reaction temperature, and regenerability. Of course, the sulfur poisoning presents a significant challenge; however, it could be address by improving sulfur resistance of the catalysts or by removing sulfur species from bio-oils, which are one of the focuses of this project. As demonstrated in the Battelle's bio-oil upgrading project, the reduced metal catalyst PNNL developed showed promising activity and stability for stabilization of Battelle's bio-oil. As a follow-up project of PNNL's catalyst development task of the Battelle's bio-oil upgrading project, this project will continue to improve the reduced metal catalysts for both stabilization and HDO step and closely compare to the conventional sulfide catalysts. TEA will be utilized to identify most promising opportunities and guide our catalyst development efforts to meet the bio-oil conversion cost goals and commercial viability.

LIQUID FUELS VIA UPGRADING OF SYNGAS INTERMEDIATES

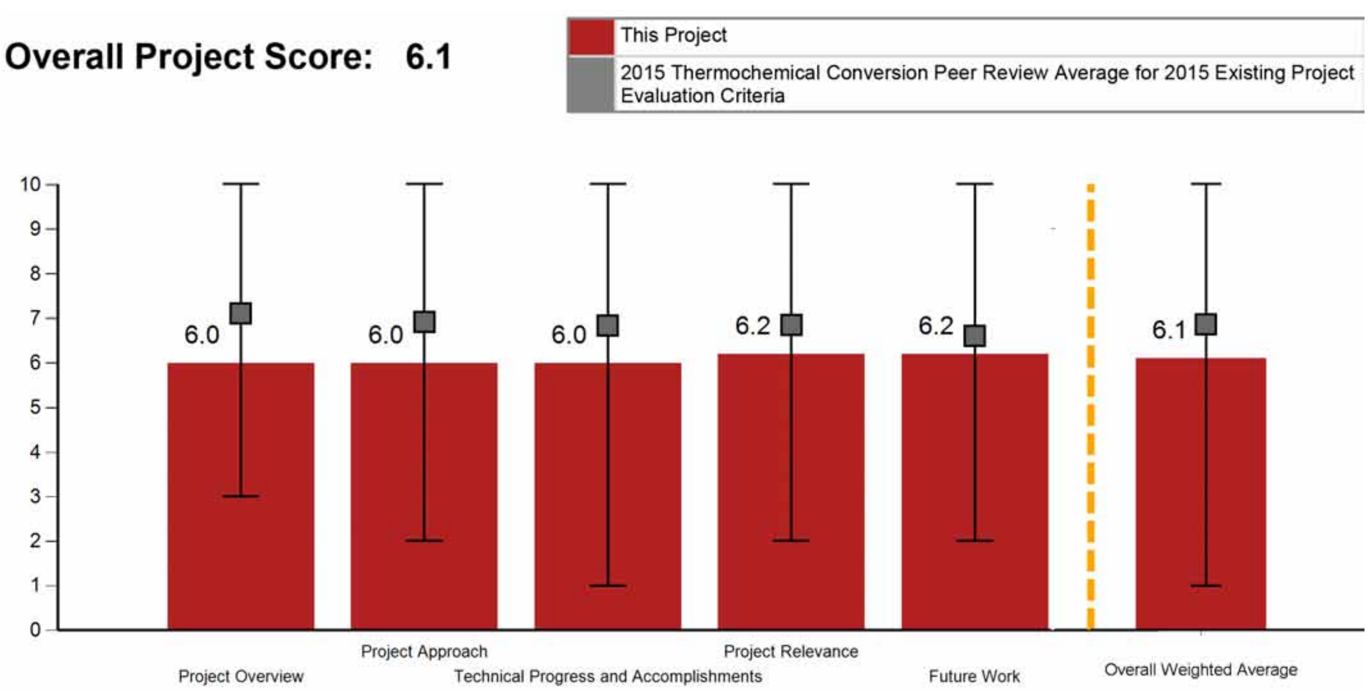
(WBS#: 2.3.1.305, 2.3.1.306)

Recipient:	NREL
Presenter:	Jesse Hensley
DOE Funding FY14:	$1,276,254
DOE Funding FY13:	$558,645
DOE Funding FY10-12:	$4,030,076
Planned Funding:	$8,548,160
Project Dates:	10/1/2010 - 9/30/2017

Photo Courtesy of NREL

Project Description

This project is a collaboration between the National Renewable Energy Laboratory and the Argonne National Laboratory to develop and demonstrate catalysts that convert biomass-derived synthesis gas to drop-in hydrocarbon fuels, while reducing total cost from the FY14 state of technology of $5.45/gge to $3.72/gge by FY17. The project is an extension of previous efforts to produce ethanol from syngas and leverages data generated prior to FY13 for upstream processes. Costs will be reduced via improvements to a novel syngas-to-gasoline and jet fuel process. The technological challenges addressed include the reduction of aromatic hydrocarbon byproducts and catalytic reincorporation of light hydrocarbons at low process temperatures (200 °C) without the use of expensive materials or severe operating conditions. Additional process challenges like recycle and catalyst lifetime are also considered. Since FY13, this task has demonstrated a two-thirds reduction in net aromatic production, coupled with a doubling of catalyst specific activity while maintaining product selectivity and cata-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

lyst lifetime. This was achieved through the addition of transition metals in small weight loadings. The project has applied advanced characterization techniques to understand the reasons for improved performance and is using data from those studies to develop strategies for additional catalyst improvements.

Overall Impressions

- The refocus from ethanol is key and it looks promising.
- The scientific work is good. A better justification of why this particular approach offers more potential than others would be useful.
- The project team needs to read the literature. There are inherent limitations to triptane due to back cracking. Also, look at the old Mobil literature if you want to obtain paraffins vs. aromatics in methanol-to-gasoline (MTG). Why not use Fischer-Tropsch (F-T), hydrocrack and hydroisom? All of this is known technology. Only by removing small amounts of products with a large recycle will the process work, and this will be costly. It would be better to target isobutane and send it to an alkylation unit to produce a high octane gasoline.
- This project has potential to produce distillate or high octane gasoline if the large C4 fraction can be converted to higher hydrocarbons.

PI Response to Reviewer Comments

- Thank you for the feedback and suggestions. The presentation contains many citations to the literature pertaining to this project, which we have reviewed extensively. We have also discussed challenges and catalyst limitations with several of the researchers who published that literature. In previous years, NREL (with PNNL) has considered the MTG and F-T process with biomass syngas. In both cases, yield loss was problematic, and this was due to the higher-severity operating conditions, higher losses to coke, and large number of process steps. As process size becomes smaller (as with biofuels), yield losses tend to have a larger impact on economics. Using F-T as an example, it has been demonstrated that massive scale is required to turn profits, even with inexpensive (or free) feedstock. The pathway we are studying holds promise in that it uses lower-severity conditions, has a smaller number of process steps, and has the potential for higher yield. The process models (developed in another project) suggest that the separation of product from recycle is straightforward and, because the process is not operated at high pressures, the OPEX/CAPEX associated with C4 recycle is not prohibitive. It is acknowledged that additional experiments with simulated and then actual recycle will be required to verify those Aspen models. Depending on the customer (refiner vs. blending terminal), we agree that optimization to isobutene production could be valuable. Our process models do not suggest, however, that an alkylation unit (instead of C4 recycle) is more attractive. We will certainly continue to explore that possibility as our research and the process models evolve. Finally, we agree with the reviewers that C4 conversion to larger hydrocarbons is critical to project success. We will focus our attention on this challenge and continue to couple our work with the thermochemical analysis project to ensure that we are spending our time and resources on the most impactful research and data.

ELECTROCHEMICAL METHODS FOR UPGRADING PYROLYSIS OILS

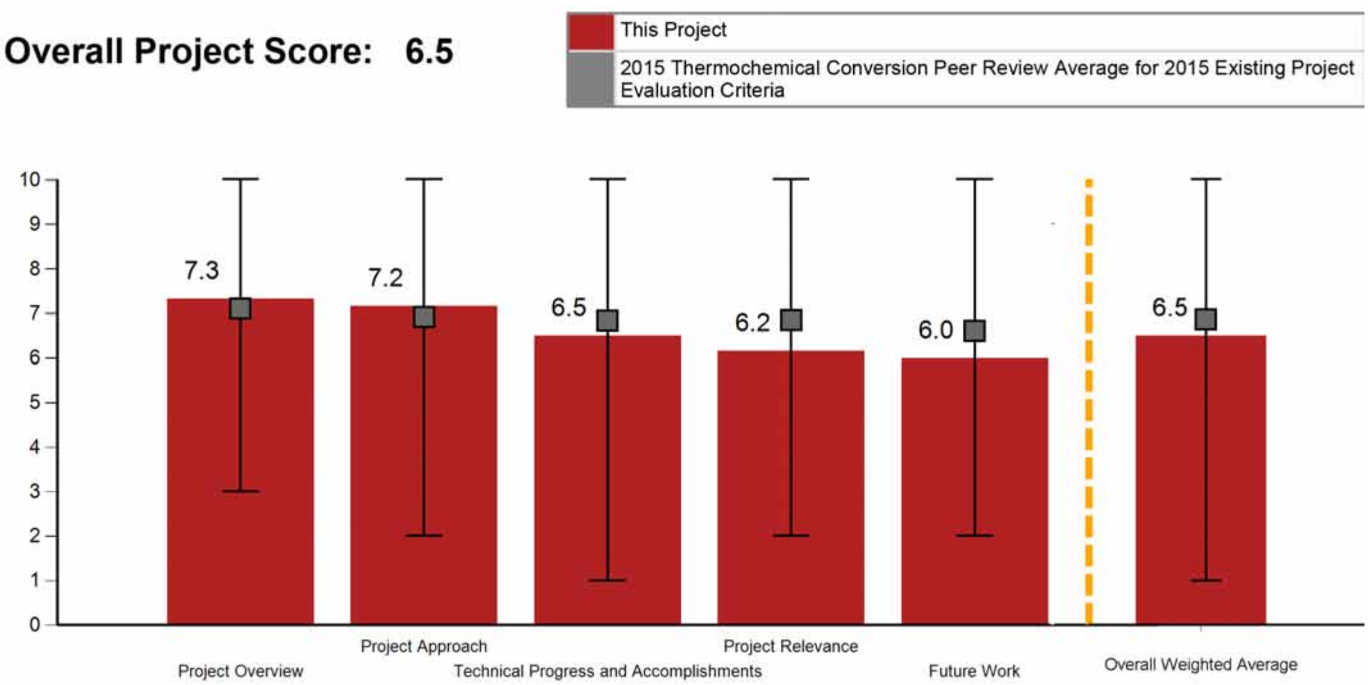
(WBS#: 2.3.1.307, 2.3.1.308, 2.3.1.309)

Photo Courtesy of INL, PNNL, ANL

Recipient:	INL, PNNL, ANL
Presenter:	Tedd Lister
DOE Funding FY14:	$715,000
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,535,000
Project Dates:	11/19/2013 - 9/30/2017

Project Description

Pyrolysis-oils require upgrading to be used in the conventional transportation fuel infrastructure. In addition, oxygenated hydrocarbons present in pyrolysis oils complicate storage, transportation and downstream processing. Conventional catalytic upgrading is technically and economically challenging because of char formation and the need for high temperatures and pressures of hydrogen. This project aims to stabilize these oils by a novel electrochemical process under mild conditions. The project is demonstrating electrohydrogenation of bio-oil and is working to address challenges associated with this new process. The expertise of three national laboratories is being applied to these challenges, each laboratory providing unique capabilities. The project incorporates processing, chemical analysis, materials performance, theoretical modeling and economic evaluations to guide development. Promising results have been observed in the initial 15 months of work where significant hydrogenation has been found. An overview



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of the project will be provided by describing the goals, technical and management approach, results, future work and finally a summary of significant findings.

Overall Impressions

- This seems to be another complex step that adds cost, which does not seem to be clearly understood by the team.
- The project brings an interesting approach to the program, using electrochemical stabilization of bio-oil. This could be particularly beneficial for distributed systems, where the stabilized oil would then be sent to refineries. The project needs to rapidly consider LCA implications that arise from significant use of electricity. Those LCA studies should be based on electricity generated from a national average of resources including coal, nuclear, natural gas, wind, etc.
- The project needs to demonstrate a compelling cost advantage of this novel approach at this point relative to conventional hydrotreating, which is not evident. Considering the amount of development that will be required, it needs to be more than just comparable. Also, the project team needs to work through GHG analysis.
- The use of electrochemistry for upgrading is of potential interest, but it must be accompanied by a strong life-cycle and techno-economic analyses to verify that the approach has real benefits compared to treating with hydrogen.
- Technology results look promising at a bench scale. Discussion raised a question of transparency of research. We look forward to published details of this research.

PI Response to Reviewer Comments

- This project has demonstrated novel electrochemical reduction (ECR), or electrochemical hydrotreatment, of carbonyl and phenolic groups in real bio-oil as an approach to distillate fuels rather than gasoline. No one has yet demonstrated that hydrotreatment brings stabilization, but it is a logical assumption that if reactive functionalities are reduced, stabilization will increase. In one ECR reaction, carbonyls are reduced to alcohols consistent with our expectation that the alcohols would not dehydrate under the reaction conditions. The alcohols could easily be dehydrated separately under relatively mild conditions to olefins and water. An advantage of this would be to preserve "handles" that can be used to oligomerize or alkylate the olefins to higher molecular weight fuels, if desired. This pathway is not available in thermal catalytic deoxygenation. Additionally, the overall balanced equation including half-cell reactions is that carbonyls are reduced to olefins and molecular oxygen as the oxygen-containing product, not water or CO_2, and that hydrogen does not appear in this overall equation.
- We agree that TEA and LCA are critical in this project. The TEA conducted was a first pass to determine if we were at least comparable to the SOT, and we are. The true comparison to the SOT cannot be made on an upgrading basis alone and feedstock costs cannot be ignored. The ECR technology will enable distributed depot-based preprocessing, meaning stranded and niche resources come into play. Densification and stabilization nearer to the source allows reduced feedstock transportation costs to the pyrolysis and stabilization facility and decreased costs for transportation of the bio-oil to the centralized bio-oil refinery, where it would be hydrotreated and refined. Dewatering of the bio-oil by the ECR process will reduce reactor sizes and capital expenditures. Removal of acids prior to hydrotreating will reduce hydrogen consumption and is expected to improve bio-oil stability under hydrotreating conditions. This will improve catalyst efficiency and lifetime. The TEA presented did not factor in these additional benefits, but future analyses will.
- We believe significant progress has been made (leading to a provisional patent application), but more

clearly needs to be done. Additional experiments are needed on bio-oil ECR (data collection for the peer review only started in October 2014) to more clearly show the effects of various processing conditions. These experiments are planned. The size of the cell (surface area) greatly influences rate of conversion. An effort proposed in the merit review would look at alternate cell designs to enhance bio-oil contact with the electrode surface. In addition, current work at the bench-scale (TRL 2-3) will feed into design, construction, and testing of larger cells, as we proposed in our merit review. Three abstracts have been submitted for presentations at professional society meetings.

CHARACTERIZATION AND VALORIZATION OF AQUEOUS PHASES DERIVED FROM LIQUEFACTION AND UPGRADING OF BIO-OILS

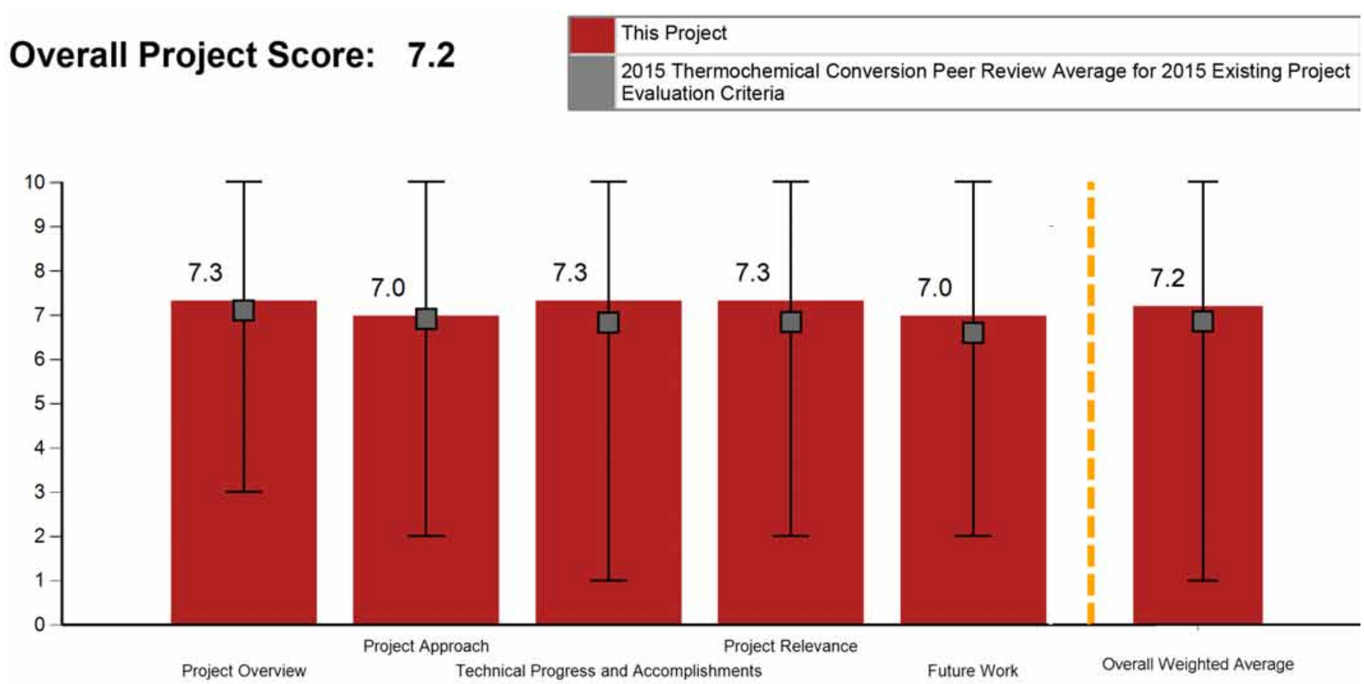
(WBS#: 2.3.1.310)

Recipient:	PNNL
Presenter:	Karl Albrecht
DOE Funding FY14:	$1,332,306
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$5,267,694
Project Dates:	10/1/2013 - 9/30/2017

Photo Courtesy of PNNL

Project Description

Biomass direct liquefaction processes [e.g., hydrothermal liquefaction (HTL), catalytic fast pyrolysis (CFP), or fast pyrolysis (FP)] produce aqueous phases during bio-oil generation and/or subsequent hydrotreating. The organic and inorganic constituents of these aqueous streams are poorly understood. The objectives of this project are two-fold. First, the project seeks to facilitate understanding of the aqueous streams via rigorous quantitative characterization of organic and inorganic compounds present in the streams. Characterization data is being widely disseminated to the benefit of all bioenergy stakeholders. Second, this project seeks to valorize biogenic carbon within the aqueous streams. Valorization investigations are underway to develop a process for converting aqueous phase organics into chemicals, such as light olefins (C3 and C4). Concurrently, work is focused and being conducted on steam reforming the aqueous phase organic compounds to supplant a portion or all of the natural gas required for hydrogen production used in the bio-oil hydrotreating. Processing of the aqueous phases is expected to



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

improve biorefinery process economics through the production of valuable co-products and diminished processing costs through lower wastewater volume and diminished external resources, such as natural gas. Specific focus has been placed on utilizing "real" biomass-derived feeds to ensure the associated challenges will not be overlooked.

Overall Impressions

- Once again, there is not enough focus on separations that is required.
- There is strong need for aqueous phase characterization and carbon recovery. This project contributes to this objective.
- Almost all of the biomass conversion projects generate wastewater. Characterizing these streams is a critical first step to capture the carbon. And then, looking to couple or recover the oxygenates is the second step. Both are being addressed by the project.
- The project is proceeding well, but it faces significant challenges in separations, conversions, and transportation costs.

PI Response to Reviewer Comments

- We appreciate the reviewers' comments and helpful suggestions on ways to improve our project. We agree the aqueous phases produced during the conversion of biomass to fuels have the potential to be a showstopper in the development of a bioeconomy. Mitigation of the technical risks associated with the aqueous phases begins with the knowledge of what is in the aqueous phases, which this project is directly addressing through the characterization task. We are also seeking to turn a potential negative into a positive by giving biorefinery designers options to derive value from the light oxygenates in the aqueous streams. Anaerobic digestion (AD) is our technical and economic baseline. Our focused efforts on valorization, whether catalytic conversion to value-added chemicals or additional hydrogen for bio-oil/biocrude upgrading, are compared to AD to understand economic benefits through additional revenue streams and/or reduced GHG emissions.
- The early development and regular updating of TEA models for our valorization processes has been greatly beneficial. We take a holistic view to TEA modeling in order to understand costs and barriers associated with all unit operations, including separations. TEA modeling has also aided us in understanding what process separation techniques could be economically viable. One excellent example was within the catalytic conversion task. Acetic acid is difficult to separate from water via distillation because it has a higher boiling point than water. However, after passing through the ketonization reactor, acetone can be readily and economically distilled from water. Thus, through a combination of experimental and TEA modeling work, we discovered the ketonization process can facilitate downstream separations.
- The steam reforming portion of the valorization process has also made excellent progress with these unique aqueous streams. Previous reports on steam reforming focused on whole bio-oil, water-washed bio-oil, or model compounds as feedstocks. In contrast, we are focusing on spontaneously separable aqueous phases. We have also discovered that implementing a pre-reformer concept rather than sending oxygenates to the high-temperature reformer minimizes coking. Additionally, we have discovered cobalt has much lower selectivity to methane (vs. Ni or Rh) when reforming oxygenates. Significant progress has been made due to our emphasis on utilizing and understanding the challenges associated with biomass-derived aqueous phases in contrast to model compounds.
- Based on the reviewers' helpful comments, we do plan to add emphasis to our ongoing separations investigations. We are planning to look at liquid-liquid separations using commercially available solvents and lab-scale distillation studies to concentrate organics. We will also continue our work with ion exchange experiments to remove dissolved solids. Experimental data from our separation studies are planned for implementation into the next updating of the TEA, now

that we are beginning to understand the extent to which dissolved solids must be removed for catalyst stability.

- Finally, the reviewers' excellent suggestion to include transportation costs in our TEA models will be implemented in the next update planned for later this fiscal year. Understanding the value of a chemical as a function of the distance from a potential consumer is extremely important. We plan to implement the transportation cost analysis as a sensitivity analysis to understand the value of the chemical as a function of the distance it must be shipped.

REFORMING PYROLYSIS AQUEOUS WASTE STREAMS TO PROCESS HYDROGEN AND HYDROCARBONS

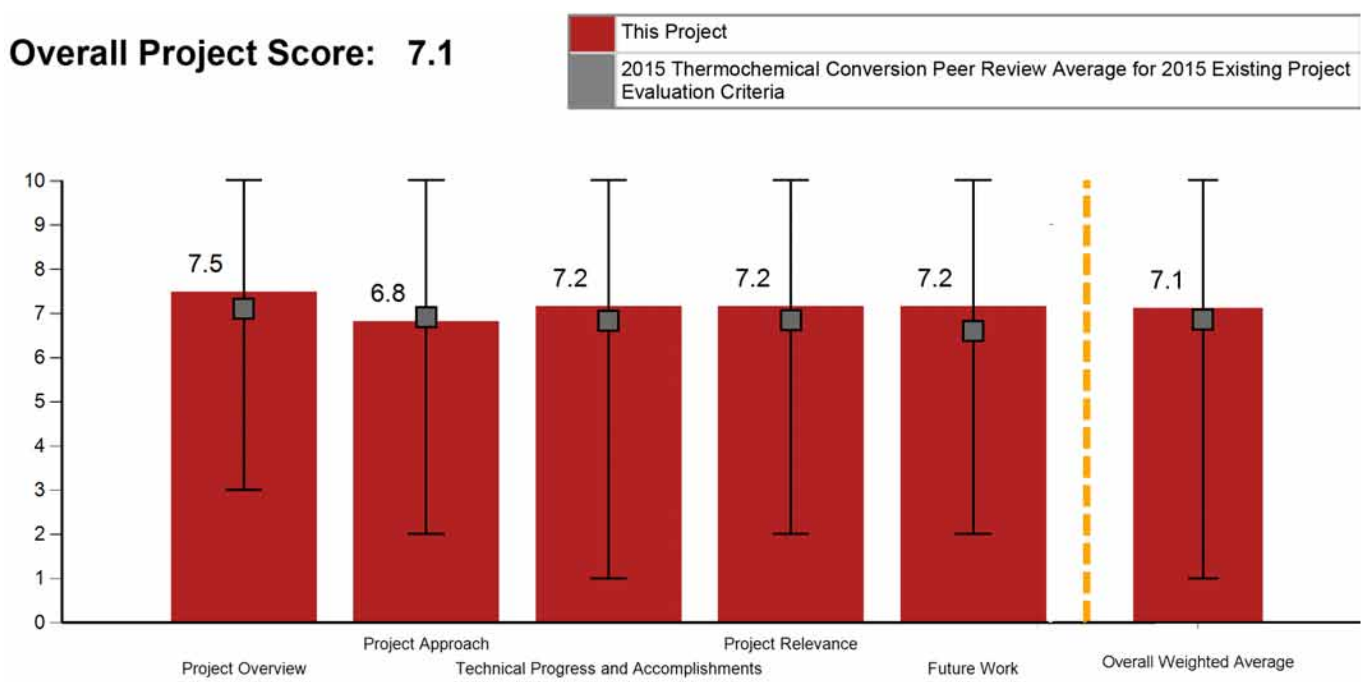
(WBS#: 2.3.1.311)

Recipient:	NREL
Presenter:	Kim Magrini
DOE Funding FY14:	$196,427
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$303,573
Project Dates:	10/1/2013 - 9/30/2017

Photo Courtesy of NREL

Project Description

This project will establish the baseline catalytic conversion of aqueous pyrolysis oil fractions to hydrogen via reforming and fungible hydrocarbon fuel intermediates via upgrading. Process wastewater from a biomass pyrolysis contains biogenic carbon with the amounts generated as a function of how much pyrolysis oil upgrading has occurred. Wastewater treatment costs are high and currently no commercial processes have been proven for treating the compound slate from these pyrolysis processes. The upgrading approach to wastewater treatment, which generates both hydrogen and fungible hydrocarbons, may be of significant value and potentially offset wastewater processing cost. This project uses the aqueous fraction as a surrogate for lignin fractionation processing and wastewater hydrocarbons to assess upgrading the light oxygenates to blend stocks and/or chemicals that may be cost efficient and improve overall biomass carbon conversion. The goal now is to produce hydrogen for upgrading (hydrotreating) raw pyrolysis oils to fuels



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

while also in parallel converting carbon species to fungible blend stocks for refinery insertion. Each of these processes can be co-located at refineries using available waste heat for processing. The overall project objective is integrating biomass-derived oxygenate upgrading with hydrogen production to achieve the best overall process economics for wastewater treatment from biomass-derived fuel production from pyrolysis.

Overall Impressions

- The partnership with Johnson Matthey and CoorsTek is a key strength of this project. It could lead to real results.
- The work is relevant to the effective use of carbon in pyrolysis systems.
- Heat is a big issue, as well as the hydrogen purity. The project team needs to conduct TEA to weight capital and operating expense vs. additional product value.
- Efforts to gain value from the aqueous phase are promising, but must be accompanied by strong efforts in conceptual process design and techno-economic analysis.

PI Response to Reviewer Comments

- We agree that heat is a big issue, as is hydrogen purity. The primary reason for the TEA is to weigh capital and operating expense against additional product value.

CATALYTIC PYROLYSIS SCIENCE

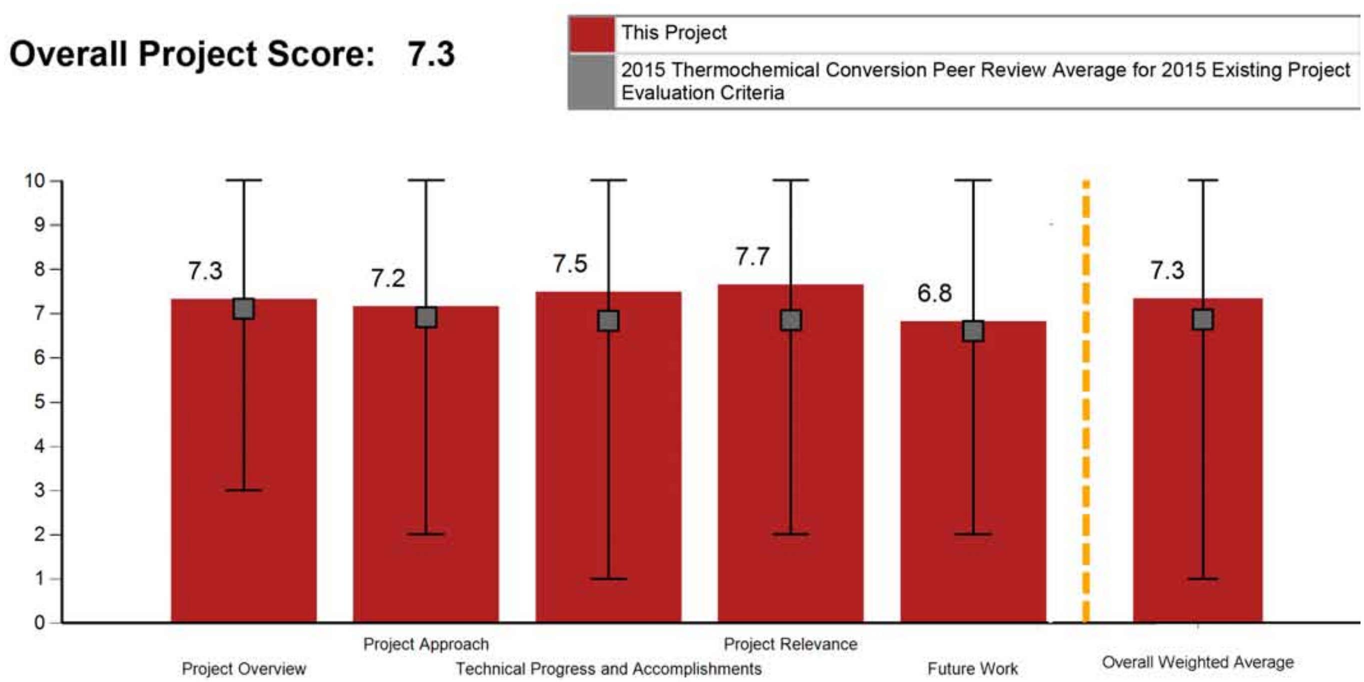
(WBS#: 2.3.1.313)

Recipient:	NREL
Presenter:	Mark Nimlos
DOE Funding FY14:	$1,816,982
DOE Funding FY13:	$1,777,052
DOE Funding FY10-12:	$0
Planned Funding:	$6,970,966
Project Dates:	10/1/2012 - 9/30/2017

Photo Courtesy of NREL

Project Description

Hydrocarbon transportation fuels produced using Catalytic Fast Pyrolysis (CFP) of biomass have potential for a cost of production that makes them competitive with fossil-based hydrocarbons. This project will reduce the time required to achieve that promise by improving our understanding of important chemical mechanisms. The project team conducts laboratory experiments using model compounds and biomass, which allows us to rapidly explore important experimental operating conditions and catalyst formulations. The results from these studies reduce the Edisonian space that must be explored with larger experimental equipment and, thereby, improve the rate of technology development. As an example, limits on the amounts of biomass processed per gram of catalyst were determined, based upon deactivation through the laydown of carbon in lab experiments. These limits have reduced the ranges of catalyst and biomass flow that will be used in larger experiments, such as those planned in riser reactors. This significantly reduces the number of experiments that must be conducted to demonstrate CFP. Specific technical targets being addressed in this project are to improve carbon efficiency from 27% to 44% and to reduce oxygen



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

content from 15% to 6.4% by FY22. Reaching these targets will demonstrate $3.33/gge. By building our understanding of the chemistry of CFP, we suggest operating conditions and catalyst improvements that can achieve the technical targets.

Overall Impressions

- The project demonstrates a good collaboration and pathway to results.
- The work is interesting and helps focus on the basic issue of the in-situ pathway and C conversion to fuels. BETO would benefit from closer collaboration between this and other catalyst projects at the labs to address higher-level problems, such as fouling.
- Work on selective hydrogenation and carbon coupling is an innovative approach to capturing light ends to increase carbon efficiency.
- The researchers are carrying out interesting research, but they need to do a thorough literature review and understand the prior state of the art in this field to guide their research. A strong reactor modeling effort is needed to support translation of their results to performance in a riser reactor.

PI Response to Reviewer Comments

- Our group has a very good handle on the literature surrounding the catalytic upgrading of pyrolysis vapors. We are continuously improving our understanding of the vast literature of zeolite catalysts.
- We are working closely with the computational pyrolysis consortium where reactor models are being developed to transfer our laboratory results into the riser experiments being planned at NREL.

CATALYTIC UPGRADING OF PYROLYSIS PRODUCTS

(WBS#: 2.3.1.314)

Recipient:	NREL
Presenter:	Josh Shaidle
DOE Funding FY14:	$2,004,173
DOE Funding FY13:	$1,519,308
DOE Funding FY10-12:	$0
Planned Funding:	$6,986,519
Project Dates:	10/1/2012 - 9/30/2017

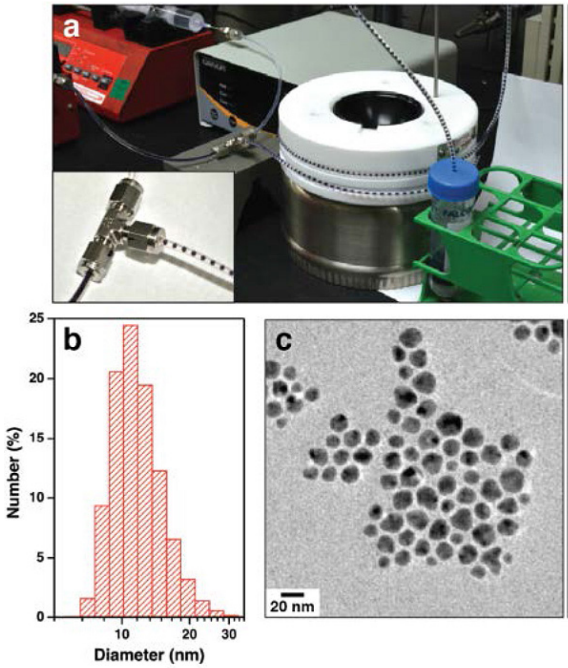
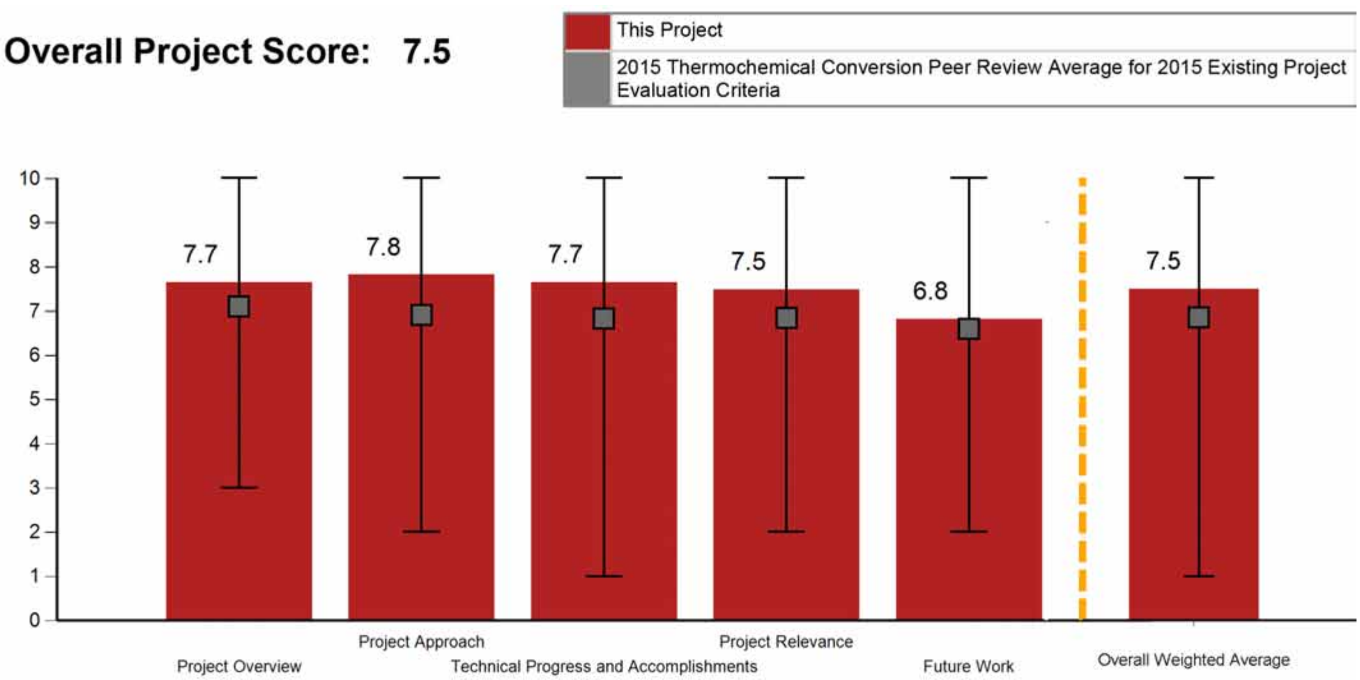


Photo Courtesy of NREL

Project Description

The main objective of this project is to develop catalysts for ex-situ catalytic fast pyrolysis of biomass that enable the production of drop-in hydrocarbon fuels at a price of $3.33/gge by 2022. Catalysts designed and developed within this project seek to improve the fuel quality and stability of the resulting bio-oil by reducing the oxygen content, increasing the hydrogen content, and increasing the carbon number into a range suitable for gasoline, diesel, or jet fuel. The approach combines experimental and computational efforts to drive catalyst discovery and development through theoretical modeling, advanced synthetic techniques, rigorous catalyst characterization, and reaction testing with model compounds and real pyrolysis vapors. The technical chal-

Overall Project Score: 7.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

lenges addressed in this project are: (1) activation and selective incorporation of hydrogen at moderate temperatures (300-500 °C) and low hydrogen pressures; (2) removal of oxygen in the form of H_2O instead of CO and CO_2; and (3) increasing product carbon number while minimizing deactivation. Furthermore, these challenges must be overcome with cost-effective and scalable materials. The project has demonstrated improvements in hydrogen incorporation and deoxygenation using low-cost catalytic materials (nanoparticle Ni and Mo_2C) as compared to Pt/SiO_2. Mechanistic insights from computational modeling will be leveraged to develop strategies for additional catalyst improvements.

Overall Impressions

- This is an ambitious project and a go/no-go decision in 2016 is appropriate.
- The project is making very good progress on the fundamentals of catalysts for mild hydroprocessing of hot pyrolysis oil vapors in the ex-situ approach.
- The project has a methodical approach to developing ex-situ catalysts for upgrading. These early results are promising. The project is trying to hydrogenate oxygen, but not at the expense of ring hydrogenation. Maybe this could be used as a stabilization step. Catalyst life is likely an issue.
- This project is taking a rational approach to catalytic bio-oil stabilization and has achieved promising results. The workers need to move to trickle bed reactors to verify screening experiments. They also need to quantify the performance of best-in-class existing catalysts to establish meaningful targets.
- This is an excellent, thorough analysis at a foundation level, with vision toward achieving an efficient, economically viable catalyst for stabilized bio-oil.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

CATALYST DEVELOPMENT/ TESTING: DECONSTRUCTION

(WBS#: 2.3.1.315)

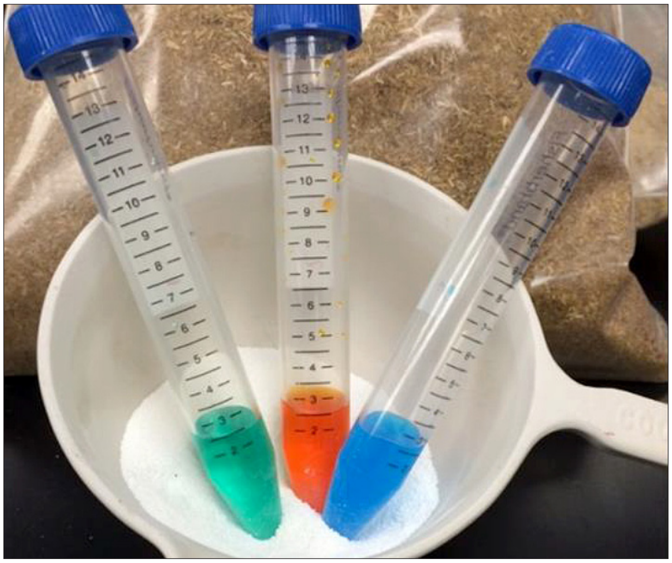
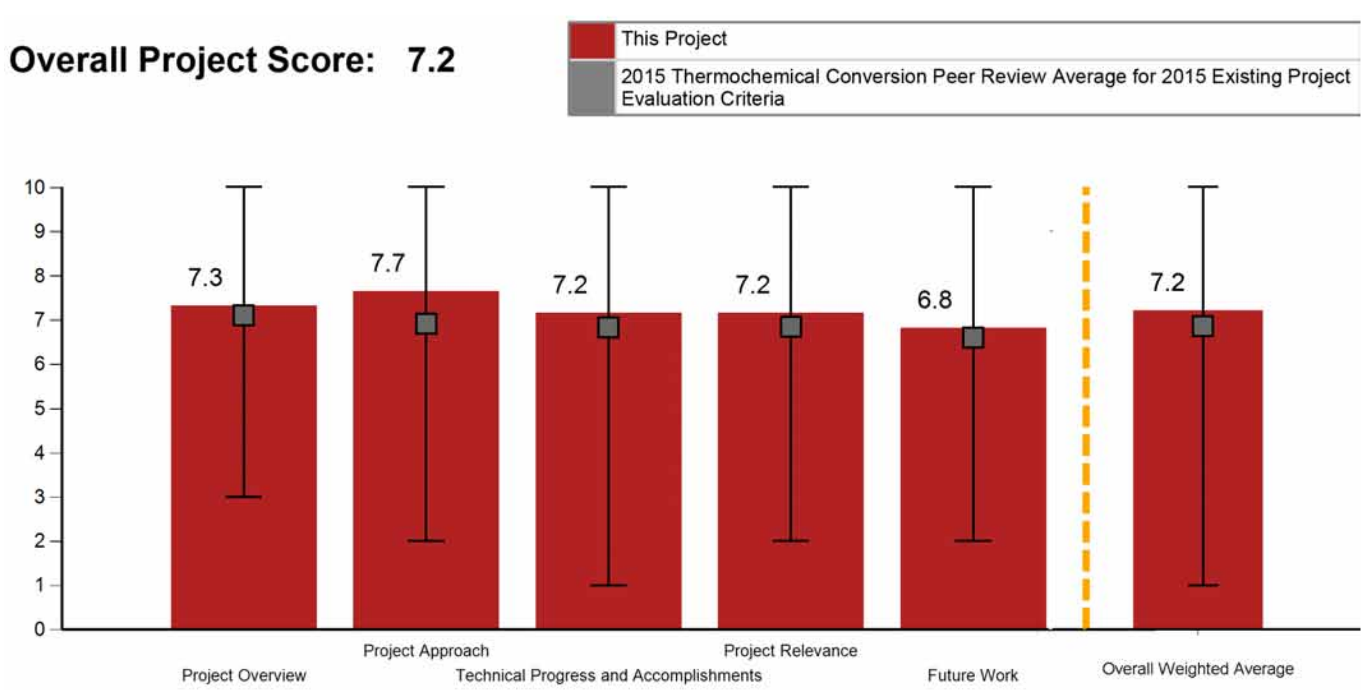


Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Kim Magrini
DOE Funding FY14:	$2,058,441
DOE Funding FY13:	$1,728,910
DOE Funding FY10-12:	$0
Planned Funding:	$2,377,649
Project Dates:	10/1/2012 - 9/30/2017

Project Description

This project is focused on characterizing and evaluating ex-situ upgrading catalysts with biomass-derived pyrolysis vapors at the Davison Circulating Riser (DCR) small pilot-scale operation. This project interfaces with the Catalytic Upgrading of Pyrolysis Products project to evaluate their catalysts with actual vapors and provides catalyst testing data to the Engineering Integration and Scale-up project and the Technoeconomic Analysis of Integrated Vapor Phase Upgrading (VPU) Processes project. The FY15-FY17 objective of this continuing project is now to develop, optimize and demonstrate an integrated process and associated catalysts for producing pyrolysis vapors and immediately upgrading them in an FCC-type reactor system to fungible hydrocarbon blend-stocks. Beyond FY17, project work will assess in-situ upgrading of pyrolysis products, co-feeding vapor with refinery fractions, and evaluating emerging catalysts for other platform projects. Project research addresses



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

barriers to Tt-E. Liquefaction of Biomass and Bio-Oil Stabilization and Tt-G. Fuel Synthesis and Upgrading. Integrated ex-situ upgrading improves efficiency and reduces costs of biomass-to-fuels conversion by minimizing the number of steps required to achieve high quality fuels. Success in developing this process will produce a biomass-based technology transferable to petroleum refineries for fungible fuel production and efficient biomass conversion catalysts.

Overall Impressions

- This unit operation has a lot of "pots and pans." I saw no review of conceptual economics to guide practicality of development.
- The project is making very good progress in the catalytic upgrading of hot pyrolysis vapors.
- This appears to be a good attempt to scale up ex-situ pyrolysis. Good luck with the issues of handling hydrogen at some point, removing vacuum gas oil (VGO) and working with 100% bio-oil, and overcoming catalyst attrition (need an inexpensive catalyst). Emphasis needs to be placed not only on joining up with other related projects (coordination appears to be good at NREL), but with any other related BETO-funded project in this area. It is costly to run large units so the project needs to absolutely maximize the value of the results to everyone.
- The project is ready to generate data that should show the efficacy of this approach. DOE needs to ensure that this expensive asset (the Davidson Circulating Reactor) is well-utilized to maximize return on its investment.
- This will be an interesting system to look at as the project progresses.

PI Response to Reviewer Comments

- We thank the reviewers for their comments and note that we are collaborating with commercial and other groups who want to use the DCR system for evaluating their catalysts, feedstocks, and process conditions.
- Near-term catalyst modifications focus on a "cheap" metal addition to FCC catalysts to improve deoxygenation and product yields, while reducing anti-coking properties.
- The DCR unit is turnkey as designed by W.R. Grace and used by refineries worldwide, so we are not sure where the "pots and pans" are. The system is coupled with a biomass pyrolyzer to provide biomass pyrolysis vapors to the DCR for upgrading with FCC-type catalysts to hydrocarbon products. DCR operations are standardized to those used by the petroleum industry.

A HYBRID CATALYTIC ROUTE TO FUELS FROM BIOMASS SYNGAS

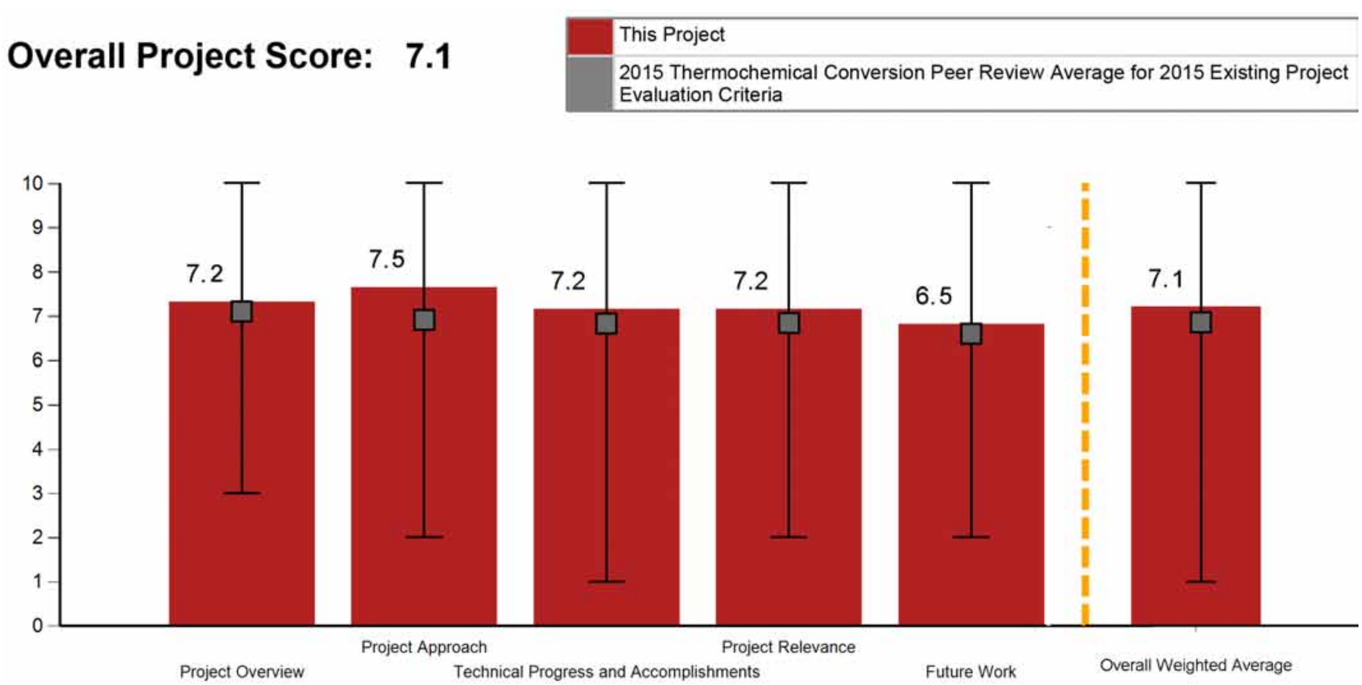
(WBS#: 2.3.1.403_Z)

Photo Courtesy of LazTech, Inc.

Recipient:	LanzaTech, Inc.
Presenter:	Alice Havill
DOE Funding FY14:	$622,293
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$559,139
Project Dates:	10/1/2011 - 9/30/2014

Project Description

LanzaTech, with PNNL, IAF, Boeing, MTU, University Delaware, and Orochem, are developing a hybrid catalyst platform for converting biomass to jet fuel. The project integrates biomass syngas fermentation and catalytic upgrading to make cost-competitive jet fuel that meets strict quality and sustainability standards. The key project objectives are to: (1) study impacts of syngas contaminants on fermentation from three biomass feedstocks to reduce cleanup costs; (2) optimize upgrading catalyst and its associated process by high throughput screening and computational studies; (3) determine fermentation broth impacts on upgrading performance to optimize alcohol recovery cost; (4) validate process stability through 2,000 hours of continuous oper-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ations and detailed catalyst characterization; (5) design a commercial hybrid process by optimizing each process step and their integration; and (6) analyze techno-economics and life cycle impacts. Key successes include: screening and optimization of jet fuel catalysts and >2,000 hours of catalyst operation and jet fuel samples produced (PNNL); completed kinetic modeling (University Delaware, PNNL); evaluated syngas contaminants; commissioned pilot bioreactor (LanzaTech); and conducted benchmark economic and life cycle assessment (MTU, LanzaTech). The project has relocated to LanzaTech Freedom Pines (GA), where an alternative biomass gasifier is being installed. Gasification/fermentation integration and jet fuel production will recommence in 2015.

Overall Impressions

- DOE requirement for integrated gasifier may be too difficult to achieve goals in a timely manner.
- This is a novel and innovative approach, which is very interesting. The impact will be determined over the next two years when the work is completed.
- So how does this process compare to cost for Fischer-Tropsch? But then again the F-T wax can be sold at a premium value for lubricants. The project must be driven by cost of BDO (or butadiene) at chemical value. The process still involves syngas production and cleanup as Fischer-Tropsch, but adds a number of costly separation steps.
- This approach is risky since it involves coupling biological and thermochemical systems, so it needs compelling economics to go forward.
- This project is one of a few that conveys an approach where actually achieving commercial integration is a design objective and possibly an achievable reality. There are many process steps, but achieving a commercial link means achieving a critical success factor for the project. The techno-economic details, compared to existing traditional commercial processes, may not be favorable to expect ready adoption.

PI Response to Reviewer Comments

- We appreciate the support and interest shown by the reviewers for this hybrid bioprocessing route to fuels and chemicals. We agree that the two main challenges this project currently faces at present are: (1) piloting this integrated technology in the project time remaining; and (2) demonstrating an economically viable platform that is competitive with traditional petroleum-based jet fuel, as well as the more direct competitor, Fischer-Tropsch.
- Current economic assessments performed on this hybrid platform indicate that a cost-competitive low carbon fuel option could be offered pending technical validation through process piloting. Couple this with the co-production of valuable chemicals, such as butadiene, and the economic volatility of this platform is further reduced.
- Despite the need to install and operate a novel gasification system in order to complete this project, LanzaTech is fully confident in its execution due to our vast experience in accelerated piloting of new technologies. In conjunction with the support of our gasification and catalyst partners, it is anticipated that this project will be successfully completed within the time remaining.
- LanzaTech and our project partners are grateful for the opportunity provided by BETO to demonstrate and evaluate this hybrid bioprocess platform and we are excited to soon be able to offer a low carbon, cost-competitive jet fuel product that is environmentally and socially responsible.

CATALYTIC UPGRADING OF THERMOCHEMICAL INTERMEDIATES TO HYDROCARBONS: CONVERSION OF LIGNOCELLULOSIC FEEDSTOCKS TO AROMATIC FUELS AND HIGH VALUE CHEMICALS

(WBS#: 2.3.1.406)

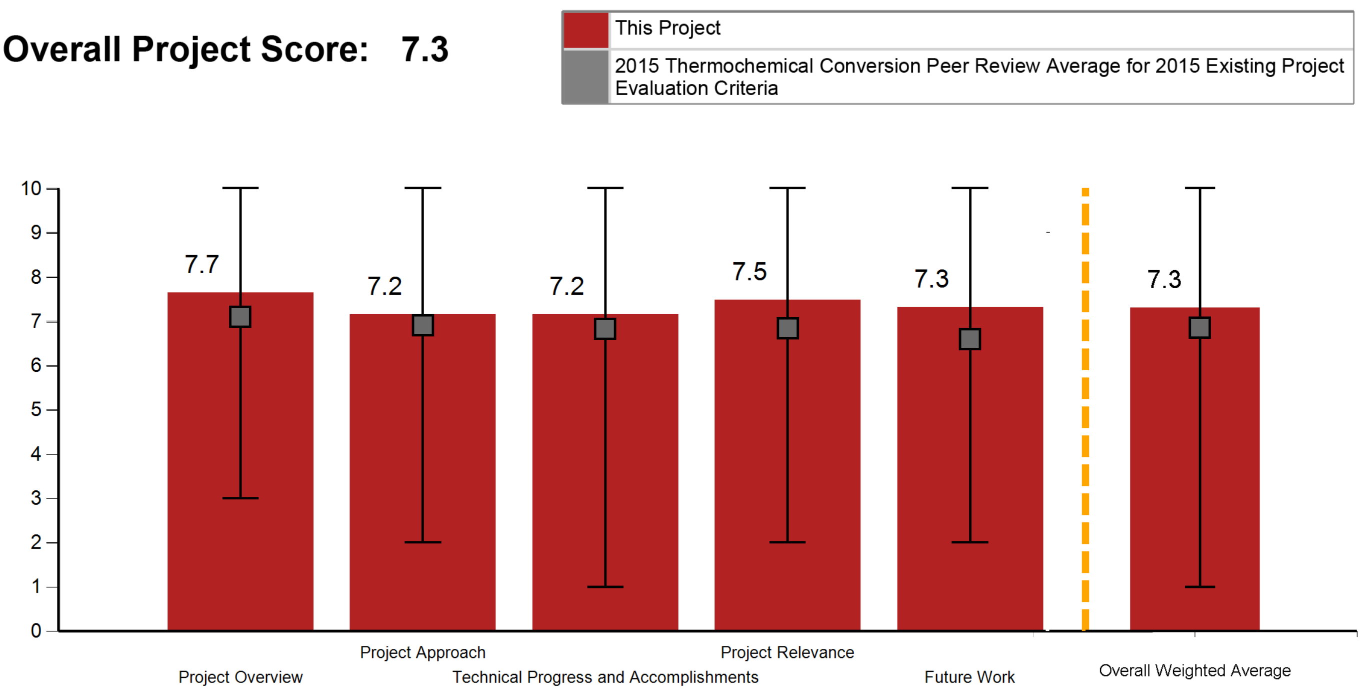
Photo Courtesy of Virent, Inc.

Recipient:	Virent, Inc
Presenter:	Randy Cotright
DOE Funding FY14:	$796,449
DOE Funding FY13:	$553,508
DOE Funding FY10-12:	$553,508
Planned Funding:	$1,612,028
Project Dates:	10/3/2011 - 10/2/2015

Project Description

The goal of the project is to couple Virent's biomass liquefaction process (Solvolysis) with the BioForming® process to convert bagasse, corn stover, and loblolly pine into aromatic-rich fuels and chemicals. The unique ability to effectively solubilize hemicellulose, cellulose and lignin components of biomass into convertible intermediates sets this process apart from other approaches. Solvolysis involves solvent assisted liquefaction of biomass coupled with stabilization of the reactive species through the use of catalysts. After stabilization, the intermediates can be fed into a condensation reactor producing a stream of aromatic-rich hydrocarbons for use as fuels and high value chemicals. Since inception in Q4 2011, several project milestones

Overall Project Score: 7.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

have been reached, including biomass liquefaction in excess of 95% and soluble oxygenates yields exceeding 80%. Stability and lifetime of the stabilization catalyst has been improved and a larger scale, fully continuous deconstruction system has been built and commissioned. Future work under this project will focus on continued catalyst lifetime improvements, optimization of the fully integrated system, a 2,000-hour demonstration run of the fully integrated systems, and updating process simulation and cost models.

Overall Impressions

- The project focus on finished products and non-dependence on refineries is a strong strength. The scale of testing is very small.
- The project should produce interesting information by the time it ends in late 2015.
- The project is on track to demonstrate technology for a 2,000-hour run. The project team needs to make sure that all recycle loops are part of this.
- The project has potential, but without independent TEA, the value is difficult to assess.
- There has been good progress on this particular demonstration project. While six months are remaining to complete the project, there is still quite a bit to be done to satisfy critical success factors. This is a common problem with many of the BETO projects reviewed in this panel. It reflects a need for DOE to closely monitor project close-out, and stress a need for the PI to achieve all of the critical success factors.

PI Response to Reviewer Comments

- The final six months of the project does entail a ramp up in the project activities and resources to satisfy critical success factors. The project team is in continued communication with DOE and maintains monthly status calls and normal reporting to ensure successful project delivery.

BIOLOGICAL PYROLYSIS OIL UPGRADING

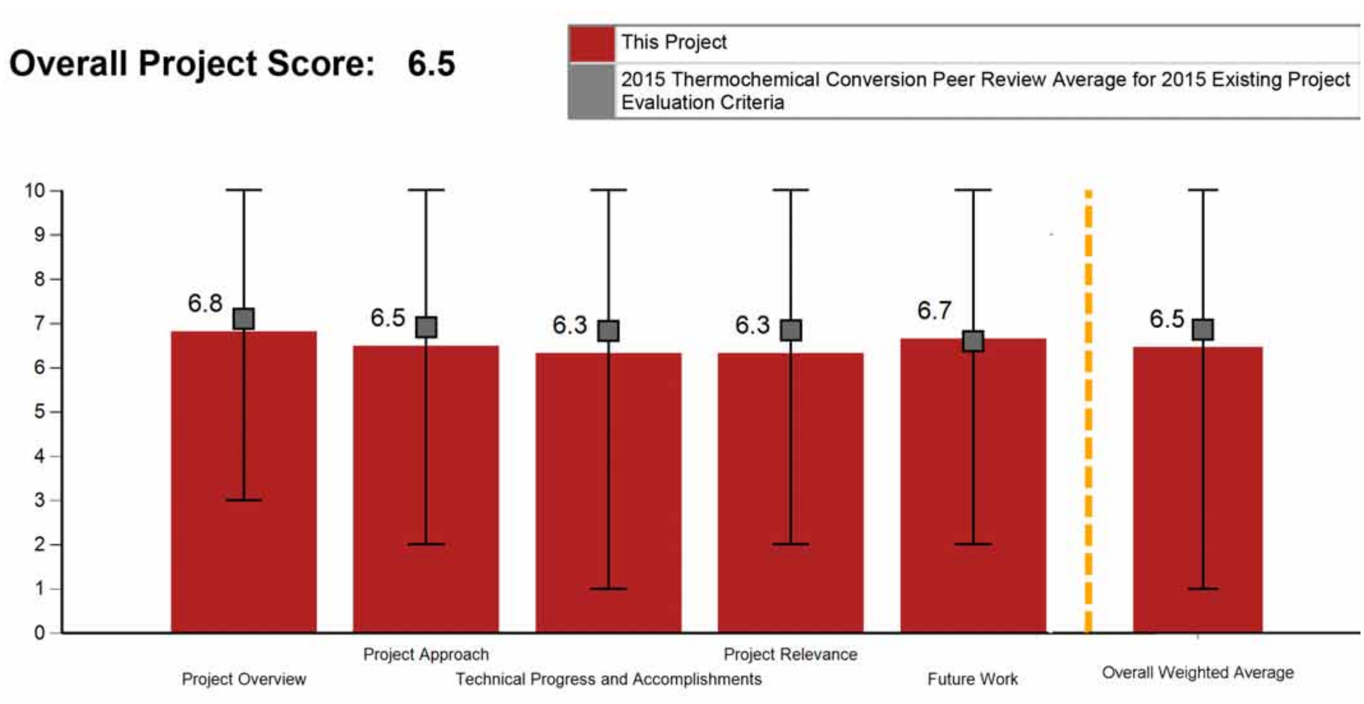
(WBS#: 2.3.2.301)

Recipient:	NREL
Presenter:	Gregg Beckham
DOE Funding FY14:	$315,837
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$934,163
Project Dates:	10/1/2013 - 9/30/2017

Photo Courtesy of NREL

Project Description

The aim of this project is to develop a process to valorize soluble carbon present in the aqueous fractions from thermochemical conversion pathways using a biological approach. Specifically, the project team is engineering and evolving Pseudomonas putida to catabolize a wide range of species, such as organic acids, low molecular weight aldehydes, oxygenated aromatics (from lignin), sugars, and sugar dehydration products. The ultimate goal is to produce fuel precursors or co-products from the biologically derived intermediates. This work, which was started as a seed project in FY14, will directly support the BETO mission towards cost-effective thermochemical conversion through the development of a process strategy to capture and upgrade a broader range of carbon. Work in FY14 included expanding the substrate range of P. putida to include phenol, levoglucosan, furfural, 5-hydroxymethylfurfural, and several other components of the aqueous fraction of pyrolysis oil. Additionally, key collaborations with an industrial partner (RTI International) and an academic partner (Iowa State University) were developed to ensure an abundant supply of process-relevant aqueous waste streams from catalytic fast pyrolysis and fast pyrolysis, respectively. Work in FY15 will focus on the continued development of the biocatalyst by expanding its slate of digestible products to cellobiosan, guaiacol, and xylose, and the construction of a techno-economic model to



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

identify key cost drivers for this process.

Overall Impressions

- The project is probably doing what was funded, but not answering the high-level economics questions.
- The project deals with an important area in cleaning up aqueous streams from pyrolysis and potentially using the carbon in those wastes more efficiently. This is a worthwhile goal. However, the project is currently very unfocused. The project needs to rapidly (in 2-3 months) identify priority process streams, the main constituents of those, and determine which products might improve economics using a quick, high level TEA. The project should then appropriately focus on a few relevant organisms that have the most promise. The project should also be more closely coordinated with other aqueous effluent characterization/valorization projects funded by BETO.
- Organism tolerance to acetic acid is an issue. This will be a huge challenge given that this is the largest oxygenated compound in the aqueous stream. Working with an actual aqueous bio-oil stream is critical. The project team needs to demonstrate techno-economics. Separation of products will also be a huge issue. I am not even sure what the target molecules are. There is way too much focus on synthetic biology at this point.
- The investigators have made good progress on engineering organisms to metabolize some of the major organics in waste streams. Selection of target "upgraded molecules" will be critical. The volumes and values of potential products must be quickly assessed to define what success might look like.

PI Response to Reviewer Comments

- We thank the reviewers for their constructive and positive comments. We certainly agree that waste carbon capture in thermochemical-based biorefineries will be an important issue with implications both in and beyond thermochemical-based processes. This relatively new project is aimed very much at developing a new approach to aid in that endeavor. The reviewer comments will be taken into account and milestones going forward will be informed and shaped by their comments.
- This project was initially a seed project idea that started approximately 18 months ago with an initial aim to demonstrate that pyrolysis-derived intermediates are amenable to biological conversion and upgrading. The initial efforts focused on substrates that we identified as primary components of fast pyrolysis waste streams and informed the biological aspects of the work presented to date to catabolize furans, low molecular weight aromatic compounds, and organic acids. As discussed in the presentation, the organism of choice to date is Pseudomonas putida, which is a robust, industrially relevant organism with broad substrate specificity. As highlighted in the presentation, with the successful demonstration of the ability to biologically upgrade these pyrolysis-derived intermediates, we have turned our attention toward demonstrating biological upgrading of biomass-derived pyrolysis aqueous waste streams, developing robust techno-economc and life-cycle analyses, identifying targeted co-product for these streams, and engineering the strains to improve carbon conversion of the broad suite of pyrolysis-derived intermediates to products.
- Regarding the perceived lack of focus of the project, we have identified and procured waste streams from two pilot-scale thermochemical processes relevant to BETO goals, including from fast pyrolysis and catalytic fast pyrolysis. We are currently working to identify the primary components of these streams by developing novel analytical capabilities. Based on initial experimental demonstrations, we are developing TEAs and LCAs to screen the wide array of products we can produce via these pathways and identify initial process conversion targets to meet economic viability. The products we are currently screening are species that will be more easily

recovered from these dilute systems, including those that are stored intercellularly (such as polyhydroxy-acids), as well as gas-phase products.

- We stress that the primary challenge of this project is to develop a robust, tolerant organism with very broad substrate specificity and we will continue to engineer and evolve the organism to improve overall conversion efficiencies. Once broad carbon capture is engineered, the carbon that is metabolized by the strain will eventually funnel down to central carbon metabolism, which can then be directed to a desired product (or to a slate of products in separate strains).

INTEGRATION AND SCALE UP

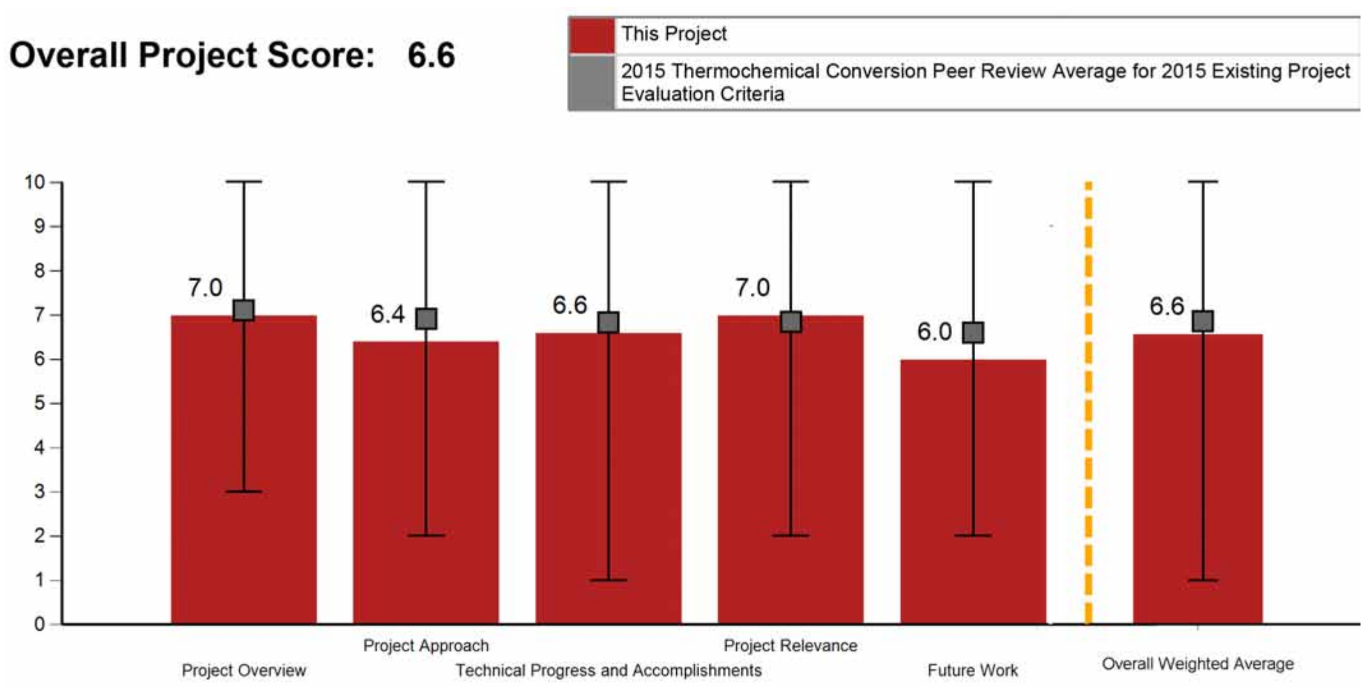
(WBS#: 2.4.1.301, 2.4.1.302)

Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Esther Wilcox
DOE Funding FY14:	$3,193,163
DOE Funding FY13:	$3,310,750
DOE Funding FY10-12:	$2,541,154
Planned Funding:	$9,557,527
Project Dates:	10/1/2010 - 9/30/2017

Project Description

This project supports the Thermochemical Process Development Unit (TCPDU); a > 0.5 ton/day pilot scale system used to demonstrate thermochemical biomass conversion chemistries, processes, and catalyst technologies developed at the lab scale. This work maintains and operates a BETO core capability for technology demonstration and deployment and directly supports BETO's mission to demonstrate integrated pilot-scale performance, meeting the 2022 hydrocarbon fuel production cost target. The primary objective of this project is to demonstrate an integrated pyrolysis pathway at an industrially relevant scale, meeting the 2017 targets. The near-term work is focused on improving the TCPDU system to enhance the overall operation and safety and to add the capability of ex-situ and in-situ pyrolysis. The primary challenge is to design new unit operations while the catalyst development is ongoing. This challenge is overcome by close collaborations with the catalyst development and techno-economic analysis tasks, and by designing



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

as much flexibility into the system as possible. Progress to date includes conducting hazard and operability assessments. Recommendations from the assessments have been designed, installed, and tested. Additionally, designs for a new scrubber and a continuous catalysis reactor (modified from an existing unit) were completed in order to add ex-situ pyrolysis capability to the pilot-scale system. These new unit operations will be installed and commissioned in FY15.

Overall Impressions

- This is a big project with lots of scope. I am not sure if it can be completed on time and within budget for the scope promised.
- Establishing state-of-the-art steady-state conversion capabilities at the national laboratories is important. However, BETO may realize more value from the investment by utilizing that equipment and expertise for some evolving issues rather than duplicate results, which have been already largely obtained by BETO-funded industry projects.
- The project team needs a core capability to demonstrate fast pyrolysis and ex situ pyrolysis. Getting quality data is the key-material balanced weight in and out, and C, H, O in and out of all major reactors. Is there an overlap between the DOE-funded unit at RTI with this one at NREL? What about the Davison Circulating Riser (DCR) unit at PNNL?
- The project will be successful if the facility is fully utilized by the program to justify the capital involved.

PI Response to Reviewer Comments

- We have online capabilities before and after each reactor system. We are continuing our efforts to improve the mass and atomic balances of the system, for example, we are evaluating total carbon analyzers to use in the system. The RTI pilot plant is capable of in-situ pyrolysis. The TCPDU system has the capability for fast pyrolysis and ex-situ pyrolysis. It provides DOE with added capabilities. The DCR system is a smaller reactor for ex-situ pyrolysis. The TCPDU provides DOE with a larger-scale system (~10x) to that of the DCR.
- The TCPDU system provides the pilot-scale capability within the national laboratory system. This allows DOE the ability to test catalysts and other technologies developed within the national labs at the pilot scale. Additionally, we can produce large volumes of product, which are required by other tasks and other labs for their efforts and can be difficult for them to source from industry.
- Although we are currently focused on the 2017 demonstration, there are future plans for the pilot plant. Due to the flexibility of the TCPDU, we expect it to be used for the demonstration of additional pathways.
- The reviewers are correct that the project scope and schedule is ambitious. We have risk mitigation plans to alleviate any potential issues that may arise.

DEMONSTRATION OF PYROLYSIS BASED BIOREFINERY CONCEPT FOR BIOPOWER, BIOMATERIALS AND BIOCHAR

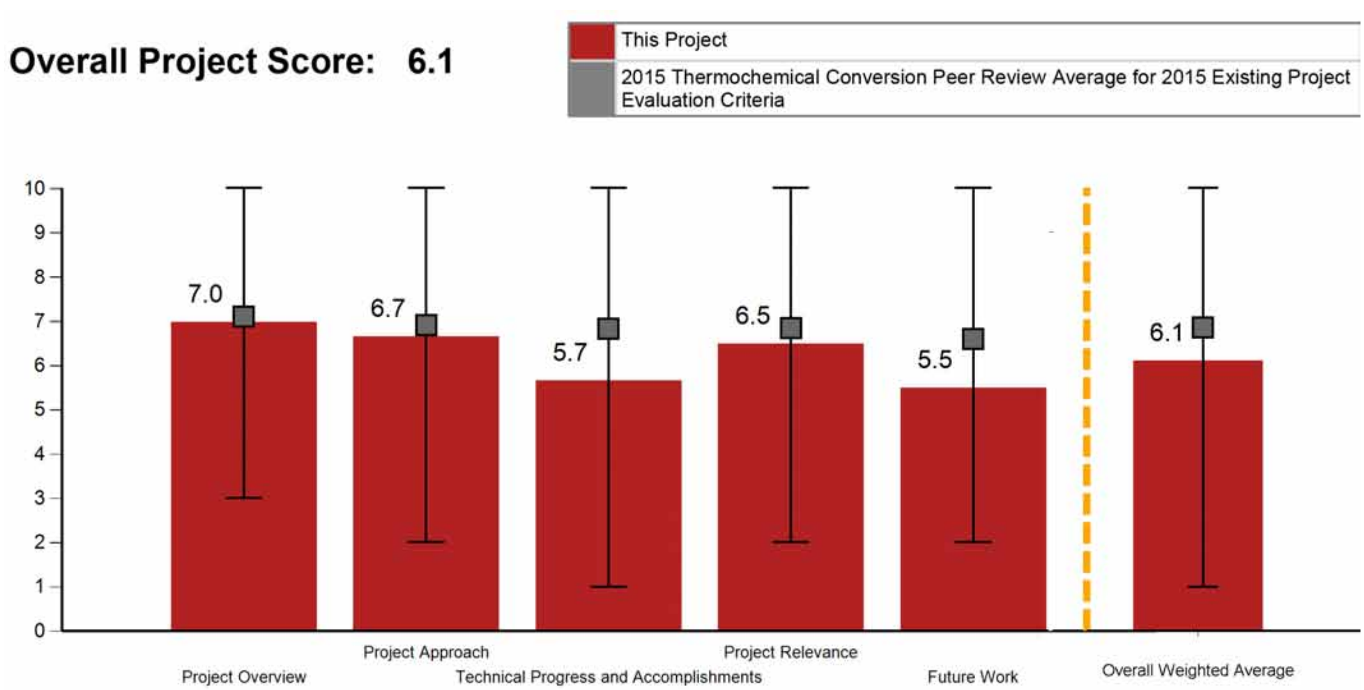
(WBS#: 2.4.1.402_Z)

Recipient:	Avello Bioenergy
Presenter:	Dennis Bansiak
DOE Funding FY14:	$46,427
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,453,573
Project Dates:	9/30/2011 - 2/28/2014

Photo Courtesy of Avello Bioenergy

Project Description

The main objectives of this project are to: (1) design, build, and operate a 2.5 ton per day integrated biomass fast pyrolysis pilot plant to produce large amounts of bioproducts; and (2) test the bioproducts performance for market acceptability. Expected outcomes include successful demonstration of Avello's proprietary integrated pyrolysis oil fractionation technology, continuous plant operation, and large-scale bioproducts testing. The project was initiated in April 2014. A Pre-Front End Engineering Design study has been completed and a Front End Engineering and Design study will be completed by the date of this review. A successful project will demonstrate and advance the commercialization of this thermochemical technology platform to convert non-food agricultural and woody biomass resources into sustainable petroleum replacements for asphalt pavements and roofing shingles, biofuel blends for clean power generation, renewable chemicals, and soil amendments, while providing bio-carbon sequestration opportunities.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- There is a poor basis for selection of plant size. The project does not show a good understanding of feeder issues.
- The project is progressing and has strong ties with Iowa State University.
- The project demonstrates separation technology and produces a number of products. Material Safety Data Sheets (MSDS) will need to be produced for products at some point. Water handling appears to remain an open issue.
- This project focuses on multiple products, some of high value, rather than maximum fuel production, to enhance profitability.
- This project does not seem to show a well-thought-out approach. There was no demonstration of a plan for how to achieve the stated objectives.

PI Response to Reviewer Comments

- Avello presented this project to DOE having 28% of the project funding already committed from a state agency and an additional 20% committed through partner in-kind funding. DOE is providing a 28% match of the funding. This project has a well-thought-out, comprehensive approach to the production of novel bio-oil fractions and their uses. Avello is designing and building a 2.5 tons per day demonstration plant (10x scale-up) to prove and de-risk our technology and demonstrate our products. We have consulted with experts to implement proven technology for critical areas including biomass handling and reactor design in addition to relying on our own experience and that of Iowa State University.
- Avello partners are leading industry experts who will showcase our products in biomaterial, renewable chemical, biofuel and soil amendment applications. Avello has adopted a rest-of-the-barrel approach to spread risk and pursue high-value market applications. The project is in the design phase and is subject to DOE review before construction can begin. Avello has assembled an experienced team to implement a carefully, thought-out work plan and achieve critical milestones and objectives for a successful project.

IMPROVED HYDROGEN UTILIZATION AND CARBON RECOVERY FOR HIGHER EFFICIENCY THERMO-CHEMICAL BIO-OIL PATHWAYS

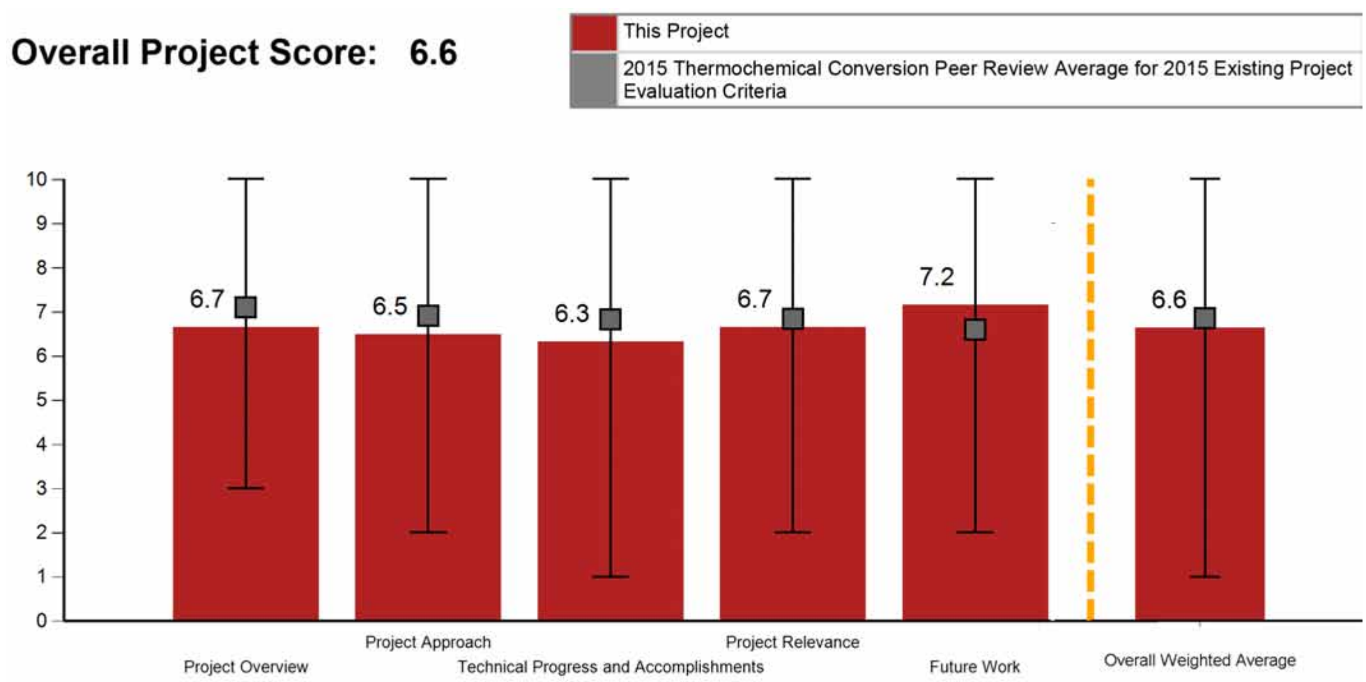
(WBS#: 2.4.1.403)

Recipient:	Research Triangle Institute
Presenter:	Dave Dayton
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$3,140,526
Project Dates:	1/1/2014 - 12/31/2016

Photo Courtesy of Research Triangle Institute

Project Description

The objective of this project is to evaluate the potential for improved hydrogen utilization and carbon recovery in a novel, direct biomass liquefaction process. The primary aspect of this concept is to use hydrogen during in-situ catalytic biomass pyrolysis to maximize the biomass carbon and energy recovery in a low oxygen content, thermally stable bio-crude intermediate that can be efficiently upgraded into a finished biofuel. The secondary aspect of this concept is to improve the carbon efficiency of the integrated process by: (1) converting the carbon in the various aqueous streams to methane for hydrogen production; (2) recovering oxygenated hydrocarbons for hydroprocessing; and (3) upgrading aqueous phase carbon to value-added byproducts. This



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

project supports the BETO goal of producing hydrocarbon transportation fuels in the gasoline, diesel, and jet range at less than $3/gallon by improving hydrogen utilization and carbon efficiency in an integrated, in-situ catalytic biomass pyrolysis process with aqueous phase carbon recovery. New and novel catalysts will be developed to improve hydrogen transfer during catalytic biomass pyrolysis to reduce bio-crude oxygen content and subsequently improve hydrogen utilization during bio-crude upgrading. Novel water treatment technologies will be evaluated for aqueous phase carbon conversion to methane that can be reformed for hydrogen production.

Overall Impressions

- Inclusion of Veolia to avoid reinventing past developments is a good idea. Process will likely evolve to many more necessary steps and hence capital complexity.
- This is an interesting new concept to achieve high carbon conversions to fuel. Historically, the in-situ catalytic pyrolysis has low carbon conversion to fuels, so the project needs to maintain the goal of high yields as a primary focus.
- The project involves new catalyst and novel carbon recovery technology. It needs a high level TEA analysis at this point to identify and make sure that the team is working on the critical issues. The project team may want to operate the hydropyrolysis unit at higher pressures than atmospheric to provide an economic driving force and unit sizing through the integrated process.
- The economic impact of this novel approach needs to be assessed to determine how much economic impact it can make.

PI Response to Reviewer Comments

- By the end of the first budget period, a bio-crude intermediate with less than 10 wt% oxygen will be produced and the potential to recover 20% of the aqueous phase carbon as methane will be demonstrated in laboratory reactor systems. These results will be used to develop a process model for an integrated direct biomass liquefaction process that utilizes methane produced from carbon recovered from the aqueous phase to generate hydrogen for upstream conversion or downstream upgrading. The process model will be the basis for a preliminary techno-economic analysis to estimate advanced biofuel production cost for the integrated process.

BIOMASS DERIVED PYROLYSIS OILS CORROSION STUDIES

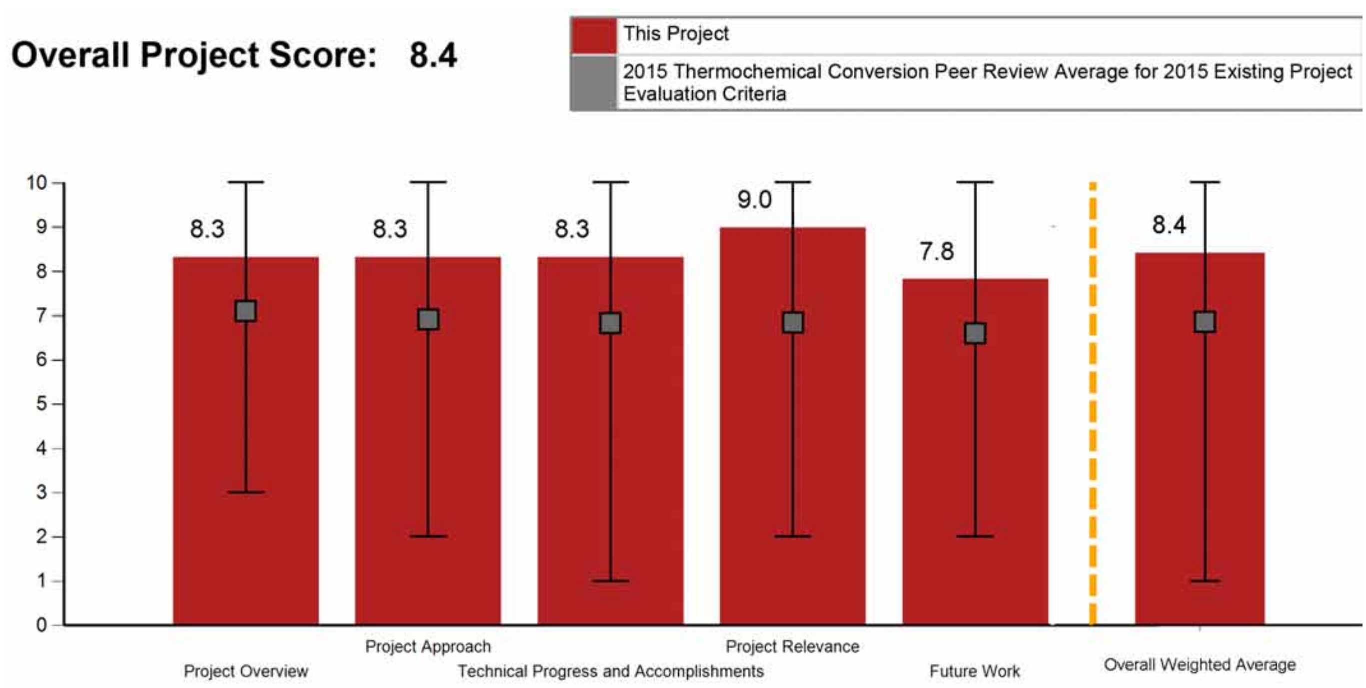
(WBS#: 2.4.2.301)

Recipient:	ORNL
Presenter:	Jim Keiser
DOE Funding FY14:	$1,284,283
DOE Funding FY13:	$773,291
DOE Funding FY10-12:	$588,262
Planned Funding:	$1,942,237
Project Dates:	10/1/2010 - 9/30/2017

Photo Courtesy of ORNL

Project Description

Acidic compounds, particularly carboxylic acids, in biomass-derived liquids are corrosive to most common structural alloys while non-metallic materials are degraded by other bio-oil components. For successful commercialization of emerging liquefaction technologies, it is essential that the least expensive structural materials that will give the desired lifetime be identified. This project has the objective of determining the degradation mechanisms that can be active in bio-oil during production, processing, transport and storage, and then identifying materials with sufficient compatibility. The project is divided into six tasks, which include laboratory corrosion studies of both metallic and nonmetallic materials, chemical characterization of bio-oils using existing methods and specially developed techniques, and physical characterization and microstructural examination of field-exposed samples and components from operating systems in order to provide guidance on alloy selection. Two new tasks include participation in a round robin study of chemical analysis methods and a controlled study of the effect of hydrotreating of bio-oils on both the oil's corrosivity and the concentration of oxygen-containing compounds. The collective goal of these tasks is to identify



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

structural materials with sufficient corrosion resistance that materials are not a barrier to successful commercialization of developing liquefaction technologies.

Overall Impressions

- This is a good example of straightforward testing and analysis that benefits a wide group.
- The project has made excellent technical progress on a topic highly relevant to the bio-oil community. The inclusion of additional outside partners is strengthening the work.
- The project is extremely important to the success of the bio-economy, addressing both safety and economics. The project works very interactively to obtain and provide samples for testing of both metals and elastomers. Understanding of which are good and bad oxygenates will be very helpful to developing strategies for upgrading; organic acids in particular are very prevalent in bio-oils.
- The determination of corrosion behavior and development of simple metrics to describe the corrosion behaviors of bio-oils are critical for the future of biofuels.
- The industry needs a comprehensive material assessment as we move to building large-scale systems. This project shows good progress in this direction.

PI Response to Reviewer Comments

- The members of this project team sincerely appreciate the positive comments provided by the review committee, as well as the suggestions for areas where improvements could be made. Increased emphasis is being put on collection of corrosion data from high-temperature sites in operating bio-oil production and processing facilities. The proposed effort to develop a standard test to determine the corrosivity of bio-oil should provide a means to better assess the corrosion potential of any bio-oil. Identification of families of compounds that cause corrosion directly or degrade or react to form corrosive species will facilitate development of metrics.

BRAZIL BILATERAL – PETROBRAS–NREL CRADA

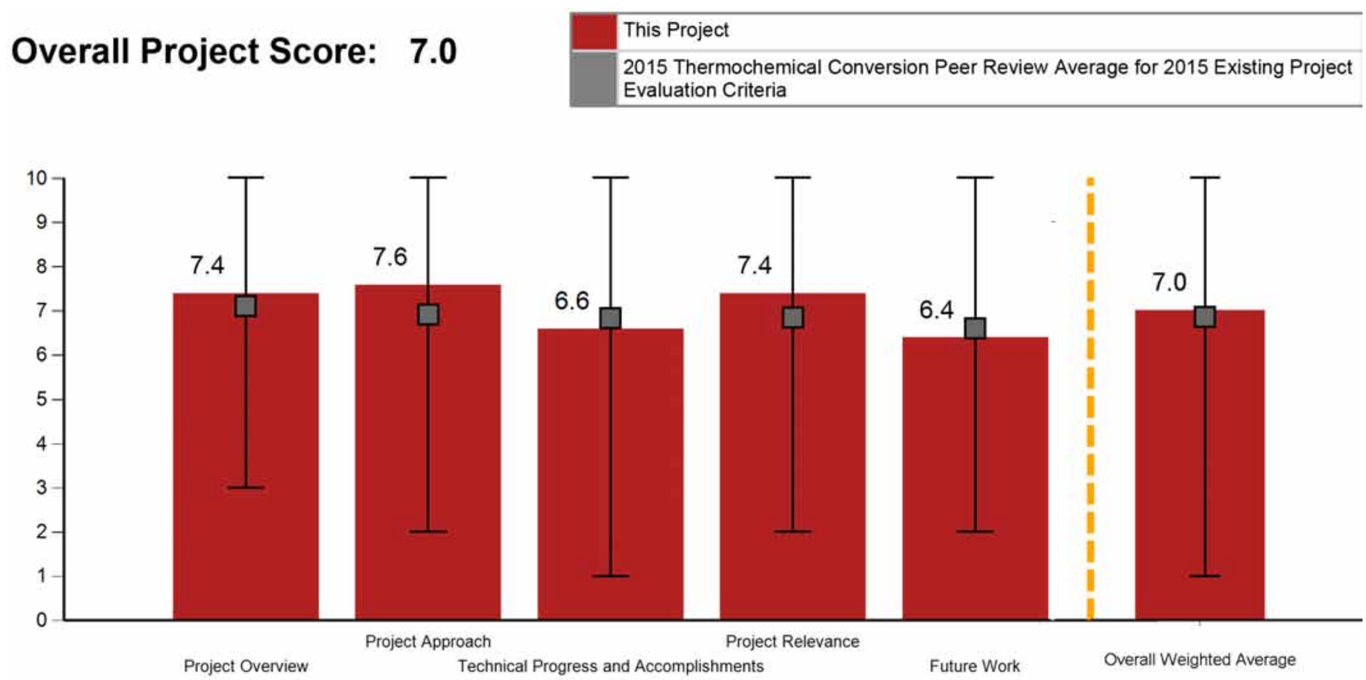
(WBS#: 2.4.2.303)

Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Helena Chum
DOE Funding FY14:	$41,437
DOE Funding FY13:	$94,014
DOE Funding FY10-12:	$755,783
Planned Funding:	$304,824
Project Dates:	10/1/2010 - 9/30/2017

Project Description

The Petrobras-NREL Cooperative Research and Development Agreement (CRADA) aims to demonstrate preliminary technical and economic feasibility of co-processing raw fast pyrolysis oil in fluid catalytic cracking (FCC) operation in a conventional refinery. The project is part of the Strategic Energy Dialogue between the governments of the U.S. and Brazil in advanced biofuels. Petrobras and NREL selected a commercial pyrolysis oil supplier, Ensyn, Corp., which provided 2,000 gallons of pine pyrolysis oil to Petrobras demonstration unit SIX, through its Brazilian partner Fibria. By December 2013, Petrobras SIX operated its demonstration FCC unit at 200 kg/hour for 70 continuous hours of operation, producing gasoline and diesel-range hydrocarbons without problems. A cumulative 400 hours of coprocessing operations of vacuum gas oil (VGO) and bio-oils was completed. Preliminary NREL TEA using the Petrobras upgrading results on Ensyn bio-oils shows that processing 5 % (wt.) bio-oil with VGO has positive economics relative to just VGO, while conversion of 10 wt. % bio-oil changes the product slate to a slightly negative impact. The impact of 5% FCC co-processing with VGO is



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

similar to that of a 1,000-1,200 tons per day cellulosic fuel facility with minimal refinery investment. The direct FCC coprocessing of pyrolysis oil in a refinery has the potential to contribute significantly towards U.S. (i.e., RFS2) and global future volumetric biofuels goals. Future work will upgrade the TEA and conduct an initial comparative LCA.

Overall Impressions

- Integration looks promising, but limited percentage may limit growth. Limited duration of testing and deep understanding of contaminants may prove to be a major problem.
- This project provides very good initial information indicating that pyrolysis oils can potentially be blended with petroleum feedstocks into an FCC. This is potentially an important pathway for bio-oil utilization.
- This is very important work for demonstrating the viability of adding bio-oil to an FCC unit. I assume that the unit is operated at steady state and that all material balances close tightly. Questions include: What are the oxygenates and how much is in the product? Has the project team kept weight basis constant and backed out carbon for oxygen? Results were a little confusing going from weight to volume and then on a relative basis (%). Also, double check benzene content in gasoline before and after and look at LPG; propylene in the C3 has potential chemical value. How do you rationalize the differences in results with those from W. R. Grace in the DCR?
- This project answers numerous questions associated with the processing of bio-oils in FCC units. Well done.

PI Response to Reviewer Comments

- Low temperature separate pyrolysis oil feeding line to FCC unit at 200 kg/h is a major difference to DCR facilities at 1/100 of the size. Coprocessing high mass balance closures were obtained with data for TEA. A modified distillation facility produced 400 gallons each of gasoline and diesel containing phenolic compounds. Based on initial TEA results, 5 wt. % bio-oil co-processing with VGO is positive economically relative to just VGO processing.

COMPUTATIONAL PYROLYSIS CONSORTIUM

(WBS#: 2.5.1.301, 2.5.1.302, 2.5.1)

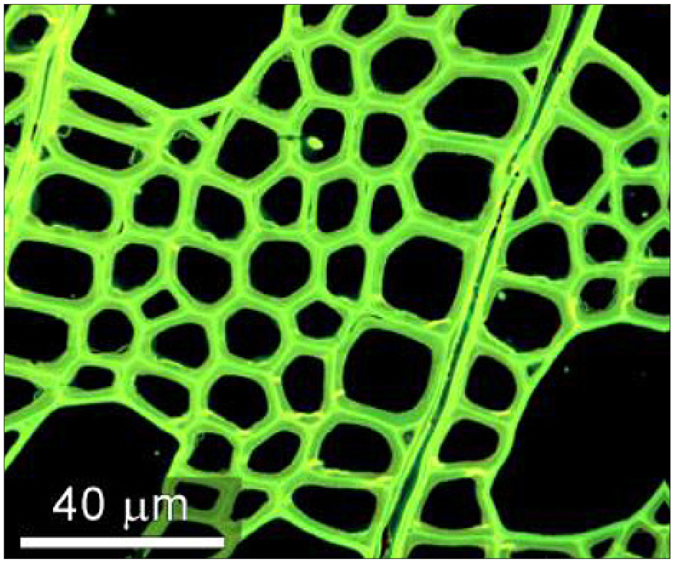
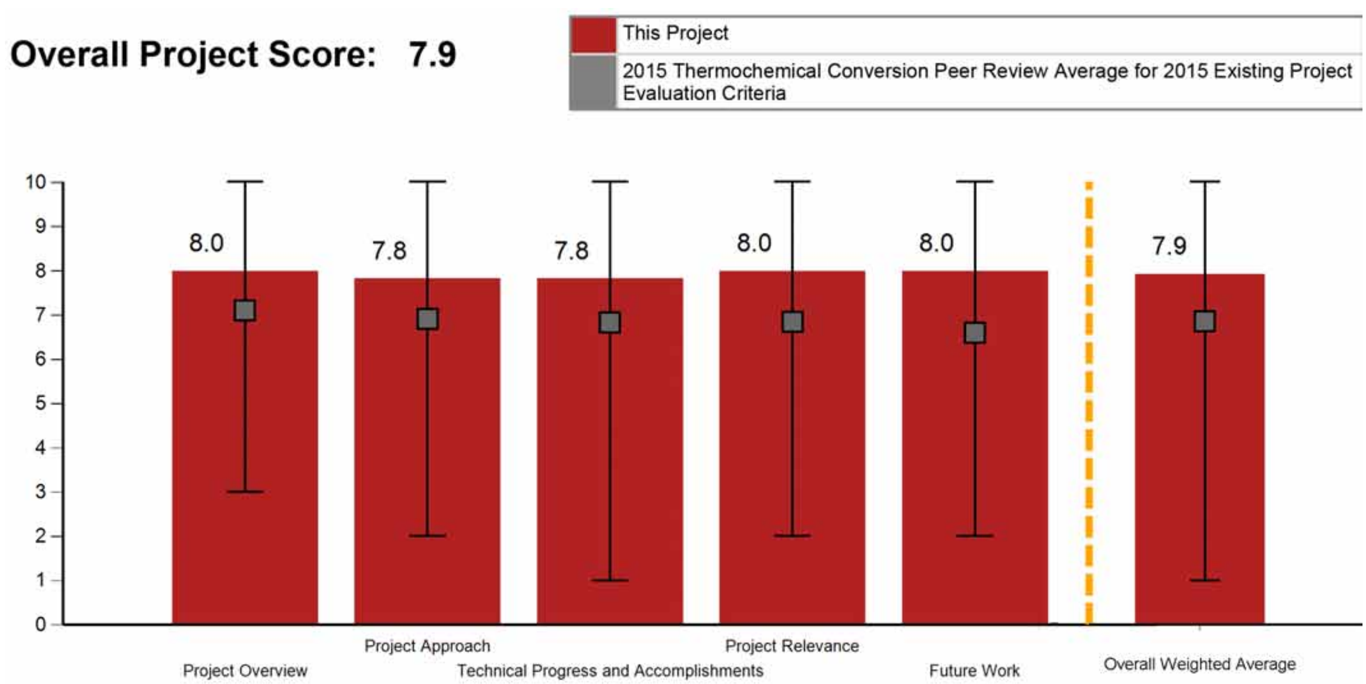


Photo Courtesy of ORNL

Recipient:	ORNL
Presenter:	Stuart Daw
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$0
Project Dates:	-

Project Description

The Computational Pyrolysis Consortium (CPC) is a joint research and development activity of five national laboratories: the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and Idaho National Laboratory (INL). The overall goal is to utilize advanced computational modeling to enable experimental bio-oil demonstrations funded by BETO to quickly and efficiently reach its 2017/2022 conversion targets. CPC efforts center on vapor and liquid-phase catalytic upgrading of oils from biomass fast pyrolysis and are relevant to three thermochemical pathways targeted by BETO (fast pyrolysis/hydrotreating, ex-situ catalytic fast pyrolysis, and in-situ catalytic fast pyrolysis). By leveraging the experience and capabilities of 5 laboratories, we are providing answers to critical technical questions raised by our experimental and techno-economic analysis collaborators and by the board of industry advisors. The activities are divided into five task areas: (1) overall team



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

coordination/integration; (2) feedstock impact modeling; (3) multiphase reactor simulations; (4) vapor-phase catalyst development and optimization; and (5) liquid-phase upgrading and hydro-treating catalyst development and optimization.

Overall Impressions

- Clearly, a well-planned and coordinated effort that will help establish technical fundamentals, which can be leveraged by others.
- The consortium provides a very useful way to focus the computational capabilities of the laboratories on biomass problems. The work could potentially lead to significant breakthroughs to help meet DOE goals. The inclusion of an external advisory committee with significant industry representation is a very useful way to keep this group focused.
- It seems scope of the project is way too large; might be better to concentrate on two or three areas. Modeling work also needs to be tied directly to projects on experimental results so that the two can work synergistically together. One of the issues facing catalytic pyrolysis is determining which reactions are catalytic and which are not. Will the modeling work address this?
- This ambitious project attacks pyrolysis issues using a broad set of tools and approaches. The consortium should determine sooner rather than later which approaches have the most promise and focus on them.
- This project is covering quite a bit of material, spread across several national labs. In some respects, it seems to be an overview type of project only because of taking a broad-scoped approach. It now needs to work toward a focused outcome, otherwise its value to subsequent projects is diluted.
- Excellent program that brings modeling/computing technical expertise to this field to identify critical science, engineering, and economic critical issues and directions. Very critical to have modeling aid in the scale-up of a new process technology. Brings together a larger organization and communication across the laboratories.

PI Response to Reviewer Comments

- We agree that identifying the most impactful areas where modeling can make a difference will be essential given the ambitious schedule and realistic cost constraints. We have built-in decision points for assessing the level of impact we are having on both the experimental demonstrations and the generation of critical scale-up information. As more experimental data, demonstration results, and modeling experience become available, it is likely that activities in one of more of the task areas will be redirected so as to have more near-term impact. An example of where this has already occurred is a shift in emphasis for liquid-phase catalysis modeling from identification of detailed micro-kinetic pathways for individual species to computer-generated reaction networks for classes of reactions and kinetic Monte-Carlo models of catalyst deactivation by gel formation.

DEVELOPMENT AND STANDARDIZATION OF TECHNIQUES FOR BIO-OIL CHARACTERIZATION

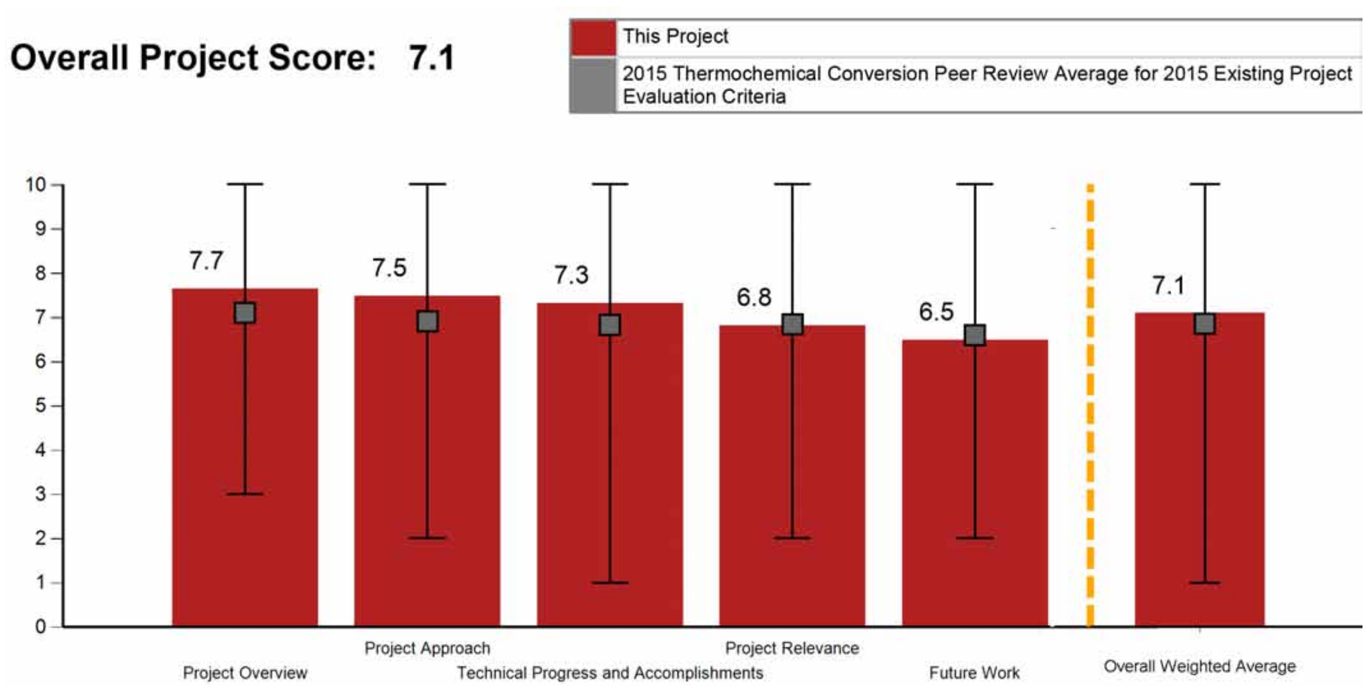
(WBS#: 2.5.2.301, 2.5.2.302, 2.5.2)

Recipient:	NREL
Presenter:	Jack Ferrell
DOE Funding FY14:	$371,000
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$3,327,000
Project Dates:	10/1/2013 - 9/30/2017

Photo Courtesy of NREL

Project Description

Bio-oil is a promising intermediate for the production of transportation fuels from biomass feedstocks. Several thermochemical routes exist for production of bio-oil, including thermal pyrolysis and hydrothermal liquefaction. Historically, due to the complex nature of bio-oil, there have been large gaps in available analytical information. Furthermore, standardized methods do not exist for bio-oils. This joint project between NREL and PNNL, started in FY14, seeks to standardize existing methods for bio-oil analysis, as well as develop new analysis techniques in areas where analytical capabilities are lacking. The development of standards will allow for comparison of results between the national labs, academia, and other stakeholders working with bio-oil, including refiners. Standardized methods will be written into Laboratory Analytical Procedures (LAPs), which are free and publicly available. Standard methods have been developed for gas chromatography – mass spectrometry (GC-MS), carboxylic acid titration (CAN/TAN), carbonyl titration, and nuclear magnetic resonance (31P NMR).



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Additionally, a technique for simulated distillation using thermogravimetric analysis (TGA) has been developed. Adoption of standardized methods will enable accurate communication throughout the bioenergy community. Additionally, methods developed in this project will allow for a more complete analysis of bio-oil, which will accelerate research in bio-oil production and upgrading.

Overall Impressions

- Perhaps the project team should take a break and solicit industry input before they get too deep in the developing novel procedures that the industry does not like or that miss the mark.
- The project is doing good work in characterizing bio-oil. However, the impact of this work on advancing the commercial state of the art or meeting DOE's cost goals is unclear. Adding an industry-based advisory panel could improve the relevance of the work.
- The costs of all of these tests are likely huge. Maybe an objective should be to translate these results into simple tests that could be done cheaply or to identify the most critical ones.
- The methods being developed are interesting and potentially useful, but they must be tied to metrics that describe their performance in refineries to be useful.
- Characterization methods have been done extensively in the past. This project adds to the effort, utilizing more advanced analysis techniques. It also should strive to develop characterization methods that are not specific to the type of bio-oil or how it was made.
- This is an excellent program. It's doing this work in years, when it took the petroleum industry decades.

PI Response to Reviewer Comments

- We appreciate the insights from the panel. We agree that industrial input is important in developing refinery-relevant standards. We aim to develop standards that are important to both bio-oil producers and refiners. We understand that there might be differences between how each stakeholder views the relevance of the current methods. As new standards are developed, the validation with other laboratories will enable determination of accuracy, repeatability and accessibility of specific characterization techniques. Correlations between measures will identify which techniques are most relevant. Engagement with industry is key to informing this process. The upfront costs seem large, but the techniques chosen utilize common instruments available in most laboratories. Additionally, correlations between different analytical techniques can drive down cost, as simpler techniques (e.g., titration) may be run in place of more expensive techniques, e.g., nuclear magnetic resonance (NMR).

FRACTIONATION AND CATALYTIC UPGRADING OF BIO-OIL

(WBS#: 2.5.4.401)

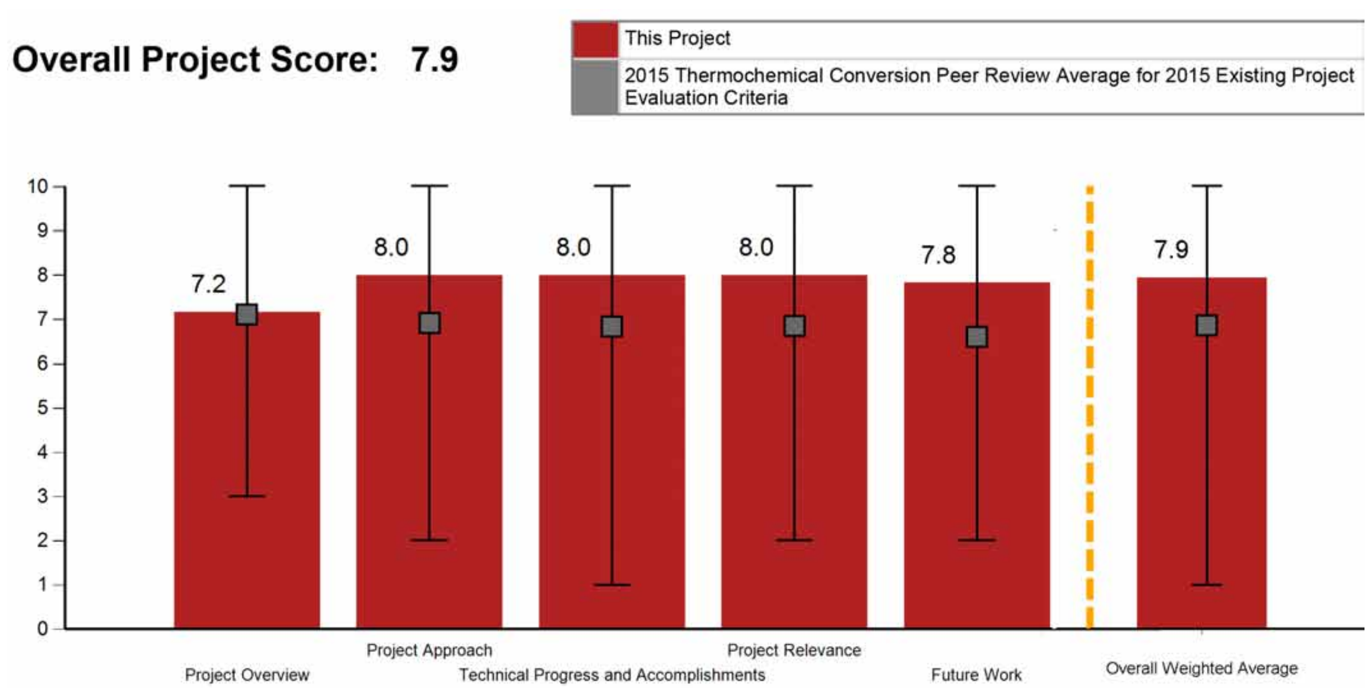
Recipient:	University of Oklahoma
Presenter:	Daniel Resasco
DOE Funding FY14:	$329,973
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,063,397
Project Dates:	9/30/2013 - 3/31/2015

Project Description

A fundamental problem in all existing technologies for the upgrading of biomass pyrolysis products is the complex composition of bio-oil, which makes it impossible to upgrade with a single catalytic stage. While it is desirable to promote condensation of small oxygenates (i.e., acetic acid), it is undesirable to do it with large oxygenated molecules (phenolics). The former allows maximizing carbon retention in the fuel range, the latter leads to coke formation and rapid catalyst deactivation. At the same time, hydrodeoxygenation of molecules that have reached the fuel range is desirable, but not for molecules in the C2-C4 range that represent 40-60% of the carbon. A judicious combination of pre-fractionation and catalytic upgrading is a revolutionary path to reach high carbon efficiency. The project attempts to maximize carbon retention in the fuel range via condensation of C2-C4 molecules, transalkylation of methoxy groups, and alkylation of small alcohols and phenolics. The hypothesis is that the net improvements in yield and catalyst lifetimes due to tailored strategies for each separate bio-oil fraction will outweigh the cost of increased complexity. This project is based on the use of thermal-staged fractionation followed by catalytic upgrade of fractions with different families of oxygenated compounds.

Overall Impressions

- This effort has a good project approach with collaboration leading to interesting results.
- The approach is interesting. The project team should consider methods to significantly reduce unit operations.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- There is a trade-off between carbon efficiency vs. adding additional reactors and separation steps. The project team must account for catalyst deactivation, but it is nice to see an attempt to capture carbon from light oxygenates rather than being lost in the wastewater.
- This novel, high-risk scheme tailoring separation strategy and upgrading has real potential to be a game changer for biomass conversion. The investigators must use TEA to assess the trade-offs in complexity and yield.

PI Response to Reviewer Comments

- We thank the reviewers for the encouraging comments. Certainly, our goal is to find the optimum balance in the tradeoff between C/H efficiency and the incorporation of additional reactors and separation steps. The capture of carbon from light oxygenates is crucial for the overall economics of the process. We will continue focusing in optimizing our process design and reduce the number of unit operations by carefully choosing the chemistries and separation strategies.

CATALYTIC UPGRADING OF THERMOCHEMICAL INTERMEDIATES TO HYDROCARBONS

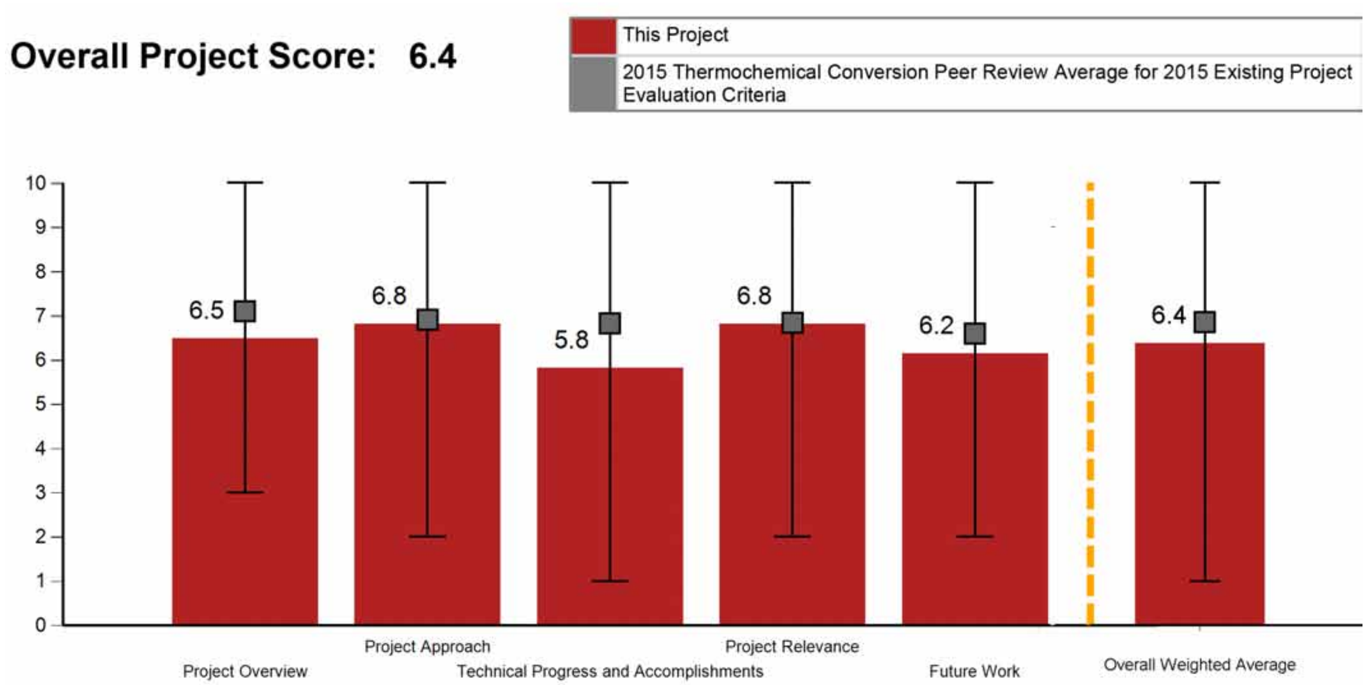
(WBS#: 2.5.4.405)

Recipient:	Research Triangle Institute
Presenter:	Dave Dayton
DOE Funding FY14:	$1,180,943
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,735,020
Project Dates:	10/1/2011 - 9/30/2015

Photo Courtesy of Research Triangle Institute

Project Description

The goal of the project is to demonstrate an advanced biofuels technology that integrates a catalytic biomass pyrolysis step and a hydroprocessing step to produce infrastructure-compatible biofuels. RTI International is developing a novel single-step catalytic biomass pyrolysis process to produce a hydrocarbon-rich bio-crude intermediate. Haldor Topsoe has developed a strategy for upgrading bio-crude intermediates based on extensive hydroprocessing catalyst and process development expertise. The proof-of-concept has been demonstrated for the individual components. The catalytic biomass pyrolysis process has been scaled up to a 1 ton/day pilot unit and a commercially scalable hydroprocessing unit has been designed, built, and commissioned. The technical goals are to: (1) optimize the catalytic biomass pyrolysis process (1 ton/day) to achieve a high degree of deoxygenation, while maximizing the biocrude production; (2) improve bio-crude thermal stability; (3) evaluate the impact of bio-crude quality in the hydroprocessing step;



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

(4) minimize hydrogen demand of the integrated process; and (5) maximize biofuels yields. A detailed plan has been developed to address these technical challenges and collect required processing and engineering data to support the development of a technically viable and economically feasible integrated catalytic biomass pyrolysis process with bio-crude hydroprocessing.

Overall Impressions

- This is a good project, but it is possible that the project team has not planned enough time and money to get the integrated system running reliably. Other integrated startups have had to spend much more than expected time and money to get over this hump. It does not appear they have this included in their plan.
- This project is nearing the completion date, and seeking a six-month, no-cost extension, but it is questionable whether or not stated project deliverables will actually be achieved.
- Assuming the no-cost time extension is approved, this project should successfully produce reasonable quantities of highly upgraded liquids. Successful completion would essentially serve as the "validation" of the ex-situ pyrolysis approach.
- Product from Haldor Topsoe hydrotreated at severe conditions of 0.5 LHSV (liquid hourly space velocity) still appears to contain oxygen based on specific gravity, and hydrotreating catalyst deactivation seems to be significant. Yield is low at 40 gallons/ton. Based on the experience at Kior (one being low carbon selectivity into liquid fuels), what technical hurdles must be overcome and will this project be able to address them?
- The large pyrolysis unit is an expensive asset that appears to be underutilized (equivalent of four full days in 18 months). This reviewer hopes that the Haldor Topsoe hydrotreater will see better utilization to justify its purchase and commissioning costs.

PI Response to Reviewer Comments

- At the current stage of development, the catalytic biomass pyrolysis process is being scaled-up in a 1 ton per day pilot plant based on a single-loop transport reactor design with continuous catalyst regeneration. RTI has discovered a novel catalyst that effectively deoxygenates biomass pyrolysis vapors in a catalytic biomass pyrolysis process. This produces a low oxygen-content, thermally stable bio-crude intermediate. To date, we have produced 60 gallons of loblolly pine biocrude for upgrading.
- A hydrotreating unit was designed, built, installed and commissioned to provide the capability of integrating bio-crude production and upgrading in a single facility. Since the Peer Review meeting in March 2015, we have successfully upgraded bio-crude for over 100 hours. The hydrotreating unit was designed with the intent of producing commercially relevant data. Highly reproducible operation for hundreds of hours of steady-state operation can be used to simulate the performance of commercial units. Long-term catalyst testing can be used to estimate catalyst deactivation rates and lifetime.
- By the end of the project, experimentally validated process conditions (temperatures, pressures, hydrogen demand, and catalyst performance) and yields (both bio-crude and upgraded products) will be input into a process model to verify the technical feasibility and economic viability of this specific thermochemical pathway using specific catalysts and feedstocks. The integrated catalytic biomass pyrolysis process with bio-crude upgrading is defined by BETO as the in-situ direct biomass liquefaction pathway and a Design Case based on this approach is scheduled for release in 2016. In principle, the data from this project can be used to support future design cases; however, they are typically based on publicly available information and proprietary technical details may need to be protected.

ADVANCED MEMBRANE SEPARATIONS TO IMPROVE EFFICIENCY OF THERMO-CHEMICAL CONVERSION

(WBS#: 2.5.5.301, 2.5.5.302)

Recipient:	ORNL
Presenter:	Michael Hu
DOE Funding FY14:	$391,420
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$908,580
Project Dates:	10/1/2013 - 9/30/2017

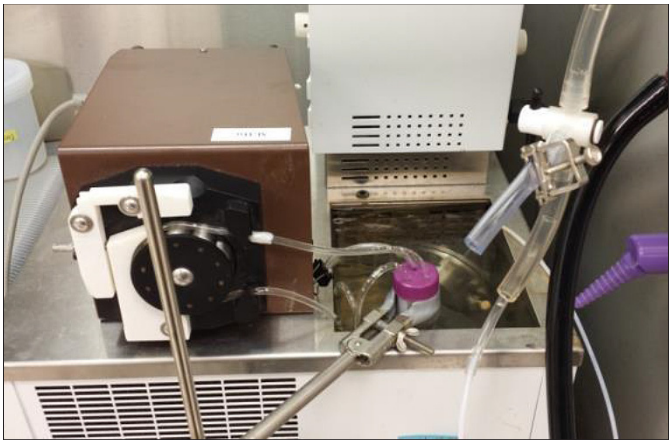
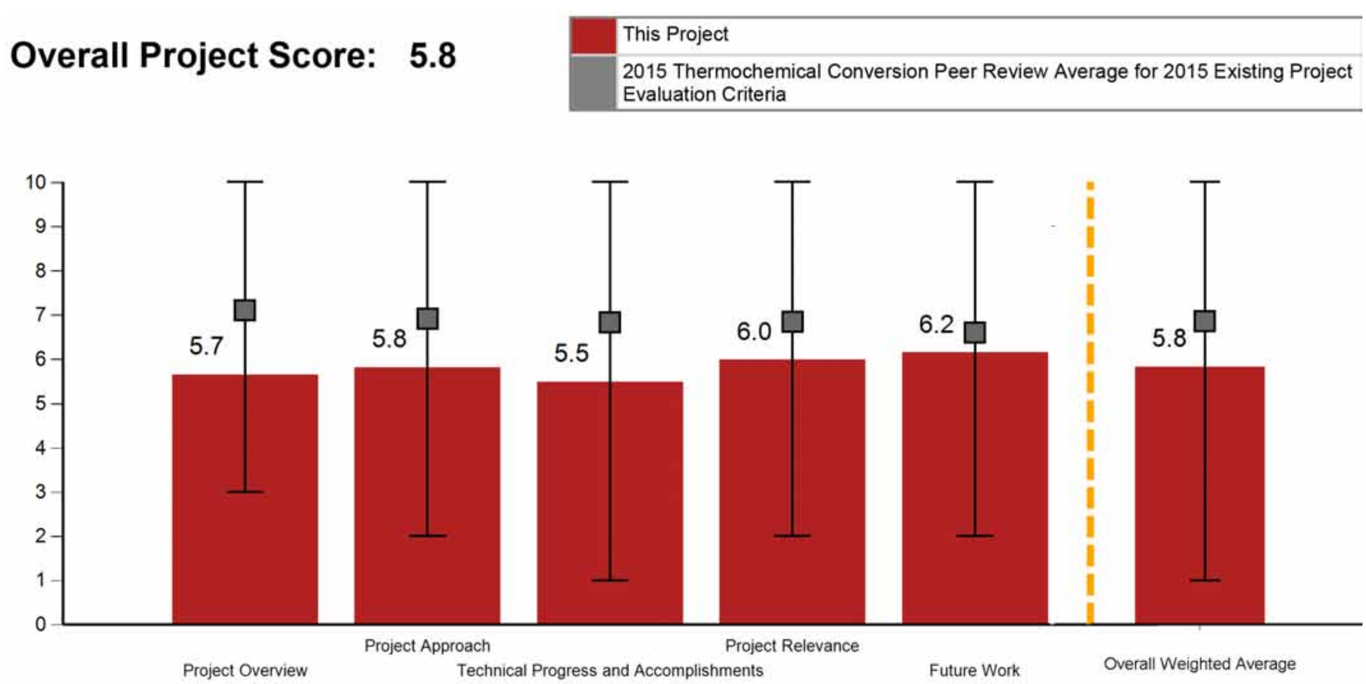


Photo Courtesy of ORNL

Project Description

The project seeks to develop and employ a new class of robust inorganic-based membranes, i.e., HiPAS (High Performance Architectured Surface Selective) for improving the efficiency of bio-oil processing through vapor-phase or liquid-phase separations. Employing HiPAS could improve the economics of bio-oil processing due to enhanced carbon recovery and separation efficiency. Oak Ridge National Laboratory (ORNL) is working with National Renewable Energy Laboratory to develop both membrane materials and processes that can intensify the thermochemical conversion. This effort merges several areas of expertise, including conversion science, inorganic membrane technology, and nanomaterials science. The challenges of integrating advanced membrane technologies into biomass conversion processes were overcome by incorporating newly developed nanostructured coating technologies with ORNL's



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

inorganic membrane support technology. Here, a series of robust HiPAS membranes with hydro-tunable surfaces were successfully synthesized. Experimental data were obtained to demonstrate that the highly tunable surface properties (i.e., super hydrophilicity or hydrophobicity) and synergistic control of nanopore size in membranes can facilitate high separation selectivity and permeability. Separation performance with biomass pyrolysis and upgraded products is approaching the target selectivity of 10/1, which validates the decision toward future high-flux membrane and process development.

Overall Impressions

- Why wasn't there discussion of the economics of the project?
- The process could potentially remove water from the pyrolysis oil stream, and progress with model compounds to establish proof of concept has progressed reasonably. However, it is not clear whether the dewatering would actually help improve economics. A rapid techno-economic analysis is needed to better understand the value proposition.
- It is not evident why separating water before the hydrotreater is advantageous. Also, performance of membrane for fouling and selectivity for a range of oxygenates represents a huge challenge. How much carbon will be lost to the water and what will be its fate? What will be the economic impact if the project is wildly successful?
- This project needs to have clear techno-economic analysis to define criteria for success.
- If this works, it could be very important to water cleanup. I am not sure that the project will have an impact upstream before the hydrotreating reactor.

PI Response to Reviewer Comments

- In the bio-oil (either vapor or liquid phase) processing industry, there is a need for separating/extracting a particular component (such as water or a particular oxygenated or de-oxygenated hydrocarbon molecule) out of the bio-oil mixtures. In a multi-component bio-oil mixture of A+B+C+... etc., selectivity of the target component (such as A) out of the mixture bio-oil is critical to the separation efficiency and related up-stream or down-stream bio-oil processing steps. Among multiple separation needs identified for the bio-oil processing industry, water separation from deoxygenated hydrocarbon (such as upgraded oil) or oxygenated hydrocarbon (such as crude pyrolysis bio-oils) represents an important initial membrane-based separation to demonstrate proof-of-principle data. Hydrothermal stability of zeolite catalysts in hydrotreater is always an issue. A suitable reduction in the amount of water present in the feed bio-oil of the hydrotreater can aid in the overall process efficiency.
- This project has demonstrated several successes in the vapor phase, namely the separation of water from aromatic hydrocarbon vapors produced from biomass feedstocks. The upstream removal of water from the bio-oil vapor stream has the potential to improve the hydrothermal stability of ZSM-5 zeolite dehydrogenation catalysts. In addition, downstream separation of water from hydrocarbons and oxygenates from deoxygenated molecules etc., are important for the quality of the upgraded bio-oil and fractionations. The physical properties of HiPAS membranes are well suited to deal with the selectivity issue associated with removing oxygenates and limiting membrane fouling. Fundamentally, the synergistic surface-pore effect would fully take advantage of the surface interactions that are important to surface fouling and enable a new surface enhanced capillary condensation mechanism for high selectivity separations. If the HiPAS membrane maintains a high selectivity (>10:1), then the permeate stream will have little to no hydrocarbons, thus limiting

the loss of carbon in the overall separation process. This scenario will limit the chances for membrane fouling as well. The main economic impact of the membrane separation technology on the bio-oil processing industry is improved processing efficiency, such as prolonged catalyst lifetime for the upgrading reactor and reducing processing costs. The more complete quantitative TEA evaluation in the upcoming task of this project will answer the questions on economic impact due to multiple possibilities of membrane separations integration with the bio-oil processing steps.

- Controlling the concentration of water (dewatering) has the potential to improve the hydrothermal stability and lifetime of upgrading catalysts and also the down-stream fractional process. Dewatering in the upstream feed could potentially impact the catalyst lifetime and thus reduce processing costs. Economics of membrane separations on the bio-oil processing industry will be evaluated through a planned techno-economic analysis evaluation task in FY16.
- We thank the reviewers for recognizing that membrane development and separation processes are worthy focus areas that contribute to the BETO biofuel conversion/processing program portfolio.

FRACTIONAL MULTISTAGE HYDROTHERMAL LIQUEFACTION OF BIOMASS AND CATALYTIC CONVERSION INTO HYDROCARBONS

(WBS#: 2.5.5.401)

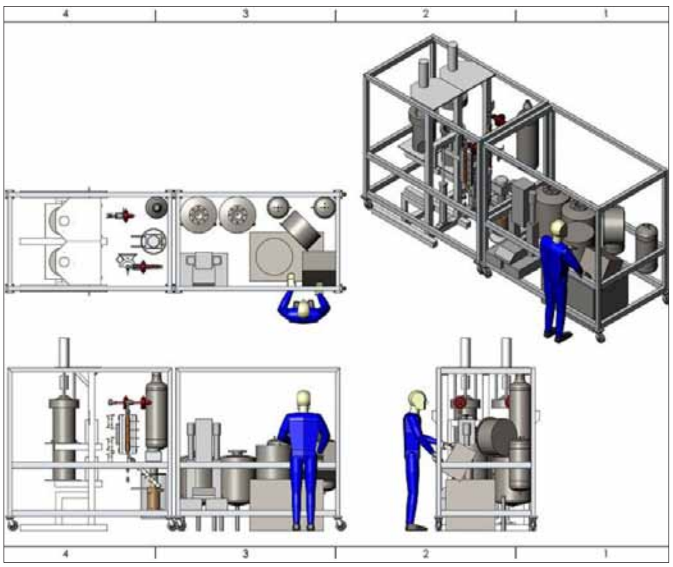
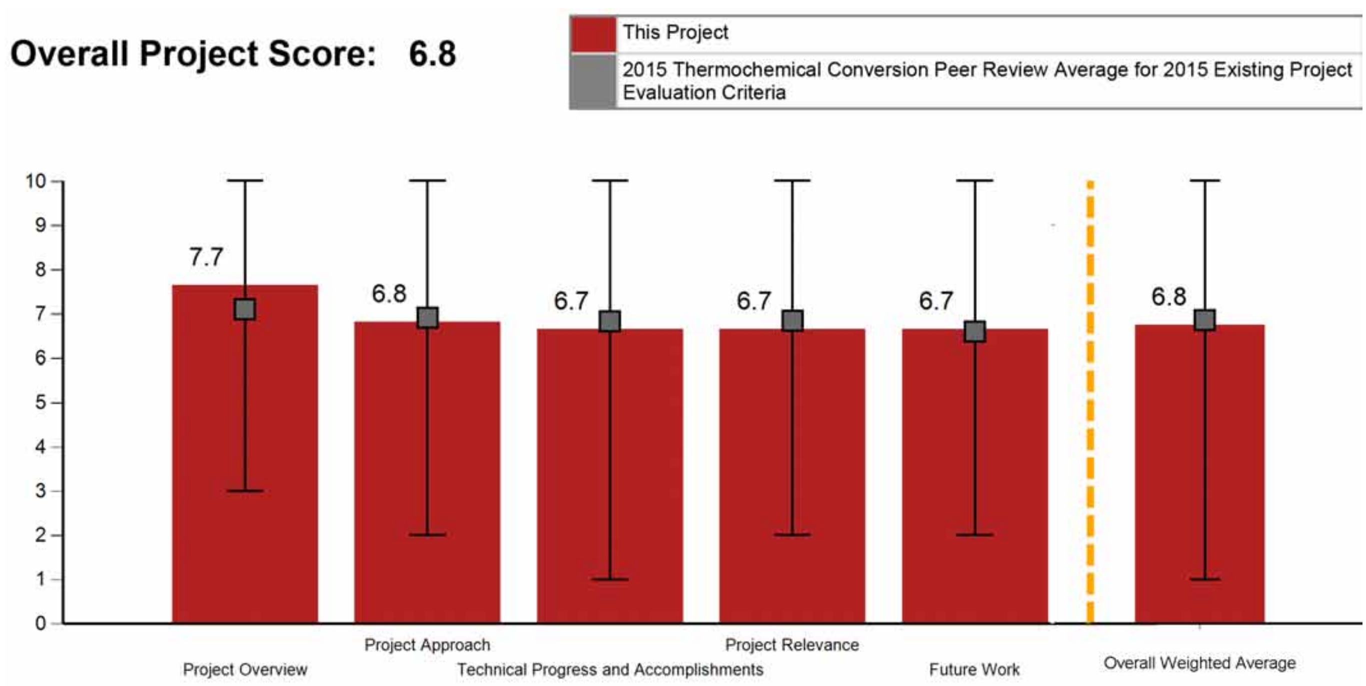


Image Courtesy of Virent, Inc.

Recipient:	Virent, Inc
Presenter:	Randy Cortright
DOE Funding FY14:	$451,831
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,948,169
Project Dates:	10/1/2013 - 9/30/2015

Project Description

The purpose of this project is to demonstrate the technical and commercial feasibility of producing distillate fuels from lignocellulosic materials. Virent is developing a novel Multistage Hydrothermal Liquefaction (HTL) deconstruction process, which will be paired with Virent's BioForming® process to produce advantaged jet fuel and diesel. Previous testing has demonstrated both fuels meet or exceed specifications for commercial and military use. In addition to Virent, the project is leveraging expertise of Idaho National Laboratory (INL) for the procurement, preconversion, and analysis of woody biomass and corn stover. Since inception in Q4 of 2013, the program progressed through Technical Readiness Level 2 (TRL-2) and completed design of a pilot unit to demonstrate the HTL process. Specifically,



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

milestones for carbon conservation have been met, and an initial kinetic model has been developed. In Q2-Q3 of 2015, the project focused on the construction of the HTL pilot unit at Virent's facilities in Madison, Wisconsin. In Q4 of 2015, this project underwent a Stage Gate review to evaluate milestones within TRL-3. Following successful completion, future work in TRL-4 will focus on continued process economic improvements through higher yields and reduced operating costs.

Overall Impressions

- The project has unrealistic expectation of feedstock contaminant removal.
- The project is proceeding as planned.
- The project is looking at different solvents to improve carbon efficiency and optimize process, e.g., mild hydrotreating of lignin rather than processing it through same steps required for other fractions.
- The project has promise, but the solvent processes need to be fully developed at bench sale before pilot plant design. Techno-economic analysis needs to be carried out before or in parallel with experiments.

PI Response to Reviewer Comments

- In the first fundamental phases of this project, Virent has investigated a wide range of solvents for each of the proposed steps. In this TRL-2 work, we have identified effective solvents that can be generated within Virent's Bioforming process and recycled to the liquefaction section to solubilize the biomass. Since the solvent is generated in-situ in the overall process, it is expected to be both technically and economically feasible.
- The project plan includes both technical and economic evaluations of feedstock contaminant removal. Results of these evaluations will be used within the project to guide the best strategy for dealing with these contaminants.
- As part of the project plan, Virent will begin work this summer to establish a process flow diagram of the overall process with an Aspen-generated heat and material balance. This will be used to conduct a techno-economic analysis of the overall process, and this analysis will be used to evaluate different options for the overall process.

RENEWABLE HYDROGEN PRODUCTION FROM BIOMASS PYROLYSIS AQUEOUS PHASE

(WBS#: 2.5.5.403)

Recipient:	ORNL
Presenter:	Abhijeet Borole
DOE Funding FY14:	$446,349
DOE Funding FY13:	$1,697
DOE Funding FY10-12:	$0
Planned Funding:	$1,686,954
Project Dates:	10/1/2012 - 9/30/2017

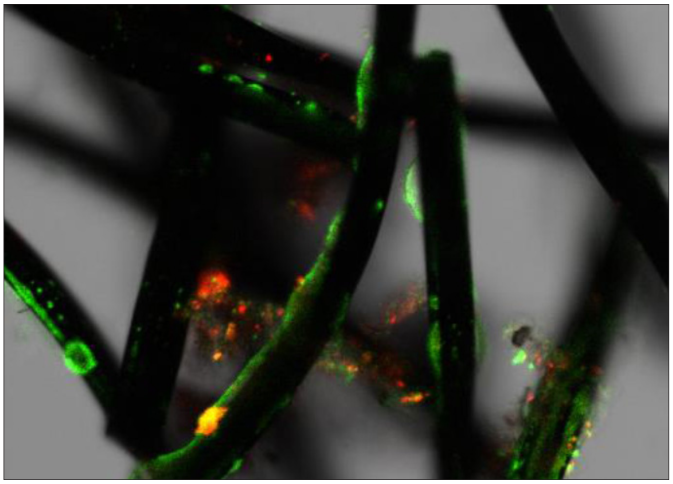
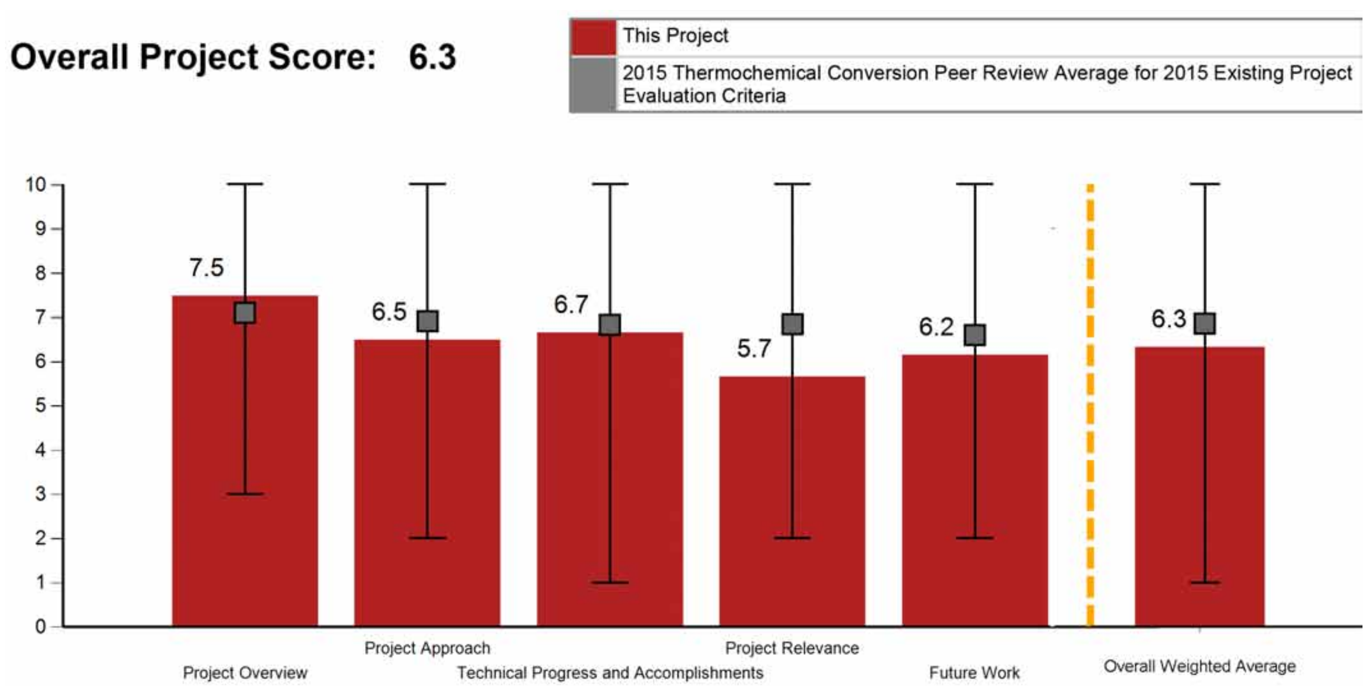


Photo Courtesy of ORNL

Project Description

The purpose of this project is to develop a reforming process for efficient conversion of bio-oil aqueous phase (BOAP) to hydrogen via microbial electrolysis. This project was competitively awarded within the CHASE FOA funded in September 2013. Successful production of hydrogen from BOAP has potential to eliminate the need for natural gas. The project addresses the barriers: Tt-M: Hydrogen Production, Tt-N: Aqueous Phase Utilization and Wastewater Treatment, and Tt-O: Separations Efficiency, listed in BETO's Multi-Year Program Plan. The work targets efficient conversion of corrosive and polar compounds to hydrogen. It can enable significant improvements in hydrogen production efficiency and utilization of carbon compounds in the aqueous phase, while reducing life cycle greenhouse gas emissions. This has potential to increase the stability of the bio-oil and reduce its corrosivity. The bio-oil contains compounds, which can be inhibitory to



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

microorganisms. This challenge will be addressed by use of electroactive biofilms, which can tolerate such compounds and exhibit high conversion efficiencies. A novel biocatalyst capable of conversion of BOAP compounds was developed. Production of hydrogen was demonstrated at a Coulombic efficiency of 56%. The ongoing effort is targeted at improving productivity and yield as well as separation methods to support microbial electrolysis cell (MEC) operation.

Overall Impressions

- This could be interesting. Separation technology and hydrogen yield are key to continuing development.
- This project has an interesting and innovative approach. The research will be helpful in determining if the concept has potential for larger scale production.
- Ultimately, this project converts electricity in hydrogen. I would like to see a compelling case showing that this project makes economic and thermodynamic sense.
- The project is novel, but needs to be compared to traditional electrolysis, as well as bio-derived hydrogen. Low productivities are likely to require large capital expenditures for large bioreactors. Cost needs to be compared to traditional clean-up technologies.

PI Response to Reviewer Comments

- The first comment on overall impression related to the MEC process being conversion of electricity to hydrogen is not accurate. In the MEC process, the electrical efficiency is >150%. This is so because the major portion of the energy in hydrogen (more than 50%) comes from biomass. Thus, compared to water electrolysis, this process uses significantly less electricity. While a compelling case for economic feasibility is yet to be made, the thermodynamic feasibility of this process is not a question. Hundreds of peer-reviewed publications in MECs have been published and it has been practically demonstrated by several other researchers, although not using a bio-oil stream, but mostly using various wastewater streams.
- The project team appreciates the positive comments related to the novelty and innovative nature of the project. As requested by the reviewer, a comparison with the traditional electrolysis and other biotechnologies was given above. The following table lists the various alternatives for conversion of biomass-derived sugars to hydrogen in comparison with MEC.
- Finally, the project team appreciates the comment from the reviewer on the key benefits of separations and hydrogen production methods on continuing development of technologies of interest to BETO.

	Process scheme	Theoretical yield	Observed yield	Free energy change (for H_2 producing step)	Overall observed energy yield	Comments
1	Hypothetical hydrogen production	12				
2	Hexose to ethanol to hydrogen via autothermal reforming	10	9.5	-265 kJ/mole *	~ 83%	Prohibitive catalyst (Rh) cost
3	Dark-light fermentation: Glucose —> acetate —> Hydrogen	8	7.1	+164 kJ/mole	59.2%	Limited by light penetration and cost
4	Methanogenesis-steam reforming	8	6.0	+261 kJ/mole	50.5%	Mature technology components
5	MEC	12	8.2	+104.6 kJ/mol	64%	Nascent technology

*Processes 3-5 require energy input for the hydrogen-producing step, but this step is energy yielding in process 2. While the hydrogen producing reaction is energy-yielding, energy input is required for production of ethanol from hexose.

Reference: Borole, A. P. (2011). Biofuels, Bioproducts & Biorefining, "Improving energy efficiency and enabling water recycle in biorefineries using bioelectrochemical cells." 5(1): 28-36.

RENEWABLE ENERGY CENTER

(WBS#: 7.3.2.6)

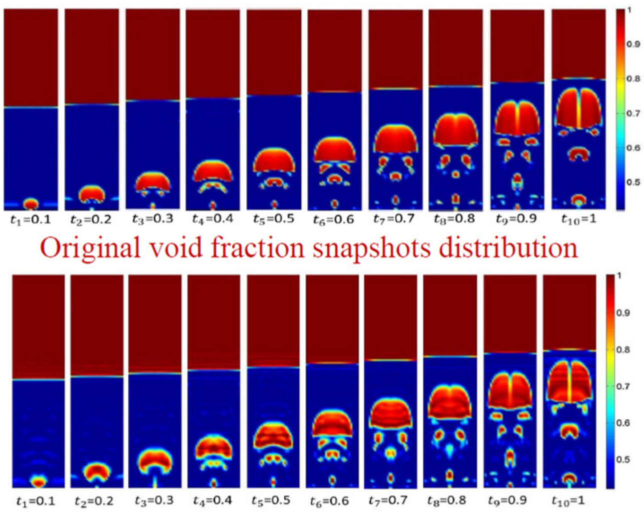
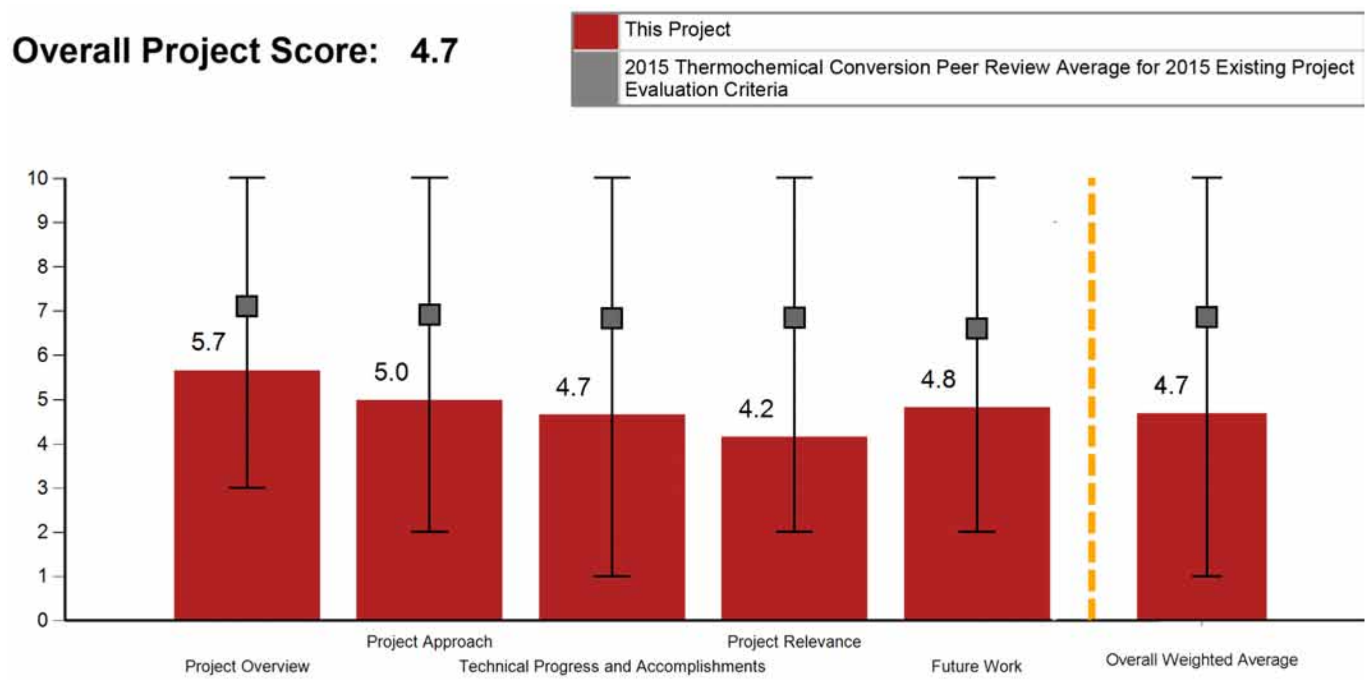


Image Courtesy of North Carolina A&T State University

Recipient:	North Carolina A&T State University
Presenter:	Abolghasem Shahbazi
DOE Funding FY14:	$145,270
DOE Funding FY13:	$219,180
DOE Funding FY10-12:	$219,180
Planned Funding:	$151,610
Project Dates:	4/1/2011 - 9/30/2015

Project Description

Biomass gasification in a fluidized bed gasifier involves complicated physicochemical and structural evolution of biomass particles, and reactive gas-particle behavior. Several impurities in syngas can severely interfere with the catalytic Fisher-Tropsch (F-T) synthesis of liquid fuels from the syngas. The major goal of this project is to use advanced experimental and mathematical modeling techniques to study an integrated biomass gasification and hot syngas cleaning process to produce high-quality syngas from woody biomass and agricultural residues and study an efficient F-T process to convert syngas into liquid fuels. Accomplishments include determining the physicochemical and structural evolution of biomass particles, and gasification kinetics during gasification; analyzing the multiphase reactive gas-particle flow behavior in a fluidized bed gasifier through advanced CFD modeling and reduced order modeling techniques; synthesizing a nickel-based catalyst



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

for tar cracking and ammonia decomposition in hot syngas; and synthesizing and testing a Fe-based catalyst for the F-T synthesis of biomass-derived syngas into liquid fuels. These accomplishments generate fundamental knowledge and tools necessary for the development of an integrated biomass gasification and hot syngas cleaning process, and subsequent F-T synthetic process to produce liquid fuels from biomass.

Overall Impressions

- This is a very poorly executed project. If these startup biocenters are going to be supported, they need an advisory panel to make it worthwhile.
- The project team needs to take a thorough look at what is available, both in the literature and at others in the BETO community, for model development and experimental data.
- The investigators did not clearly show how their work differs from previous work and advances the field.
- Project targets are vague and appear to be an exploratory approach to simply understand bio material/utilization.

PI Response to Reviewer Comments

- We have conducted a comprehensive literature review in the fields of biomass gasification and F-T synthesis. Although there is a lot of information on biomass gasification and F-T synthesis in the literature, our research focus is to add more information on our identified technical barriers to further advance the biomass gasification and F-T technologies. We have made several innovative contributions to the field, including the research on: (1) the evolution of the physical and chemical properties of biomass during gasification; (2) modeling of the interaction of two solid phases of biomass particle and particulate bed materials on the heat transfer during fluidized bed gasification; (3) the reduced order model for fast process simulation; and (4) catalytic F-T synthesis of liquid fuels from syngas with high CO_2 content.

CITY OF GRIDLEY BIOFUELS PROJECT

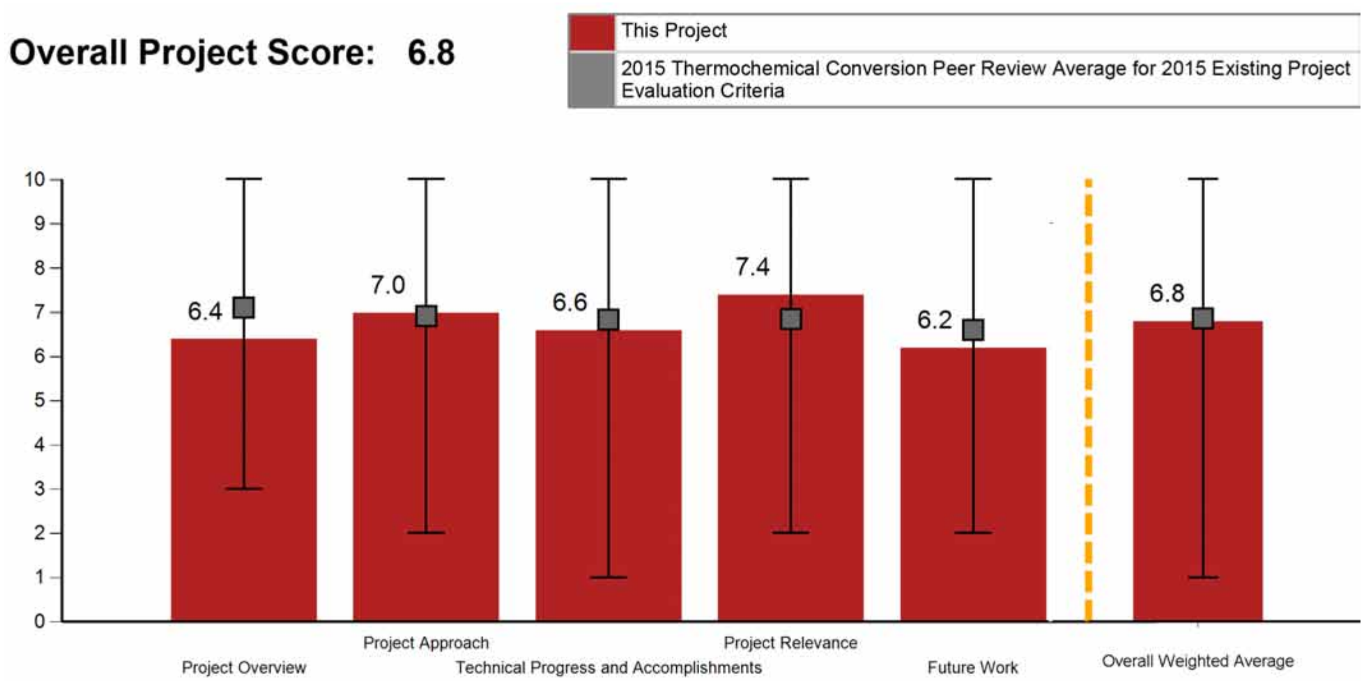
(WBS#: 7.5.4.1)

Photo Courtesy of Greyrock Energy

Recipient:	City of Gridley
Presenter:	Dennis Schuetzle / Matt Michaelis
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,493,227
Project Dates:	4/22/2003 - 3/31/2016

Project Description

The primary goal of this project is to complete the final design of a 240 dry ash free ton (daft) per day commercial-scale plant in Gridley, California, as based upon the successful Gridley Budget Period 1 (BP1) and DOE integrated biorefinery (IBR) efforts. This plant can efficiently convert rice harvest waste (and other local agricultural wastes) into biofuels, biochar and biopower. It has been demonstrated that this technology can directly convert biomass residues into renewable fuels with an average biofuel yield of about 57 gallons/daft of biomass. The biofuel products consist of 70% synthetic diesel fuels and 30% reformulated gasoline blendstocks. The synthetic diesel fuel contains no sulfur, has high cetane and excellent lubricity,



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

resulting in efficient operation with in-use, current, and future model diesel engines. The synthetic diesel has been demonstrated to reduce tailpipe emissions by up to 20% for current model vehicles and more than 50% for in-use vehicles compared to current petroleum diesel fuels. LCA modeling predicts that greenhouse gases will be reduced by up to 169% compared to current petroleum fuels. REI International's (REII's) preliminary economic models forecast a diesel wholesale value of $2.48/gallon (at $50-$60 per barrel of oil) and biopower of about $0.085/kwh, while providing an internal rate of return (IRR) of 10-11% over the plant's 20+ years lifetime.

Overall Impressions

- Too much data is kept close to the vest. Perhaps this offers a small scale alternative. I can't tell from energy data.
- The basic approach of using a modest-sized gasifier to produce liquid fuels has been tried several times. The remaining work will determine whether this project successfully advances the state of the art.
- The project continues to move forward. It is unclear as to what happens to the naphtha fraction of the product.
- This project, along with the IBR work, should provide a good case for DOE investigators to study and see the issues involved with building and operating a real-world biofuels project.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

UPGRADING OF INTERMEDIATE BIO-OIL PRODUCED BY CATALYTIC PYROLYSIS

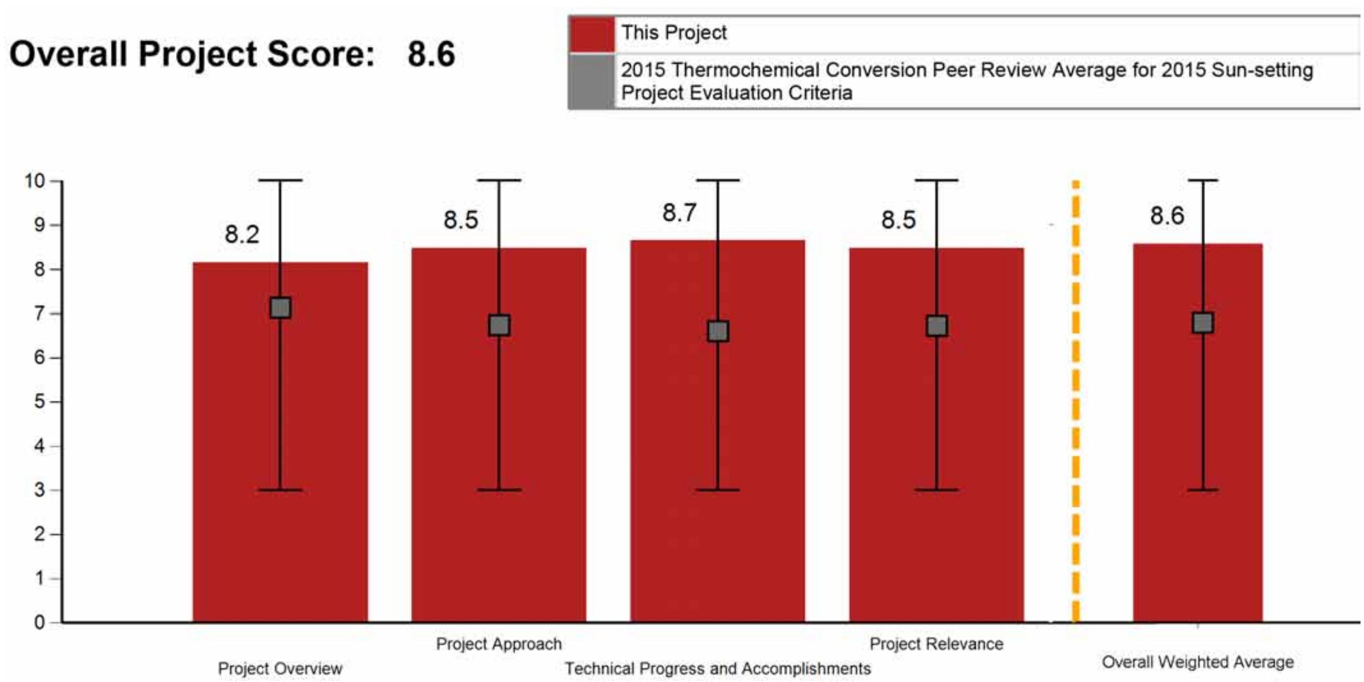
(WBS#: 2.3.1.401)

Photo Courtesy of Battelle Memorial Institute

Recipient:	Battelle Memorial Insititute
Presenter:	Zia Abdullah
DOE Funding FY14:	$359,233
DOE Funding FY13:	$815,276
DOE Funding FY10-12:	$815,276
Planned Funding:	$821,528
Project Dates:	9/30/2010 - 9/30/2015

Project Description

The project objectives are: (1) advancing the state of pyrolysis oil upgrading technology, including developing upgrading catalysts and an integrated process tailored to upgrade the many molecular fragments that collectively constitute bio-oil; (2) demonstrating system operation for more than 1,000 hours using a single catalyst charge; and (3) the ability to produce a final product that can be blended to 30% by weight with ASTM petroleum fuels or that is compatible with existing petroleum refining operations. The project will also generate extensive data on system performance, catalyst performance, material corrosion, and hydrocarbon product composition. Upgrading of conventional fast py-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

rolysis bio-oils results in rapid coking and deterioration of the catalyst and corrosion of the equipment. In this application, a multi-pronged approach is designed to meet these challenges; targeting the root cause of the problem first by altering the chemical composition of the bio-oil feedstock entering the upgrader, and then also targeting the upgrading catalyst, operating conditions and process equipment. The project will also investigate a novel commercialization model for the technology by embedding it in small-scale, skid-mounted, factory-built systems deployed widely where biomass is available at low cost. These systems can be built at significantly lower cost relative to large fixed biorefineries and the reduced cost of entry will greatly accelerate the commercialization rate.

Overall Impressions

- This project may have accomplished its goals by developing technology enough to spin off.
- The project has made excellent progress in meeting goals of producing large quantities of liquids and meeting the goals of the Funding Opportunity Announcement (FOA) it was funded under.
- Targets hit, but there seemed to be a lot of missing results, especially on the ion exchange step for removing inorganic contaminants. This could be a big step forward to improving catalyst life. Aldehydes are the trouble makers and they are removed in the stabilization step. These results need to be shared with others working on bio-oil upgrading projects within BETO.
- This project was well planned and executed with clear goals and targets. The investigators executed well and were quick to improvise and adapt their approach as unanticipated problems occurred.
- The six-month extension granted to this project seems to have resulted in concisely articulating the close-out of the project. This technology development is an example of DOE funding resulting in a technology that should benefit bio-oil utilization.

PI Response to Reviewer Comments

- Thank you for taking the time to review our project and for providing very constructive feedback. We were, unfortunately, unable to present some of our detailed results during the Peer Review presentations mainly because of time limitations. We had a lot to say and limited time, so we focused only on the highlights. We are planning to provide the additional data in patent applications and publications, which are in progress.

NEW EBULLATED BED TECHNOLOGY FOR HYDROPROCESSING BIO-OILS TO PRODUCE GASOLINE, DIESEL AND JET FUELS

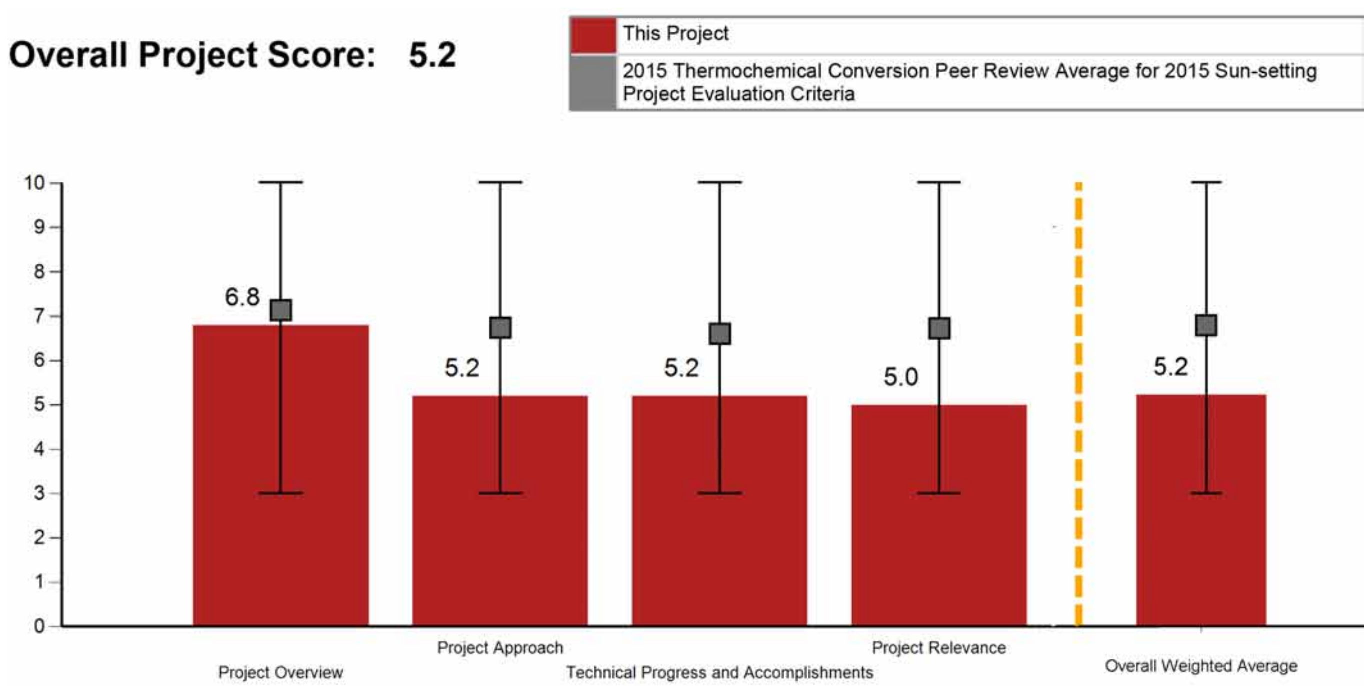
(WBS#: 2.3.1.407)

Photo Courtesy of W.R. Grace && Co

Recipient:	W.R Grace & Co
Presenter:	Corinne Drennan
DOE Funding FY14:	$50,313
DOE Funding FY13:	$245,465
DOE Funding FY10-12:	$245,465
Planned Funding:	$1,001,419
Project Dates:	9/30/2010 - 9/29/2014

Project Description

This project will develop new bio-oil hydrotreatment processes that are stable to fouling and other process challenges presented by pyrolysis oil. The project is designed to evaluate a catalytic, three-phase, fluidized reactor known as an ebullated-bed for the purpose of overcoming reactor fouling and poor catalyst life, a noted problem with upgrading pyrolysis oils. Ebullated-bed reactors have been applied industrially to handle "problem" petroleum feedstocks with high coking potential, but have not been evaluated for renewable feedstocks such as pyrolysis oils. A key deliverable for this project is to demonstrate >1,000 hours of operating history on a single catalyst loading and reactor apparatus to



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

form the basis for catalyst characterization and characterization of materials of construction. To accomplish this goal, the research program includes steps to: (1) develop an appropriate catalyst; (2) experimentally optimize the ebullated-bed reactor operation for hydroprocessing of bio-oil; (3) fully analyze the intermediate and final fuel products; (4) determine the points of insertion for the intermediates/products into a petroleum refinery operation; and (5) perform techno-economic and life-cycle analyses of the process to determine the cost of fuels and their carbon footprint.

Overall Impressions

- This is an interesting project, but not particularly novel in the world of catalysts.
- The project has been completed successfully and provided useful information about the ebullated bed. The results suggest that, going forward, it is unlikely the technology will provide a major breakthrough for bio-oil conversion.
- Ebullated beds have very complex hydrodynamics, which make them difficult to model and to scale-up. Additionally, bio-oils that are being formed in the ebulated-bed reactors contain oxygenated-hydrocarbons, which can lead to emulsions and foaming of the bioproducts. Both of these factors (complex hydrodynamics and foaming/emulsification) combine to create a very complex reactor system. The team should have interacted with a group experienced in ebullated beds right at the beginning of the program.

  The performers should also look into a technology called Veba Combi-Cracking. This is a commercialized technology capable of upgrading bio-oil that uses an ebullated-bed reactor.
- The project failed to show that ebullating beds worked well for bio-oils, but additional work might be justified to see if novel approaches might work.
- Many projects by several organizations, including this particular work, seek capture of Intellectual Property (IP). This practice fragments an ability to collect data and move forward. This may have been a contributing factor to this work; in effect, simply showing the same outcome as several other current and past projects.

PI Response to Reviewer Comments

Thank you for the review and comments. While the use of an ebullated bed for bio-oil remains elusive, this project gave two primary findings. One is the development of the hot, liquid water tolerant catalyst for the processes that have experienced the degradation of oxide catalysts. The other is the great insight on the complex phase behavior of bio-oil upgrading that has now changed the understanding and approach of core fixed bed upgrading research. In addition, this project developed a better understanding of the unique approaches needed for bio-oil upgrading, and the path toward refining an ebullated bed as a potential solution to that complex challenge.

TESTING, EVALUATION, AND QUALIFICATION OF BIO-OIL FOR HEATING

(WBS#: 2.4.2.302)

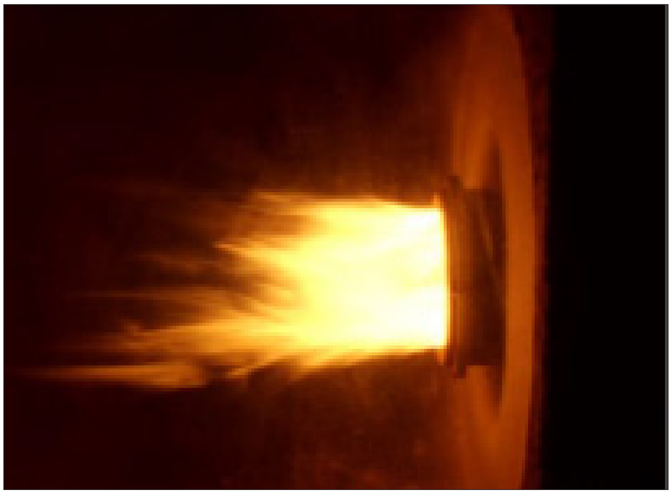
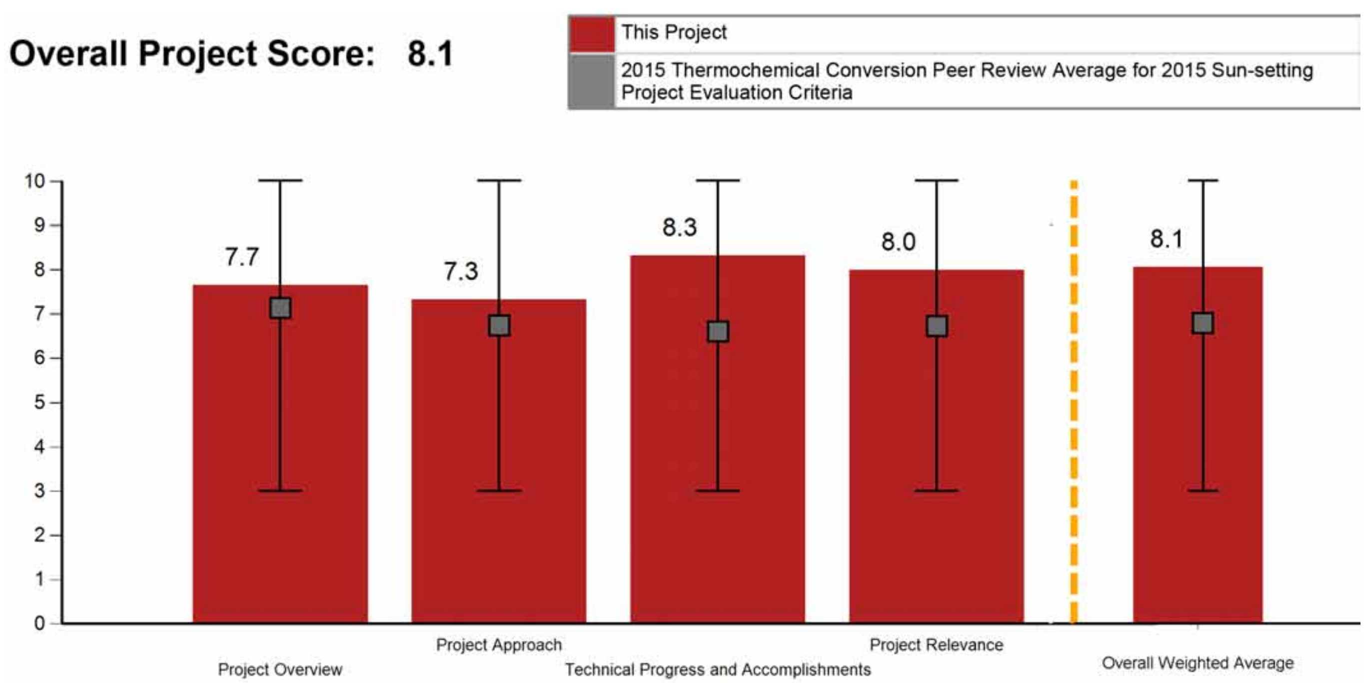


Photo Courtesy of BNL

Recipient:	BNL
Presenter:	Tom Butcher
DOE Funding FY14:	$199,988
DOE Funding FY13:	$64,970
DOE Funding FY10-12:	$0
Planned Funding:	$85,042
Project Dates:	10/1/2012 - 9/30/2015

Project Description

This work is focused on exploring the use of upgraded pyrolysis oil to displace part of the 7.2 billion gallons of petroleum fuel used for heating in residential and commercial buildings. This is an attractive market entry path for these fuels, and an opportunity to address many of the technical aspects required for the larger transportation market. This project seeks to understand the cost and performance tradeoffs for deploying a less-than-perfectly conditioned bio-oil as a drop-in fuel at a target blend level of 20%. This work is part of a coordinated effort involving several national laboratories and the National Oilheat Research Alliance (NORA) market outreach. Candidate fuel blends have been supplied by the team and evaluated for stability, elastomer compatibility in legacy systems, and combustion performance in an unmodified oil burner. Miscibility, fuel handling, flame stability, and air pollutant emissions are seen as



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

very good. With the fuels evaluated, elastomer compatibility and storage stability for this market are seen as remaining concerns at the level of processing explored to date.

Overall Impressions

- The project accomplished its goals, yielding good information and data.
- The project developed interesting information about the compatibility of partially upgraded bio-oil in heating systems.
- There was a comprehensive set of tests conducted with impressive market outreach. Now, they just need some positive results.
- Although bio-oils appear to be unsuitable for home heating, this study clearly shows what the issues are and allows potential producers to take steps to address them. This type of work may not be as glamorous as some work, but it is absolutely essential.
- This project provides a key benefit in characterizing fuels and relating a biofuel to a petroleum-based fuel. It was not succinctly identified in this way, and could still use work along this line to help move biofuels into acceptance in the petroleum refining and petroleum product markets.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

REFINERY UPGRADING OF HYDROPYROLYSIS OIL FROM BIOMASS

(WBS#: 2.4.2.401_Z)

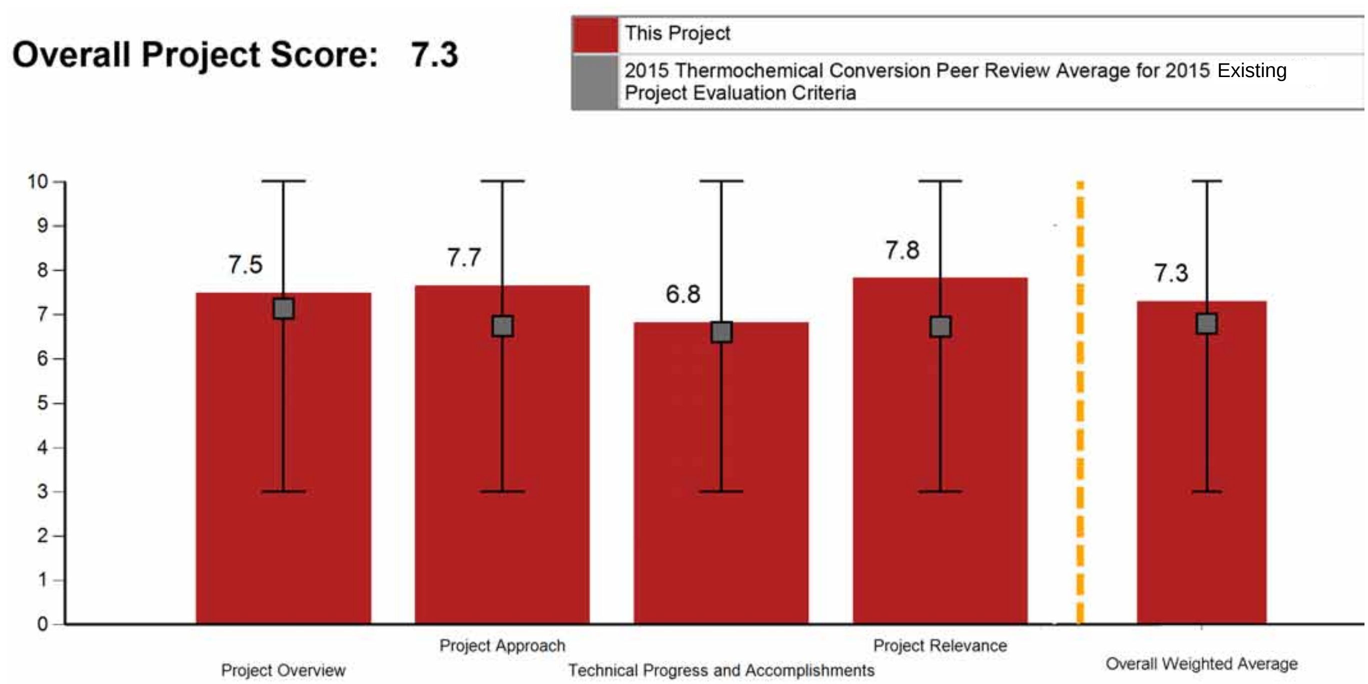
Recipient:	Gas Technology Institute
Presenter:	Terry Marker
DOE Funding FY14:	$1,174,468
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,250,518
Project Dates:	11/1/2012 - 10/31/2015

Project Description

Samples of hydropyrolysis oil were produced from wood and corn stover feeds by fast hydropyrolysis in a hydrogen environment with a catalyst. Hydropyrolysis oil contains 5-8% oxygen compared to pyrolysis oils, which typically contain 41% oxygen. Hydropyrolysis oils have lower corrosion than pyrolysis oils and can be blended with hydrocarbon fuels for refinery upgrading. Hydropyrolysis oils were upgraded at typical diesel hydrotreating conditions and produce high quality blending components for gasoline and diesel with no detectable oxygen. Valero Refining completed a risk analysis and decided that even for hydropyrolysis oil, which has low corrosion and low oxygen, the risk for upgrading oils in the Valero refinery system was too great and could not be justified. They preferred a separate integrated IH2 system of hydropyrolysis plus hydroconversion, located next to a refinery, which directly produced drop-in gasoline and diesel. To ensure the diesel would meet U.S. specifications, CRI Catalyst, the projeect partner, created a low cost, integrated third stage, which increased the diesel cetane from 27 to 43 for diesel derived from wood or corn stover. The study also showed that many U.S. refineries, including the Valero's Memphis refinery, are located near to wood supplies and have excellent locations for biomass conversion processes.

Overall Impressions

- The project has made excellent progress and actively involves feedstock providers and refinery users. The project has identified a potentially effective



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

pyrolysis pathway that could readily be used by existing refiners. DOE needs to consider how it can more effectively move projects such as this forward when they achieve success.

- The project team worked with the entire chain from timber, catalyst provider, refiner, GHG analysis, and EPC contractor for costing. The next step seems to be to operate a fully integrated and recycling pilot plant to demonstrate long-term operation. Some challenges continue to exist in the details, such as wastewater treatment, but they are steadily being addressed.
- This project was well executed and it is on schedule to meet all targets. It leverages GTI's significant investment in IH2 to closely examine the issues related to refinery integration. Its greatest value may be to show what's involved in actually integrating a process with an existing, risk-averse refinery.
- In some aspects, this integration analysis has been done before. The project adds a novel technology at the reaction and reactor level. The techno-economic analysis and process details, though, really need to be much more extensive than is typical of a research-driven project before it will be adopted by the refinery industry.

PI Response to Reviewer Comments

- In this study, we have learned a lot. First, we learned that refiners are unlikely to be adding intermediates with oxygen to their refineries anytime soon. Second, we certainly learned that wood is likely to be the U.S. feedstock of choice for a long time to come.
- We had the feedstock preparation costs as a separate item and they are included in the report in terms of $/ton. We just did not present it at the conference as a capital cost, but it will be in the final report. KBR has done detail design of the IH2 and this detailed engineering information is available to clients. These studies cost millions of dollars. The results presented were simply a distillation of those detailed designs.

OPTIMIZING CO-PROCESSING OF BIO-OIL IN REFINERY UNIT OPERATIONS USING A DAVISON CIRCULATING RISER

(WBS#: 2.4.2.402_Z)

Recipient:	PNNL
Presenter:	Corinne Drennan
DOE Funding FY14:	$2,027,483
DOE Funding FY13:	$251,482
DOE Funding FY10-12:	$0
Planned Funding:	$1,221,035
Project Dates:	10/1/2012 - 9/30/2017

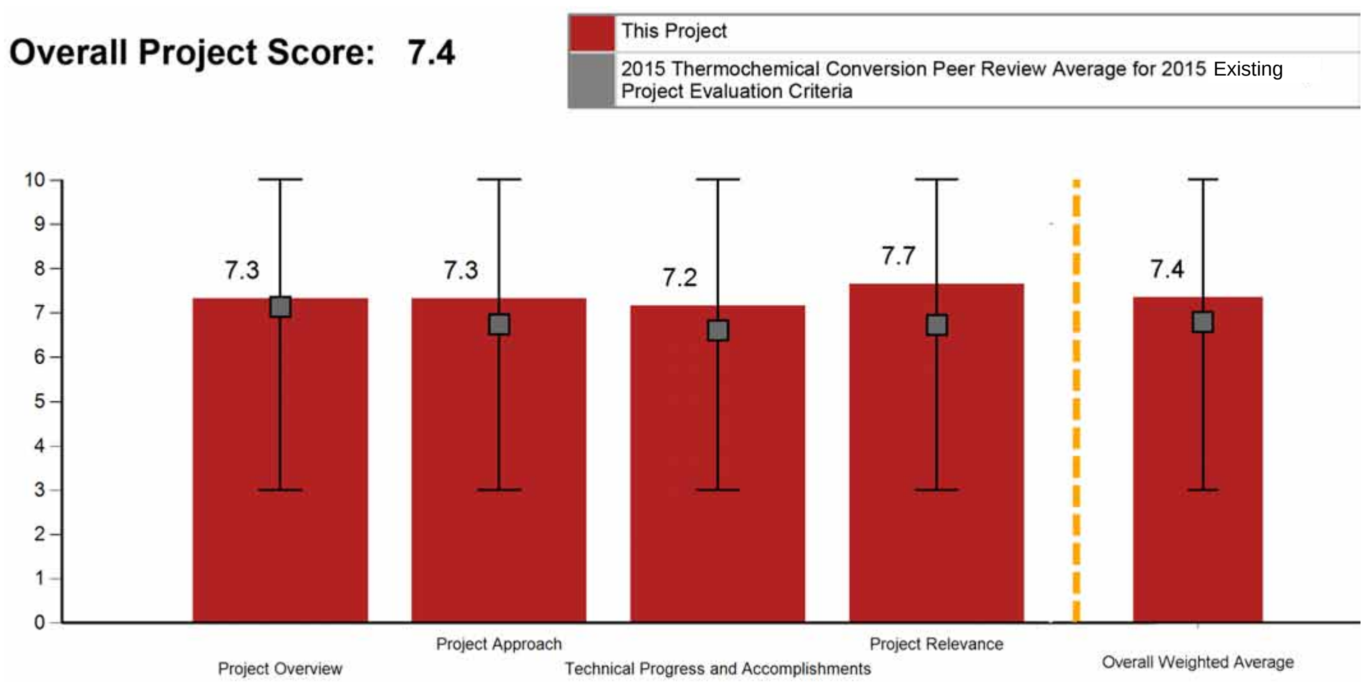
Photo Courtesy of PNNL

Project Description

This project purpose is to develop the technology to stabilize bio-oils and successfully co-feed them into a Fluidized Catalytic Cracking (FCC) unit. Raw bio-oil is not compatible with existing refinery unit operations, and the baseline technology for liquid transportation fuels results in a processed fuel blend stock through specialized unit operations. Success of this project would enable biomass insertion into the refinery earlier in the processing chain alongside petroleum intermediates in order to leverage existing refinery capital. The outcome is a preliminary engineering design package of this technology and operating envelope for biomass and co-processing that will be used to inform industry to the potential of this technology.

Overall Impressions

- This is a good project, but needs better understanding of the contaminants.
- The project has successfully completed its work to show how VGO and bio-oils can be co-blended for refining.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- This is a great team for an attempt to evaluate processing bio-oils in the FCC refinery unit, although results do not appear to be very promising. Davison Circulating Risers (DCRs) are expensive to build and operate. It seems that there could be coordination with the catalytic pyrolysis program at NREL.
- The project has the potential to yield important results if sufficient DCR runs are carried out and sufficient analysis is carried out to determine bio-oil effects on product yields and product quality.
- Future work is really a collection of close-out documents and wrap-up. That appears to be in line with what is needed.
- I suggest that the project continue and complete the data collection and TEA to determine if this is a viable option.

PI Response to Reviewer Comments

- Thank you for your review. We also feel that this is answering some interesting questions, even though some of those answers have not been as good as hoped. The quality data is something we are capturing, as it is clear that industry can be very sensitive to various contaminants at extremely low levels. This project is in a great position to provide real data to answer a lot of questions that are currently not well answered.

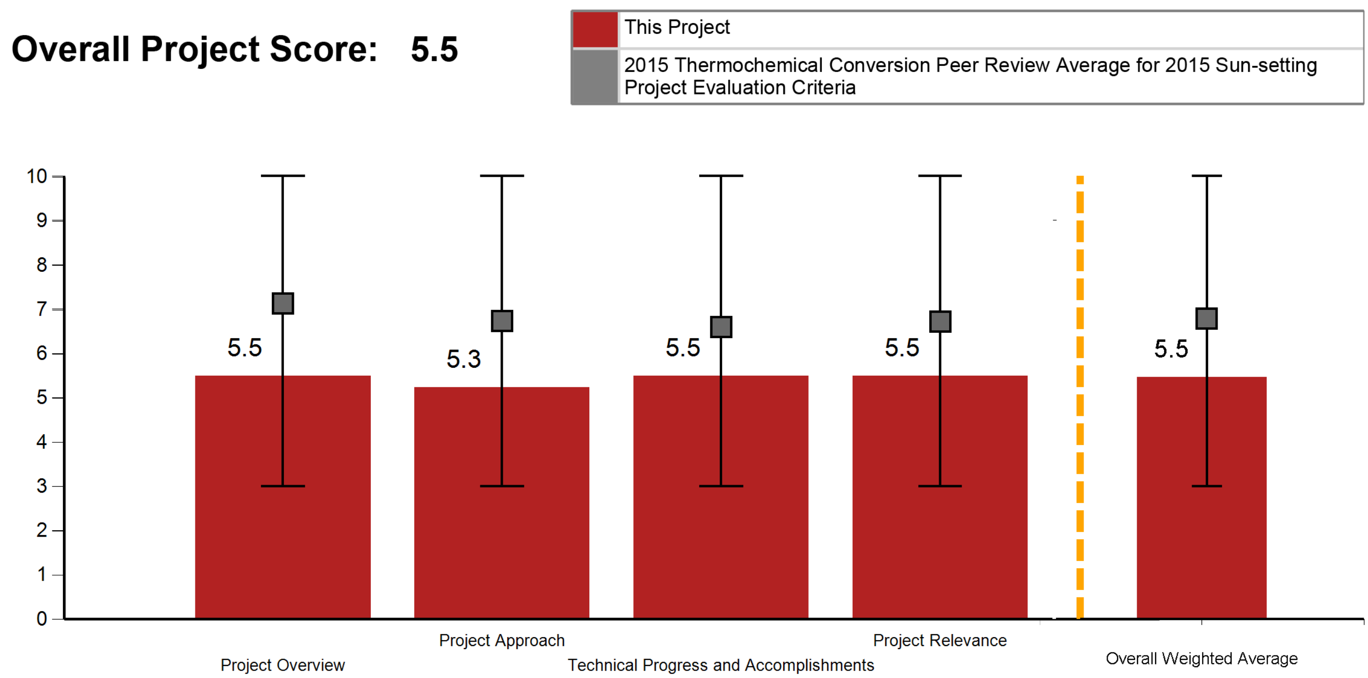
MILD BIOMASS LIQUEFACTION PROCESS FOR ECONOMIC PRODUCTION OF STABILIZED REFINERY-READY BIO-OILS

(WBS#: 2.4.2.406)

Recipient:	Southern Research Institute
Presenter:	Santosh Gangwal
DOE Funding FY14:	$227,094
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$124,867
Project Dates:	1/2/2013 - 6/30/2015

Project Description

The basis of the methanol solvent-based woody biomass liquefaction/hydro-deoxygenation (HDO) process is synergy between methanol and water that allows efficient liquefaction at milder conditions than hydro-thermal liquefaction. Process challenges to meet cost targets include: (1) production of sufficient, stabilized HDO-compatible raw bio-oil from the liquefaction step; and (2) reduction of HDO severity and hydrogen consumption to convert the raw bio-oil to refinery-ready bio-oil. Experimental development was carried out in concert with techno-economic evaluation to refine the commercial embodiment of the process. Data was generated for preliminary design of the final commercial embodiment of the process. Based on input biomass, a yield of 37 wt. % raw bio-oil was achieved that was free flowing at 40 °C for further processing by HDO. The raw bio-oil was shown to be stable over several months. A partnership was established with a catalyst company for development of the HDO process. HDO experiments using their proprietary catalyst were carried out to demonstrate bio-oil oxygen reduction down to 1.5 wt. % with hydrogen consumption of 0.02 g/g bio-oil. TEA/LCA of the commercial embodiment showed that the process has the potential to achieve a life cycle HDO oil cost of less than $3/gallon and >50% reduction in GHG emissions compared to a petroleum baseline.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The results are similar to those from other hydrothermal process approaches. At this point, it is not yet clear that methanol solvent results in substantial advantages over other hydrothermal approaches.
- The project should have a refiner or fuels partner for guidance and evaluation. There are lots of process steps going on and carbon efficiency seems low. The TEA seems too positive for all of this – maybe due to adding a RIN credit. A block process diagram would be helpful showing all processing steps, feeds and byproducts with each step material balanced to follow the carbon and oxygen. This should cover the aqueous product and its fate. It is very difficult to follow both LCA and TEA analyses.
- The use of methanol/water for hydro-liquefaction differentiates this project from much previous hydro-liquefaction work. If process improvements can improve the economics enough, this approach may have promise.

PI Response to Reviewer Comments

- This was a seedling project, not requiring a refinery partner at the onset. It was competitively awarded based on the merit of the concept to overcome the barriers. Measurable targets of process conditions and oil yield were provided in the application and presentation. TEA was used to guide the development of the overall commercial embodiment that had potential for producing refinery-compatible HDO oil at approximately $3 per gallon. Compared to other approaches, the proposed concept gave high liquefaction yield and produced a stable liquid (the two main barriers) at relatively mild pressure and temperature.
- Although the barriers were overcome in the project, and a HDO catalyst partner was established, when it came time to present the promising data to refineries, they did not show a lot of interest in setting up an NDA. Most likely, there were two reasons for this: (1) the oil price collapse; and (2) the refineries interested in biomass already had committed collaboration and did not have the resources to start a new one.
- Presently, discussions are ongoing with potential refinery partners. If the oil price begins to go up again, we should be able to line up a refinery partner, particularly since some of the other bio-fuel process concepts that other researchers have worked on have not been able to deliver on efficiency and economics.
- If the RIN credit is removed, the updated cost result for our HDO oil is $3.22 per gallon. The steps taken to periodically update and establish the final commercial embodiment of the process were based on the lab data generated. This final commercial embodiment on which the TEA and LCA are based are proprietary and patent pending.
- We want to emphasize that our bio-oil is produced under more commercially viable milder conditions than other direct liquefaction processes, e.g., HTL. In addition, our single-stage bio-oil HDO process with low hydrogen input and low temperature is also highly advantageous compared to upgrading of pyrolysis oil or HTL oil to a similar oxygen level (high hydrogen consumption, two-stage upgrading process and high upgrading temperature at second stage). These achievements are clearly a significant advancement over the current state of the art.
- Methanol requires a much milder temperature (~240 °C) and pressure (~1,200 psi) to reach supercritical condition compared to water (374 °C, 3,200 psi). Based on the Organosolve process, lignin and hemicellulose can be dissolved in methanol under the operating conditions we optimized and allow fragmentation of these biomass components to form bio-oil. Simultaneously, subcritical water hydrolyzes cellulose to form bio-oil. Therefore, methanol and water have a synergetic effect to enhance the oil yield for biomass liquefaction.

NOVEL ELECTRO-DEOXYGENATION PROCESS FOR BIO-OIL UPGRADING

(WBS#: 2.5.4.403)

Recipient:	Ceramatec
Presenter:	Elango Elangovan
DOE Funding FY14:	$485,825
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,118,327
Project Dates:	9/30/2013 - 9/30/2016

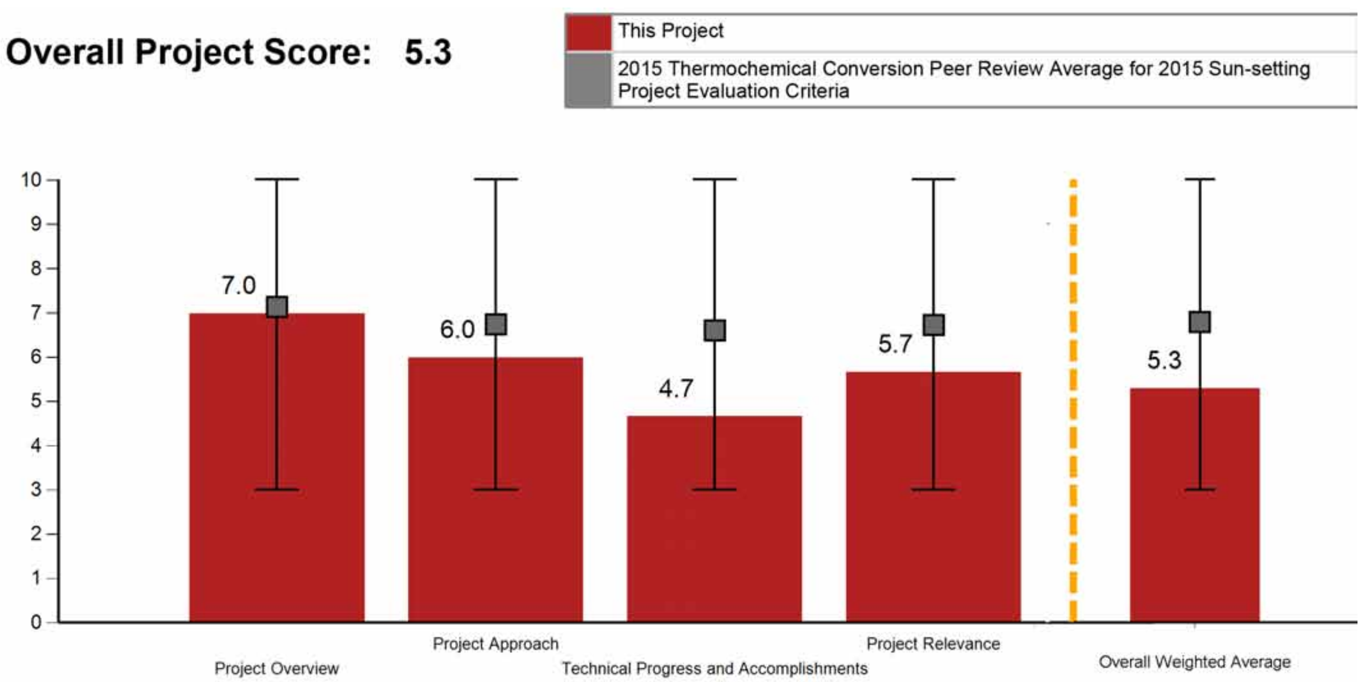
Photo Courtesy of Ceramatec

Project Description

Biomass is a potential renewable source for liquid fuels and most commodity chemicals. Non-edible lignocellulosic biomass residue, such as agricultural and forest wastes, can be converted to liquid fuels via bio-oil production by fast pyrolysis. The high oxygen content of bio-oil poses a challenge for its practical use. The conventional approach to deoxygenate is the hydro-deoxygenation process. Typical bio-oil is biphasic and only the organic phase is processed in subsequent upgrading steps, leaving behind valuable carbon-containing material in the aqueous phase. Deoxygenation of model compounds and the aqueous phase of pine wood bio-oil have been tested using an oxygen ion conducting ceramic membrane-based electrochemical cells operated in the temperature range of 500-600 °C. The product from the electrochemical cell contained a suite of compounds with significantly lower oxygen content.

Overall Impressions

- This is interesting technology, but not enough proof yet to determine efficacy.
- The project has made reasonable progress to estab-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

lishing proof of concept with model compounds. The work needs to promptly move to actual bio-oils, and the project needs to consider LCA implications for using significant amounts of electricity. LCA efforts should be based on electricity generated from a national average of feedstocks including coal, natural gas, wind, etc.

- The process is trading hydrogen production efficiency for electricity production efficiency. I am not sure that this makes GHG-related or economic sense. The project needs to demonstrate a compelling case and conduct an overall material and energy balance analysis.
- The utility of this method for bio-oil stabilization will only be known when it is tested with real bio-oil and the products subjected to stability testing. Life-cycle and techno-economic analyses need to be carried out.
- The level and detail of reporting are appreciated, but a complete mass/element balance is needed to validate the experimental study.
- Novel concepts, such as this, are necessary for breakthrough and need to be tested.

PI Response to Reviewer Comments

- The deoxygenation process is highly efficient (based on both thermodynamic analysis and experimental evaluation of steam electrolysis to produce high purity hydrogen and oxygen). In the bio-oil electrode-oxygenation process, in-situ hydrogen is generated, again at very high electrical efficiency, from electrolysis of steam present. Experiments to-date show that the electro-deoxygenation (EDox) process occurs at ambient pressure compared to hydrodeoxygenation. This fact allows for potential physical integration of the electrochemical unit with the pyrolyzer, thereby not requiring condensation and storage of the produced bio-oil. This avoids the bio-oil storage stability issues of current methods. Furthermore, distributed availability of electricity provides flexibility in locating an integrated pyrolyzer-electrodeox unit at an economically favored location near the source of biomass. These aspects will be considered in our TEA and GHG analysis.
- LCA will include all the electricity sources in the sensitivity analysis portion. Appropriate electricity cost will be used for LCA to compare the electrodeoxygenation process with the hydrodeoxygenation process.
- Testing with real bio-oil is planned. In addition, the project will culminate in an integrated test where a slip stream from a pilot-scale pyrolyzer will be fed to the EDox unit after removing solids. The product will be fully characterized for stability and composition. A detailed mass balance will be performed. The techno-economic analysis performed will be updated with the results of the findings.
- We started with TRL-2 and plan to move it to TRL-4 by demonstrating the efficacy of the project. We plan to perform mass/element balance in laboratory tests as well as for the integrated pyrolyzer/EDox test.

CASCADE REACTIONS WITH TECHNISCHE UNIVERSITÄT MÜNCHEN (TUM) AND UNIVERSITY OF TORONTO (U OF T)

(WBS#: 2.5.4.407_Z)

Recipient:	PNNL
Presenter:	Mariefel Olarte
DOE Funding FY14:	$330,737
DOE Funding FY13:	$25,195
DOE Funding FY10-12:	$599,955
Planned Funding:	$180,115
Project Dates:	10/1/2010 - 9/30/2015

Project Description

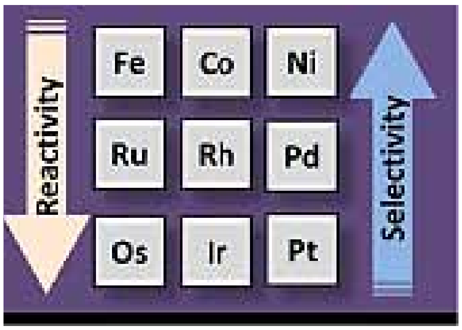
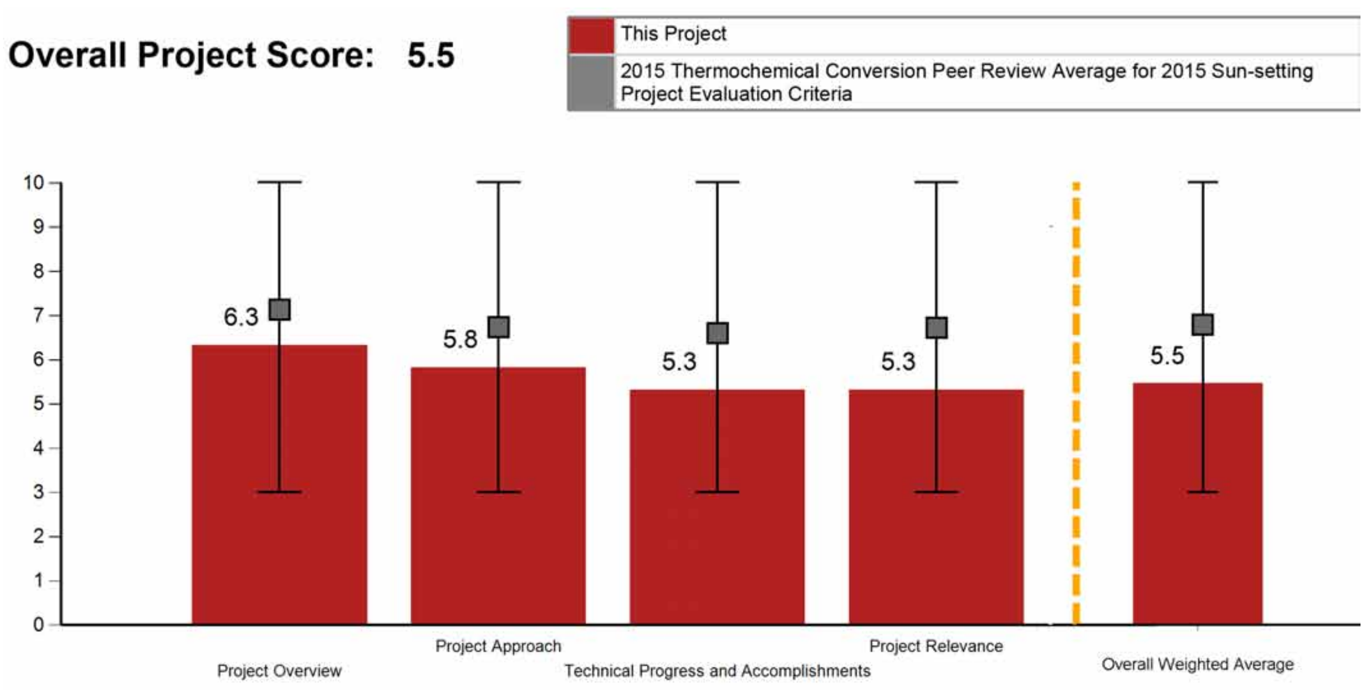


Image Courtesy of PNNL

The objectives of this project are to reduce hydrogen demand and increase fuel yield. Bio-oil contains up to 25% of small oxygenated compounds that, upon hydrotreating, uses large amounts of hydrogen, only to be lost as gases. The proposed strategy to achieve the project goals is to capture the small compounds and build them up to oil-range molecules. There is also the potential of lowering current operating temperature and pressure based on one of the partners' (TUM) previous study. TUM showed that both model compounds and the fractionated lignin-derived portion of the bio-oil can be alkylated at 250 °C and pressures as low as 50 bar. This has not been demonstrated in whole bio-oil. To achieve the objectives, an interim target of recovering about 20% of the small oxygenated compounds at a lower operating pressure, but still utilizing the two-stage configuration of the current upgrading system is proposed. The interim goal aims to apply the process at the first catalyst bed. By improving the catalyst design, the goal



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

is to reduce the cost associated with the whole upgrading. Capturing the small compounds in the pyrolysis oil into the upgraded product involves developing the scientific underpinnings of a reaction cascade in a single reactor with the following reactions: selective hydrogenation of light acids and aldehydes to alcohols; alkylation of the aromatics and alcohols; hydrogenation of the aromatic rings; and, hydrodeoxygenation/dehydration of alkylated compounds.

Overall Impressions

- After significant delays in startup, this project has made reasonable technical progress and will be completed in 2015.
- Work is too fundamental, and it has not been used to make a better catalyst, which should be the ultimate aim. Impact of low conversion kinetics in a batch reaction to high conversion, flow reactors of industrial interest is highly questionable.
- The project was well planned and the early stages were well executed, but the elimination of testing in actual bio-oils and continuous reactor testing significantly decreased the value of this research.

PI Response to Reviewer Comments

- Thank you for your comments. We also expect these findings to enable improvements in bio-oil catalysts as they are applied to continuous and actual bio-oil testing. The empirical-fundamental gap of bio-oil research is notoriously difficult to navigate, but both are needed to advance applied science.

PRODUCTION AND UPGRADING OF INFRASTRUCTURE COMPATIBLE BIO-OIL WITH VTT

(WBS#: 2.5.4.408_Z)

Recipient:	PNNL
Presenter:	Doug Elliott
DOE Funding FY14:	$501,387
DOE Funding FY13:	$1,003,890
DOE Funding FY10-12:	$211,061
Planned Funding:	$83,337
Project Dates:	10/1/2010 - 9/30/2015

Project Description

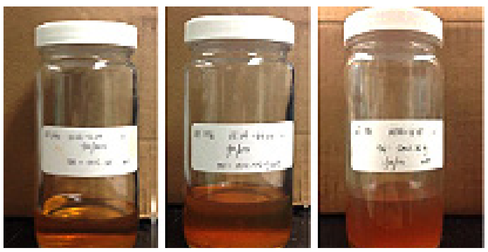
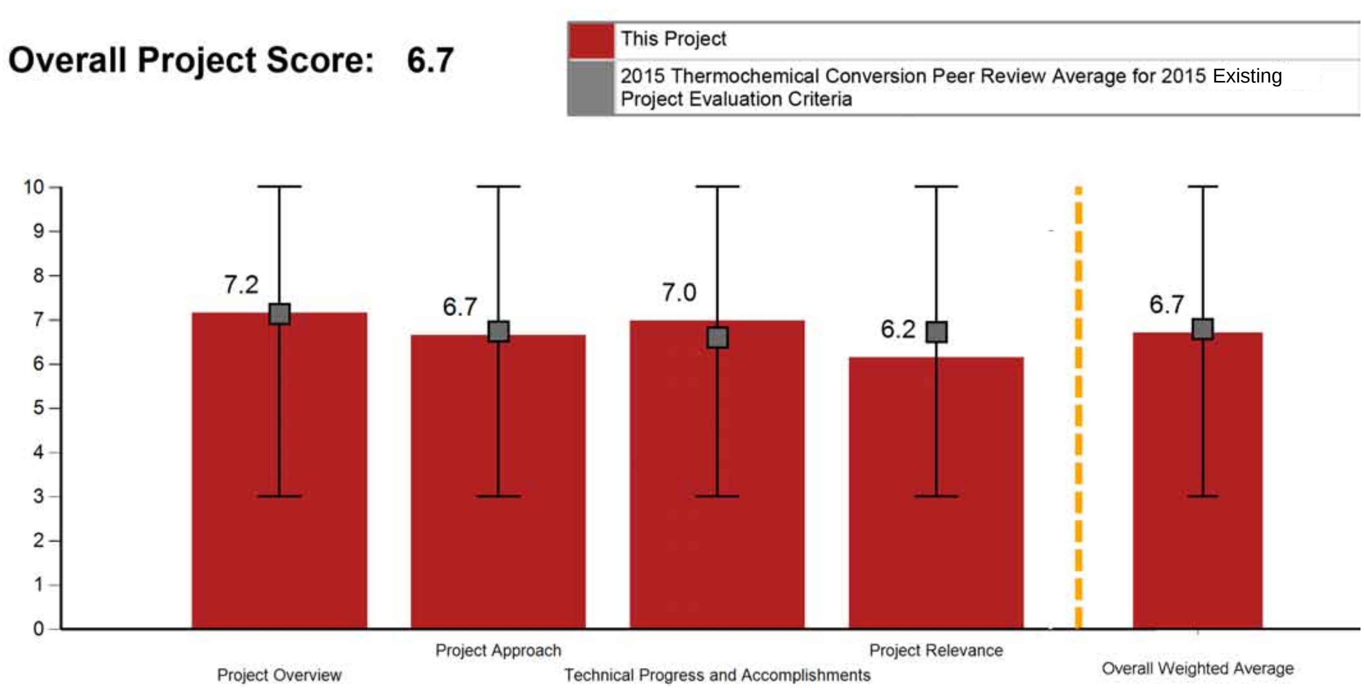


Photo Courtesy of PNNL

This project utilized the biomass fast pyrolysis expertise at VTT (Technical Research center of Finland) in conjunction with the hydrotreating (HT) expertise at PNNL. The project involved development of infrastructure-compatible fuels including stabilized bio-oil fuel through low severity hydrotreating (HT), renewable fuel oil by partial upgrading of bio-oil to replace #2 heating oil in the Northeast U.S., and liquid transportation fuels by full HT of "improved" bio-oils produced at VTT. The project evaluated low-severity HT of bio-oil for stabilization for fuel oil applications, a near-term entry into the market. VTT collaborated in providing bio-oil products (including raw bio-oil, fractionated bio-oil and in-situ catalytic pyrolysis bio-oil) and validation of the processes through collaboration on the techno-economic analysis. The TEA effort compared fast pyrolysis and upgrading with hydrothermal liquefaction and hydrotreating. The project also included process development for improved pyrolysis methods with subsequent HT testing with the products (not otherwise available in the U.S.). PNNL and VTT shared



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

findings annually at a collaborative meeting at which industry partners participated. This project identified in-situ catalytic pyrolysis as an improved bio-oil and subsequent work on producing such bio-oil at VTT. Hydrotreatment process development at PNNL is now underway in a new BETO-funded project.

Overall Impressions

- Identifying home heating oil as a direct blend market is a good idea and a way to implement more quickly.
- The inclusion of highly qualified international partners has resulted in significant progress.
- Lots of different LCAs and TEAs have been conducted by the NREL and PNNL. Are they all consistent? How did this work differ from what was done in NABC? Not sure how this project improved the technology for HTL. Fouling remains an unsolved problem in hydrotreater.
- The project would benefit by more focus on solving the problem associated with upgrading rather than just finding the same problems observed by others and stopping.
- The project's contribution to the technical and techno-economic aspects are appreciated. As this project is just one part of the larger thermochemical picture, it will be nice to see integration of multiple project results (technical, techno-economic, and advancement toward commercialization) in a single comparison report.

PI Response to Reviewer Comments

- Thank you for these comments. We are encouraged by the longer time on stream with our initial tests with hydrotreating in-situ catalytic pyrolysis bio-oil, and the effort will continue in a new project beginning in FY15. We are intimately aware of the difficulties of hydrotreating fast pyrolysis bio-oil and consider the results obtained with the in-situ catalytic pyrolysis bio-oil to be significant and worthy of further study.
- The comparative TEA of fast pyrolysis and upgrading with hydrothermal liquefaction and hydrotreating was done on a comparable basis to the earlier IEA study as the authors include three of the participants in the earlier IEA study. The current study included ASPEN modeling, while the earlier IEA study was performed in Microsoft Excel. It is not perfectly comparable with other DOE studies as it used a methodology closer to the earlier IEA study, but the results suggest that this type of comparison be considered for further DOE studies.
- The study of home heating oil based on hydrogenation of bio-oil using precious metal catalysts for partial deoxygenation suggests an alternative route to miscible fuels, which could be of interest; however, the potential catalyst poisoning in the long term suggests a topic for further research.

DEMONSTRATION AND MARKET TRANSFORMATION

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Demonstration and Market Transformation (DMT) Technology Area is one of seven key technology areas reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of 21 projects were reviewed by six external experts from industry, academia, and other government agencies. These projects represent a total U.S. Department of Energy (DOE) investment of approximately $181 million (FY2013-FY2014) in awards, which equates to around 45% of the total BETO portfolio covered at the Review. The Principal Investigator (PI) for each project was given 30-45 minutes to deliver a presentation and respond to questions from the Review Panel. Projects were evaluated and scored for their project management, technical progress, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the DMT Technology Area, full scoring results and analysis, Review Panel Summary Report, and BETO Programmatic Response are also included in this section. BETO designated Jim Spaeth as the DMT Technology Area Review Lead. In this capacity, Mr. Spaeth was responsible for all aspects of review planning and implementation.

DEMONSTRATION AND MARKET TRANSFORMATION TECHNOLOGY AREA

OVERVIEW

The goal of DMT is to de-risk bioenergy production technologies through validated proof of performance at the pilot, demonstration, and pioneer scales and to conduct activities that will transform the biofuels market by reducing or removing commercialization barriers. This goal is achieved through the formation of public-private partnerships that build and operate integrated biorefineries (IBRs) and through support for projects focused on infrastructure and end-use market barriers. These activities are essential to resolving key issues in the construction and scale-up of IBR systems, primarily because they reduce risk, and therefore, help overcome the commercial financing barriers that currently face the bioenergy industry. By creating a pathway to market, DMT addresses the final links of the bioenergy supply chain and supports the robust demand for end products.

The advanced bioenergy industry includes production of biofuels, bioproducts, and biopower. Similar to other process industries, the advanced bioenergy industry faces significant challenges and risks in the scale-up to pilot, demonstration, and pioneer stages. These include risks related to technology, construction, environmental impact, feedstock supply, operations, market offtake, and financing. The specific risks of feedstock supply and market offtake are more pronounced for advanced biofuels than for other renewable sources of energy because of the variability inherent in biomass and the lack of long-term offtake agreements in the fuel and chemicals markets. Advanced infrastructure-compatible fuels, e.g.,

[1] More information on review criteria and weighting is available in the Peer Review Process section of the Final Report.

for automotive and jet engines, require an extra level of certification for end use, as well as infrastructure compatibility testing for integration into refinery equipment, pipelines, rail cars, and storage tanks. DMT activities are targeted to reduce these barriers for the private sector by facilitating large-scale projects that address these risks and further catalyze the desired transformation in the U.S. transportation fuel supply from fossil-based to renewable.

BETO is uniquely positioned to leverage both its legislative authority to provide financial assistance and DOE's successful track record in technology commercialization to assist developers through validated proof of performance at pilot, demonstration, and pioneer scales.

DEMONSTRATION AND MARKET TRANSFORMATION SUPPORT OF OFFICE STRATEGIC GOALS

The program's biorefinery and infrastructure projects are focused on testing advanced biofuels, bioproducts, and biopower from high-impact feedstocks, including herbaceous, woody, and algal feedstocks, as well as from municipal solid waste (MSW). The purpose of these projects is to reduce risk to the consumer and the private sector and help overcome challenges to financing the industry's expansion, which is required to make a major contribution to our nation's energy independence.
The DMT Technology Area's strategic goal is shown below:

> Develop commercially viable biomass utilization technologies through public-private partnerships that build and validate pilot-, demonstration-, and pioneer-scale integrated biorefineries; and to develop supporting infrastructure to enable a fully operational and sustainable biomass-to-bioenergy value chain in the United States.

DEMONSTRATION AND MARKET TRANSFORMATION SUPPORT OF OFFICE GOALS

Specific DMT goals in support of Office performance goals are as follows:

- By 2017, validate a mature technology modeled cost of cellulosic ethanol production, based on actual integrated biorefinery performance data, and compare to the target of \$2.15/gallon ethanol (\$2007).
- By 2027, validate a mature technology modeled cost of infrastructure-compatible hydrocarbon biofuel production, based on actual integrated biorefinery performance data, and compare to the target of \$3/gge (gasoline gallon equivalent) (\$2011).

DMT milestones toward reaching these goals include the following:

- By 2018, validate three infrastructure-compatible hydrocarbon biofuel or bioproduct manufacturing processes at pilot scale.
- By 2020, validate one to two infrastructure-compatible hydrocarbon biofuel or bioproduct manufacturing processes at demonstration scale.
- By 2024, validate one infrastructure-compatible hydrocarbon biofuel or bioproduct manufacturing process at appropriate scale.

The objective of validating these technologies is to prove techno-economic viability and enable commercial production facilities. The 2017 goal reflects the validation efforts of the existing pioneer cellulosic ethanol facilities in the DMT portfolio. The goals for 2018 and beyond reflect the focus on infrastructure-compatible hydrocarbon biofuels.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the DMT Technology Area:

Market Challenges	Technical Challenges
Inadequate Supply Chain Infrastructure	End-to-End Process Integration
High Risk of Large Capital Investments	Technical Risk of Scaling
Codes, Standards, and Approval for Use	Risk of First-of-a-Kind Technology
Cost of Production	Engines Not Optimized for Biofuel
Offtake Agreements	
Uncertain Pace of Biofuels Availability	
Biofuels Distribution Infrastructure	
Lack of Acceptance and Awareness of Biofuels as a Viable Alternative	

APPROACH FOR OVERCOMING CHALLENGES

BETO's efforts to overcome the challenges and barriers associated with the DMT Technology Area are organized around five pathways: Analysis and Sustainability, Technology Interface, Feedstocks, Integrated Biorefineries, and Infrastructure and End Use. DMT activities are primarily performed by industry partners, with national laboratories and universities also making significant contributions.

For more information on the Demonstration and Market Transformation Technology Area, please review BETO's Multi-Year Program Plan at: *http://www.energy.gov/eere/bioenergy.*

DEMONSTRATION AND MARKET TRANSFORMATION TECHNOLOGY AREA REVIEW PANEL

The DMT Review Panel was comprised of six independent industry experts, who are recognized subject-matter experts in the field, and who had no conflicts of interest that would interfere with an unbiased review of the projects. The following external experts served as reviewers for the DMT Technology Area during the 2015 Project Peer Review.

DEMONSTRATION AND MARKET TRANSFORMATION	
REVIEWERS	
Bill Crump (Lead Reviewer)	Leidos
James Doss	Professional Project Services, Inc.
Brian Duff	Northrup Grumman
Alan Propp	Merrick & Company
Dan Strope	Refining Sciences, LLC
John Wyatt	Carmagen Engineering, Inc.

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.

Project Scoring Information: The final score charts depict the overall weighted score for each project in each technology area. Titles for each project and the performers are also provided in the scoring charts.

Review Panel Summary Report: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.

BETO Programmatic Response: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.

Project Reports:

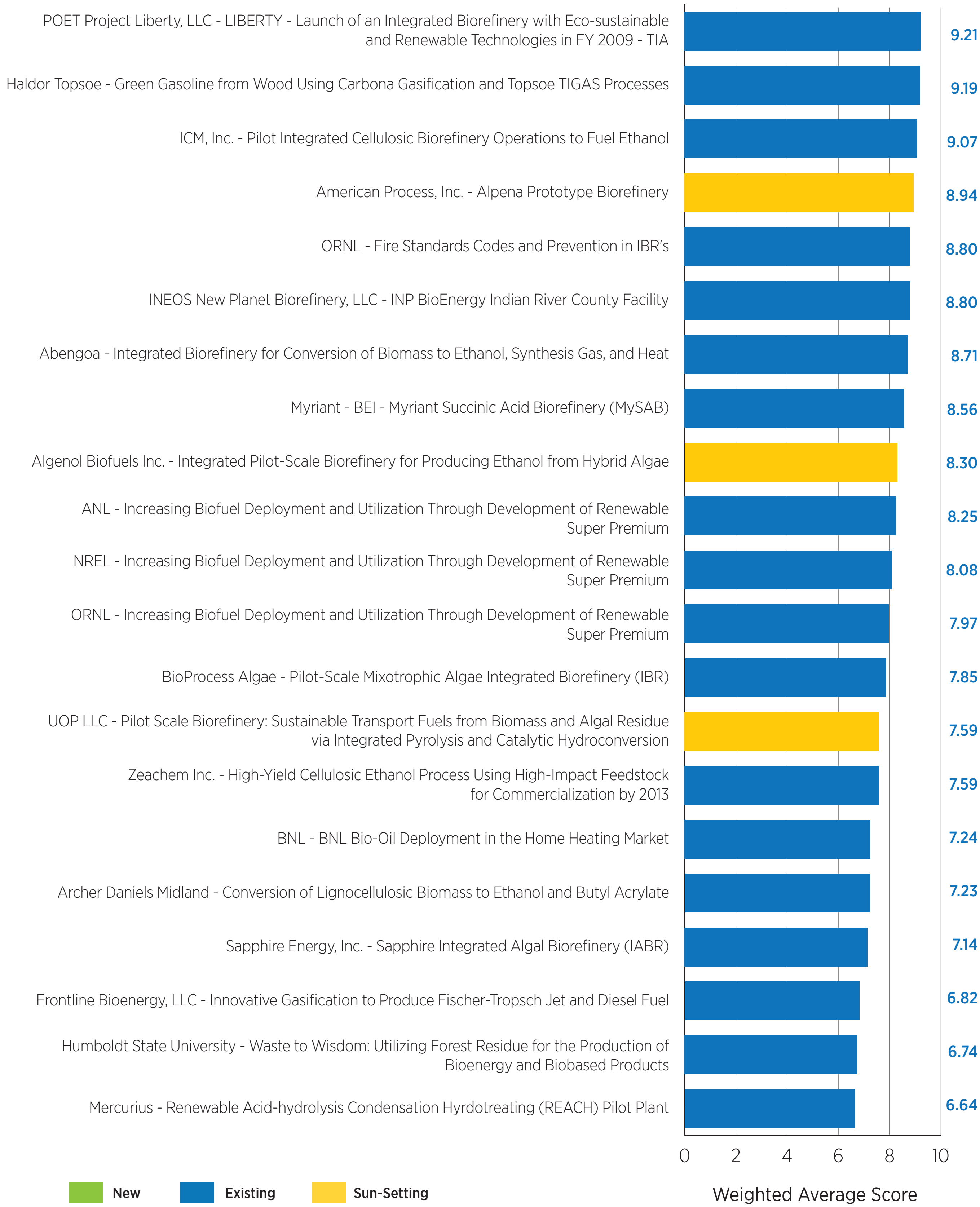
- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space allotted.
- **Project budget and timeline information** are based on self-reported data as provided by the PI for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and whiskers charts depict the range of scores for each evaluation criteria across all projects reviewed within each technology area.
- **Reviewer comments** are represented as they were provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.
- **PI responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the Review Panel. This unique formatting was maintained to uphold the integrity of the comments.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Demonstration and Market Transformation Technology Area.

DEMONSTRATION AND MARKET TRANSFORMATION TECHNOLOGY AREA SCORING



REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

The goals of the Review Panel were to provide an objective and unbiased review of the individual projects and the overall structure and direction of the DMT Platform. The following external experts served as reviewers for the DMT Technology Area during the 2015 Project Peer Review.

IMPACTS

The Review Panel concluded that the primary strength of the project portfolio was the large number of projects that have constructed or commissioned a facility, or that intend to further develop technologies that were funded by a DOE grant. These include projects by ICM, Algenol, INEOS, POET-DSM, Haldor-Topsoe, Myriant, American Process, Inc., and Abengoa.

The Review Panel identified the above project as having a particularly significant impact and noted that the majority produce ethanol as the final product. This appears to result from the fact that DOE grant recipients that were focused on producing oils as their finished product were not successful in executing their projects. As a result, they are no longer participating in the program or their projects appear to have limited future applicability for the developer. To address the shortfall in oil-type projects in the portfolio, DOE has recently added three new pilot plant projects. These new projects are the Frontline Bioenergy project producing Fischer-Tropsch products; the BioProcess Algae project producing crude oil and/or finished fuels; and the Mercurius Biofuels project producing jet-fuel and diesel. These projects are in the early stages of development and, as such, were not able to present much information on the development of their pilot plants.

The consortium of Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), and the National Renewable Energy Laboratory (NREL) presented their research work on increasing biofuel deployment by investigating automotive engine requirements to allow higher blends of ethanol to have mileage parity with current petroleum-based gasoline on a volumetric basis.

Brookhaven National Laboratory (BNL) presented information on the potential of bio-oil being used in the residential heating oil market. Key drivers for entering this market included the use of the established supply and distribution chain and the simplicity of the equipment, which would use this fuel as compared to diesel engines.

ORNL described the progress they have made in helping to modify fire codes and establishing best management practices for biomass handling facilities. As part of this effort, ORNL helped establish a committee, which includes major industrial companies, to serve on a Biomass Industry Panel on Codes and Standards.

Humbolt State University (HSU) presented details on their efforts to develop biomass conversion technologies, which would be located near forest residue sources. The Review Panel appreciated the fact that low-value biomass is available at in-forest sites and could provide an impactful approach to expanding the industry. However, the Panel also believes that the scope of HSU's effort, which involves a large number of partners, presents a challenge and will make it difficult to achieve solid results from which others can work.

The remaining four projects in the portfolio are Sapphire Energy, UOP, Zeachem, and Archer Daniels Midland (ADM). The Panel believes these projects will have a more limited impact on the overall program. These projects are hindered by a number of factors including the low-value product they are producing; high capital cost of building the facility; lower than expected technical performance of the process; difficulty in raising capital; and poor or weak project execution.

The Review Panel believes that DOE could enhance its portfolio by increasing alignment with private interests and investments. This could be achieved by encouraging the production of non-fuel products as the primary product; development of the ethanol to final products pathways; and additional development of projects that use established feedstock supply chains, such as the use of MSW and synergies with existing pulp and paper facilities.

The Review Panel noted that many of the successful construction projects mentioned above shared several common factors. The most critical factors were:

- The availability of sufficient funding to allow the projects to work through difficult technical issues during the development, construction, and start-up phases;
- The knowledge and prior experience of the project team in project execution; and
- The patience of project stakeholders to support the ongoing efforts for the extended period of time needed for complex new technology projects to be successfully built and commissioned.

INNOVATION

The Panel evaluated the projects to determine if certain identified market and technical barriers were addressed. The primary challenges that face these new facilities include difficulty in obtaining investment; commitment by stakeholders to the extended period of time required to build and start up complex new technology projects; the lack of potential revenue due to the need to produce a lower value transportation fuel; the development of feedstock supply chains and the potential to develop the feedstock supply for commercial-size applications; the need to reduce capital and operating costs through innovation and value engineering; the ability of the project to demonstrate proof of concept in an integrated facility; and the ability of the project team to competently develop and execute a project plan.

The Panel concluded that nearly all projects were addressing issues in innovative ways, as would be expected for projects focused on new technology development. It was apparent from the presentation slides that projects were improving our understanding of large-scale feedstock collection, materials handling, organism development, photo-bioreactor production, market barriers, and creative use of co-location, to name a few. Although Sapphire appeared to be using pond design and dewatering techniques, which had been previously demonstrated, the Panel felt that the Sapphire project was advantageous due to its construction and operation of many acres of ponds. These allowed the company and DOE to experience large-scale operating challenges, including contamination from both biological and non-biological sources.

The Review Panel considered whether BETO was funding projects at the appropriate technology readiness levels. The Panel believes that projects will not necessarily be at the ideal location in the project development cycle when they are chosen for funding. It should be expected that underfunded developers may oversell their technology readiness in order to attract investment or that policy may dictate when, or what, projects get funded. For example, two of the projects that the Panel considered as being particularly impactful were the commercial POET-DSM and Abengoa projects. These projects received funding before the other portfolio projects and are only now in the start-up phase. It is clear that these projects had considerable pre-project work to complete prior to actually building their current facilities. Therefore, it appears that these projects were funded before they were ready for the construction phase. However, these projects represent a quarter of all projects the Panel found to be impactful and represent by far the largest potential consumers of feedstock and producers of product.

The Review Panel believes that selection and funding of projects that are not yet ready to proceed to the next stage of development are to be expected. The Panel feels that DOE's use of active project management to release funding at defined stage-gates and the use of go/no-go decision points serves to protect the public funds and is useful to guide funding recipients in proper project execution. It was apparent in the project presentations that the three most recent projects to be selected for grant funding (Frontline, BPA, and Mercurius) were or had been held at a stage-gate point, while DOE and their independent engineer reviewed the projects' actual progress to that point. However, while this example of the stage-gate progress was obvious to the Panel during the review of the presentations, the Panel believes that a similar process was likely used for the two commercial projects mentioned above. The project funds were used for building the facilities and not for the pre-project work that still needed to be completed after the project had been selected for the DOE grant.

The Panel concluded that the DMT projects are addressing the broad problems and barriers that BETO is attempting to solve. While all the projects include innovative elements, which contribute to the projects' ability to address barriers, the Panel observed that the patience of the main stakeholders and access to funding are equally important in project success.

GAPS

The Review Panel believes that the DMT portfolio is critically underfunded, which represents the biggest and most important "gap" in the DMT program. The current portfolio is represented by 15 projects. Funding for 10 of the projects, those funded under the American Recovery and Reinvestment Act of 2009 (ARRA), will end in 2015. The remaining five projects are the two commercial projects, POET-DSM and Abengoa, and the three newer innovative pilot projects (Frontline, BPA, and Mercurius). The two commercial projects are in start-up mode and have received the majority of their DOE funding. The completion of these two commercial projects will leave three construction projects in the portfolio. Subsequently, a once vibrant and diverse portfolio, which has helped advance the state of the bio-economy and address wider issues and goals, appears to be in jeopardy of becoming irrelevant. The Panel identified additional areas where program support could benefit the industry. These include:

- Align with private sector investment in the development of non-fuel, higher-value products. These products would need to be diverse and targeted at larger markets to minimize the effect of price depression due to new market entrants.
- Re-purpose or co-locate with existing pulp and paper facilities to capture the benefits of their established feedstock supply chain, materials handling knowledge, and use of product or coproduct streams, such as pulp, lignin, and tall oil.
- Continue development of a sugar-based platform that focuses on the production of fungible sugars separate from the technologies that convert the sugars to chemicals and fuels.

In addition to the market development activities listed above, the Panel identified some technology-specific areas that could be beneficial to the industry. Some of these items might be better addressed through individual technology areas rather than in the DMT program.

- Find a value-added purpose for utilizing the separated lignin for certain technology pathways rather than just burning it as a fuel.
- Identify and/or keep a trained labor force in remote locations, as several projects reported that they faced difficulties in this area. The Panel believes that an opportunity exists, maybe in cooperation with the U.S. Department of Agriculture rural development program, to provide training to a labor force in return for an extended commitment to work in rural locations.
- Develop methods to remove foreign material from feedstocks. These techniques could apply to dry feeds like corn stover, or to wet feeds such as algae grown outdoors.

- Develop more cost-effective algae dewatering and nutrient recovery techniques and product recovery techniques from dilute aqueous solutions.
- Continue work on the development of a robust dry biomass feed system that can feed biomass across a pressure boundary. Support for publishing of reliable information in this area would also be useful.

SYNERGIES

The Panel found that, given the similarities among projects, there could be considerable value in sharing lessons learned. However, sharing this information may not be feasible during project execution given the considerable effort and cost expended by the companies, and the resulting corporate intellectual property ownership. Further, it is not clear if this type of sharing during project development would necessarily be beneficial, as it could hinder an individual company's innovation in overcoming barriers.

While sharing lessons learned in areas, such as development of processes and equipment; feedstock characterization and collection; enzyme performance; and clean-in-place practices (and many more), may not be practical across the companies in the BETO Program at the time of deployment, the Panel thinks that this valuable information will be leveraged between current projects and future projects. For example, the Panel believes that future projects will benefit from the feedstock development work and equipment and process development that is currently being accomplished through interactions with technology providers, licensing of intellectual property, knowledge gained by feedstock providers, and development of the regulatory and market requirements.

RECOMMENDATIONS

The Panel arrived at the following recommendations:

- The BETO Program is critically underfunded. The efforts of the last decade—to inform the public, develop technologies, and build knowledgeable teams of people and companies to address issues—is in great danger of being compromised. The Panel believes that current low oil and natural gas prices are causing decision makers to de-emphasize the very relevant BETO Program messages concerning the need to reduce consumption of foreign oil; develop domestic and sustainable feedstock; help establish a domestic industry to improve the economy and provide jobs; and reduce carbon emissions. The near-term reduction in the diversity and size of the DMT portfolio appears to reflect a reduced commitment to support these developing technologies. This lack of commitment appears to be short-sighted and could negatively impact the long-term goals of DOE and the nation.
- BETO should expand its portfolio to include projects that produce a higher-value non-fuel primary product. This would provide a better opportunity for projects to be commercially viable, while developing feedstock chains; address the many identified issues surrounding materials handling and biomass conversion; and still address the BETO goals.
- To increase the chances of a technology success, BETO should consider placing greater emphasis on funding facilities that are co-located with existing facilities where synergies exist and which use existing feedstock supply chains, such as those associated with MSW, pulp and paper, and ethanol facilities.
- In addition to the grant program, projects need a financial assistance program that is willing to accept the risk associated with these types of projects.
- Most of the projects receive funding under ARRA and are required to complete their involvement with DOE by mid-2015. Some of these projects are still working through start-up issues. The goal of this program is not only to construct facilities, but to operate them and determine their operating performance. DOE should provide additional grant money

to carry these projects through start-up and early operations to allow DOE to perform a technology assessment for viability.

- DOE should provide grant money to encourage the most successful, and potentially commercially viable, pilot plant projects to proceed to the next scale.

BETO PROGRAMMATIC RESPONSE

BETO appreciates the Review Panel's participation, as well as the feedback that we received from the panelists and steering committee during the Peer Review meeting in March 2015 and the Program Management Review meeting in June 2015. Through its comments, the Review Panel endorsed the work being carried out by BETO's DMT Program. The Panel concluded that the primary strength of the DMT program can be attributed to a large number of projects engaged in developing technologies and constructing operating facilities in accordance with the stated objectives in their DOE grant applications. The Review Panel provided additional actionable recommendations that BETO could implement to further improve the DMT program.

The DMT program portfolio, reviewed by the Peer Review Panel, comprised a total of 19 projects, of which:

- Two are pioneer commercial-scale projects (Abengoa Bioenergy and POET-DSM), funded under the EPAct 2005 Section 932 Solicitation, currently in start-up and commissioning stages;
- Ten pilot-/demonstration-scale projects (Algenol Biofuels, American Process, Inc., ADM, Haldor-Topsoe, ICM, INEOS New Planet Bioenergy, Myriant Bioenergy, Sapphire Energy, UOP, and ZeaChem), funded under ARRA, with DOE funding set to expire on September 30, 2015;
- Three innovative pilot-scale projects (BioProcess Algae, Frontline Bioenergy, and Mercurius Biorefining) funded under the Innovative Pilot (iPilot) Solicitation; and
- Four projects focusing on supporting areas to enable wider deployment of bioenergy projects (ANL, BNL, NREL, and ORNL) funded under the Annual Operating Plan for National Laboratories and the HSU project funded under the Biomass Research and Development Initiative (BRDI).

The DMT program's response to the Peer Review and Program Review Panel's Summary is as follows.

IMPACTS

The Review Panel noted that successful projects within the DMT portfolio shared several common factors, including:

- Completion of undergoing construction of facilities to produce biofuels and bioproducts;
- Availability of sufficient funds to progress through the development of first-of-a-kind technologies, construction, and start-up phases of biorefinery projects;
- Development of feedstock supply chains to support commercial-scale operations;
- Necessary experience and skills to handle complex projects;
- Consideration of bioproducts beyond ethanol; and
- Support and patience of project promoters and DOE to make these initiatives successful despite the extended length of time that it takes for complex new technology projects to be successfully built and commissioned.

The Panel classified the DMT program portfolio of 19 projects into four groups:

1. Particularly Impactful Projects: These comprie Abengoa Bioenergy, Algenol Biofuels, American Process, Haldor-Topsoe, ICM, INEOS New Planet Bioenergy, Myriant Bioenergy, and POET-DSM. The Review Panel highlighted the fact that several of these projects produce ethanol as the final product. The Panel also noted that projects attempting to produce oils as the finished product were not successful. BETO would like to point out that other projects funded under ARRA, such as Amyris, Elevance Renewables, and Solazyme, have produced products other than ethanol and successfully completed their projects before the review meeting in March 2015.

2. Developing Projects: These include BioProcess Algae, Frontline Bioenergy, and Mercurius Biorefining. These projects will be involved with the production of fuel products other than ethanol. As the reviewers mentioned, these projects are in the early stages of the development cycle and will continue beyond 2015. We look forward to working with them in bringing their technologies to fruition.

3. Minimally Impactful Projects: These consist of ADM, Sapphire Energy, UOP, and ZeaChem. The Panel observed the limited impact of these projects based on their moderate progress. This limited progress could possibly be due to financial constraints and challenges, lower than expected project performance, poor or weak project execution, and higher than expected capital expenditure to build the facility. We intend to continue working with these companies to capture and document the "lessons learned."

The Panel also indicated that "the low value product they were producing" could also be a factor. These companies are planning to produce either ethanol, pyrolysis oil, or other liquid fuels; hence, the program would appreciate further clarification from the Review Panel on what was meant by "the low-value product."

4. Other Impactful Projects: These comprise BNL, consortium of ANL, ORNL, and NREL, Humboldt State University, and ORNL. These projects support diverse areas such as entry into the residential heating oil market, performance of automotive engines using fuels containing higher ethanol blends, energy densification of biomass, and best management practices of biomass storage facilities, including fire codes and safety procedures and systems. We intend to continue supporting this work in order to facilitate the deployment of biorefinery projects.

The reviewers recommend that DOE consider projects focusing on the production of non-fuel products as the primary product, products using ethanol as the starting material, MSW as feedstock, and colocation synergies with existing pulp and paper facilities. We would like to point out that, as per the Biological & Chemical Upgrading for Advanced Biofuels solicitation, DOE has awarded $13.4 million to five projects addressing the production of:

- Industrial chemicals and resins from biomass;
- Solvents from cellulosic sugars;
- Muconic acid as a platform chemical intermediate from biogas;
- Lactic acid and fuels from biogas; and
- Diesel, gasoline and jet fuels from ethanol.

Future solicitations are likely to include the production of non-fuel products; however, fuel may remain the primary product. We plan to explore the use of MSW as feedstock and to further study the colocation strategy.

INNOVATION

The reviewers highlight the primary challenges faced by these projects: securing investments; obtaining sustained commitment by stakeholders during lengthy project cycles; addressing the impact of crude oil prices on the price of ethanol; managing logistics and supply chain systems for feedstock to support commercial operations; effective use of innovation and value engineering to reduce CAPEX and OPEX; and the need for seasoned project teams for successful execution of projects. The report concluded that the above-mentioned issues and challenges have been adequately addressed.

The Review Panel noted that almost all of the DMT projects generated innovations on several fronts including: feedstock collection and aggregation; characterization and understanding of the properties of feedstock; organism and enzyme development; solids handling, including feeding at pressures; equipment development to handle biomass; photo bioreactor systems at lower cost and increased productivity; colocation synergies to reduce CAPEX and OPEX; and developing new markets for biofuels and bioproducts. The Panel added that, in addition to innovations, the support and patience of the project stakeholders and access to funding have played a vital role in the success of these projects.

The Panel acknowledged that DOE's adherence to, and implementation of, active project management procedures for disbursement of funds at defined stage-gates and the use of go/no-go decision points serve to protect the public funds and have been useful to maintain uniform project management methodologies among the funding recipients.

GAPS

The Panel highlighted that the pending decrease in the number of projects in the DMT program portfolio, owing to reduction in funding, is the program's biggest and most important "gap." It should be noted that the funding for six (ARRA projects) of the eight "Particularly Impactful" projects will expire at the end of September 2015. The Review Panel observed that "a once vibrant and diverse portfolio, which has helped advance the state of the bio-economy and address wider issues and goals, appears to be in jeopardy of becoming irrelevant." As articulated in our FY2015 and FY2016 Congressional Budget Request, we are cognizant of the current funding situation and are taking steps to increase funding by working on a new Funding Opportunity Announcement (FOA).

The Panel identified additional areas where the DMT program could benefit the bioindustry. These include:

- Align with private sector investment in the development of non-fuel, higher value products;
- Re-purpose or co-locate with existing pulp and paper facilities to capture the benefits of their established feedstock supply chain, materials handling, and the use of product or coproduct streams, such as pulp, lignin, and tall oil; and
- Develop a sugar-based platform that focuses on the production of cellulosic sugars as finished products.

We appreciate the efforts of the Review Panel to identify additional and synergistic areas, and will consider these as we work through our upcoming and future funding opportunities.

The Panel additionally recommended a number of technology-specific areas for consideration by other programs outside of the DMT program, such as Conversion research and development (R&D). These technology-specific areas include:

- Upgrading the value of lignin beyond use as a boiler fuel;
- Removal of foreign material from biomass feedstocks;
- Robust feeding of solid feedstocks at elevated pressures;
- Cost-effective dewatering techniques and efficient nutrient recovery techniques, especially with respect to algal biomass; and
- Identifying and promoting outreach programs to increase the availability of a skilled workforce at remote locations where these biorefinery projects could be located.

We agree with the Panel recommendations and hope to address them in the coming years.

SYNERGIES

The Review Panel observed that, given the similar nature of projects within the DMT portfolio, sharing of "lessons learned" could be beneficial to current, as well as future projects. The Panel recognized that the exchange of information may be constrained due to the proprietary nature and confidentiality of the issues being addressed. We recognize the difficulty of protecting proprietary information; however, we are committed to working with the DMT portfolio members to document and disseminate information on issues that are not proprietary and confidential. We are also working with our national laboratories and industry partners on important issues, such as fire codes and safety standards specific to bioindustry by involving members from the DMT portfolio, external consultants, and members from standards organizations.

RECOMMENDATIONS

The Review Panel provided the following recommendations:

- Increase the DMT portfolio's diversity and funding level—this is essential for maintaining the momentum established thus far and to show commitment to developing technologies;
- Focus on primary products that are not fuels;
- Give consideration and preference to projects that co-locate with existing facilities based on potential benefits owing to colocation;
- Consider a breakeven scenario, instead of positive cash flow, for pioneer commercial-scale projects; and
- Continue to support promising ARRA projects.

As mentioned in other sections, BETO will consider the Panel recommendations and incorporate these, as appropriate, in program elements and future funding opportunities. The DMT team will also coordinate with the Conversion R&D team to assess the applicable program area for implementation of some of the recommendations.

CONCLUSIONS

We would like to take this opportunity to thank all the members of the Review Panel for their thorough, insightful, and constructive review of the BETO's DMT program. The Panel concluded that the primary strength of the DMT program can be attributed to a large number of projects engaged in developing technologies and constructing operating facilities in accordance with the stated objectives in their funding applications. The Review Panel's overall positive comments, performance rating of various projects, and identification of areas for improvement demonstrate that the DMT program is achieving the goals of BETO and is well managed.

FIRE STANDARDS CODES AND PREVENTION IN IBRs

(WBS#: 3.1.3.2)

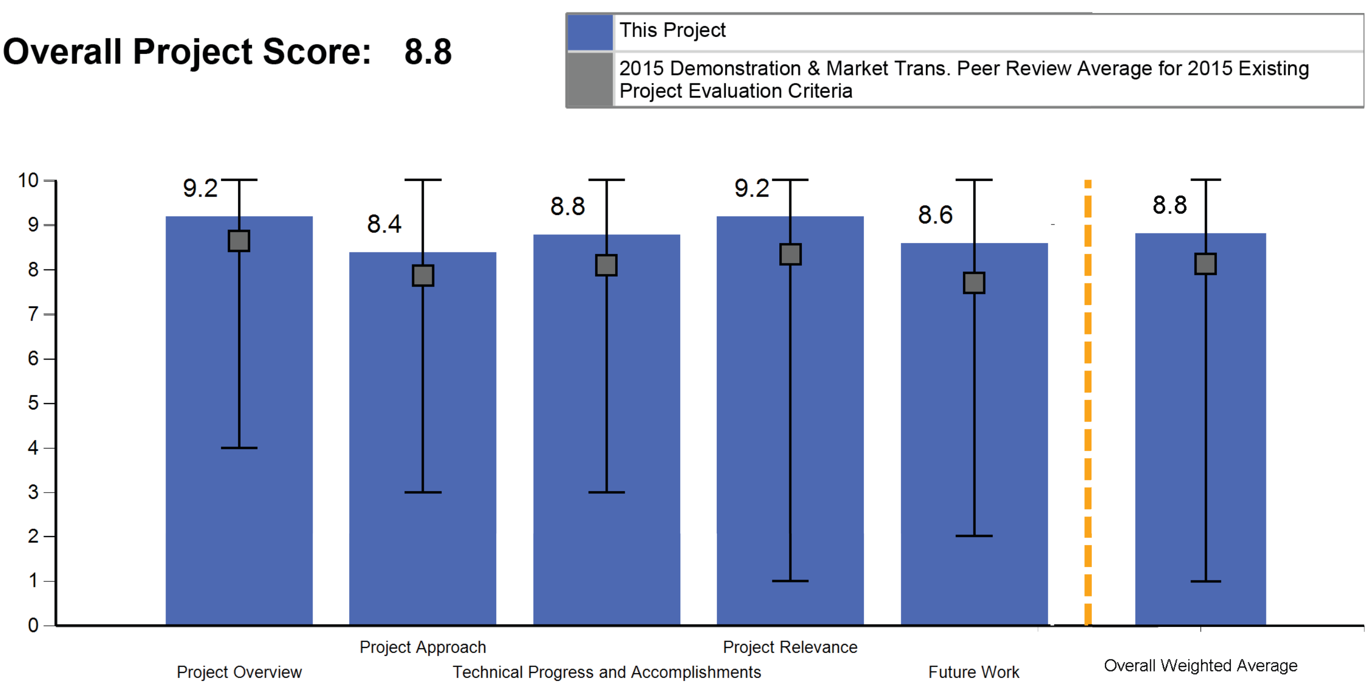

Photo Courtesy of ORNL

Recipient:	ORNL
Presenter:	Erin Webb
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,102,000
Project Dates:	10/1/2015 - 9/30/2017

Project Description

Successful scale-up of a commercial biomass supply industry will require harmonized codes and standards to ensure the safety of people and assets, reduce risk and improve insurability, meet market expectations for sustainability, and reduce costs for biomass industries. The project team is leading and facilitating industry-backed committees to develop codes and standards to address risk of fire in biomass-handling facilities and standardize sustainability assessment. The Biomass Industry Panel on Codes and Standards (BIPCS) conducts analysis of existing national fire and building codes, performs R&D to understand the behavior of biomass fires, prepares code change proposals to facilitate development of a commercial-scale biomass industry while maintaining a focus on safety, and develops training and reference materials for engineers and code reviewers. An ASTM subcommittee was recently formed to develop a new international standard for U.S. firms interested in export of biomass-derived products, aiming to reduce market barriers and provide a more consistent basis for sustainability assessment. For both committees, the project goal is to enable industry to proactively overcome

Overall Project Score: 8.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

barriers by contributing to the development of codes and standards that address risk while reducing transaction costs.

Overall Impressions

- This is an excellent project where DOE is partnering with the industry to help solve an immediate challenge.
- This project is targeted exclusively on market transformation and is not typical of previous grants from the Demonstration and Market Transformation (DMT) Program. It represents an area that has historically been underfunded or ignored, but represents valuable work in the area of industry standards that needs to be addressed as an integral part of enabling the emerging biorefinery industry, especially in the area of feedstock storage requirements to meet the requirements of insurance providers. DMT should remain open to other such programs and grants in other enabling areas, such as certification of biofuels, and supply chain issues for other bioenergy technologies, such as bio-heat, infrastructure certifications.
- This is very good work and a presentation on an area definitely needed for the industry.
- The project team has done an excellent job in preparing for the upcoming challenges that are involved with handling large quantities of biomass, while still maintaining adherence to relevant codes and regulations. Working to modify the relevant codes in advance of a new technology's introduction is a far-thinking approach, and warrants further support.
- This is important work since biomass refining on a large industrial scale introduces new standards and code issues. The project showed effective use of industry stakeholders in developing standards. Good progress was made in modifying existing fire codes.

PI Response to Reviewer Comments:

- We sincerely appreciate the encouraging comments from the reviewers. This project, focused on development and harmonization of codes and standards for the biomass industry, is a relatively new effort and, as noted by the reviewers, the structure and deliverables of this project are different than many BETO-funded projects. We hope that this BETO work can be a model, even beyond the bioenergy industry, for how government and industry can work together to proactively address safety and market barriers to enable industry growth while protecting personnel and assets.

SAPPHIRE INTEGRATED ALGAL BIOFINERY (IABR)

(WBS#: 7.6.2.7)

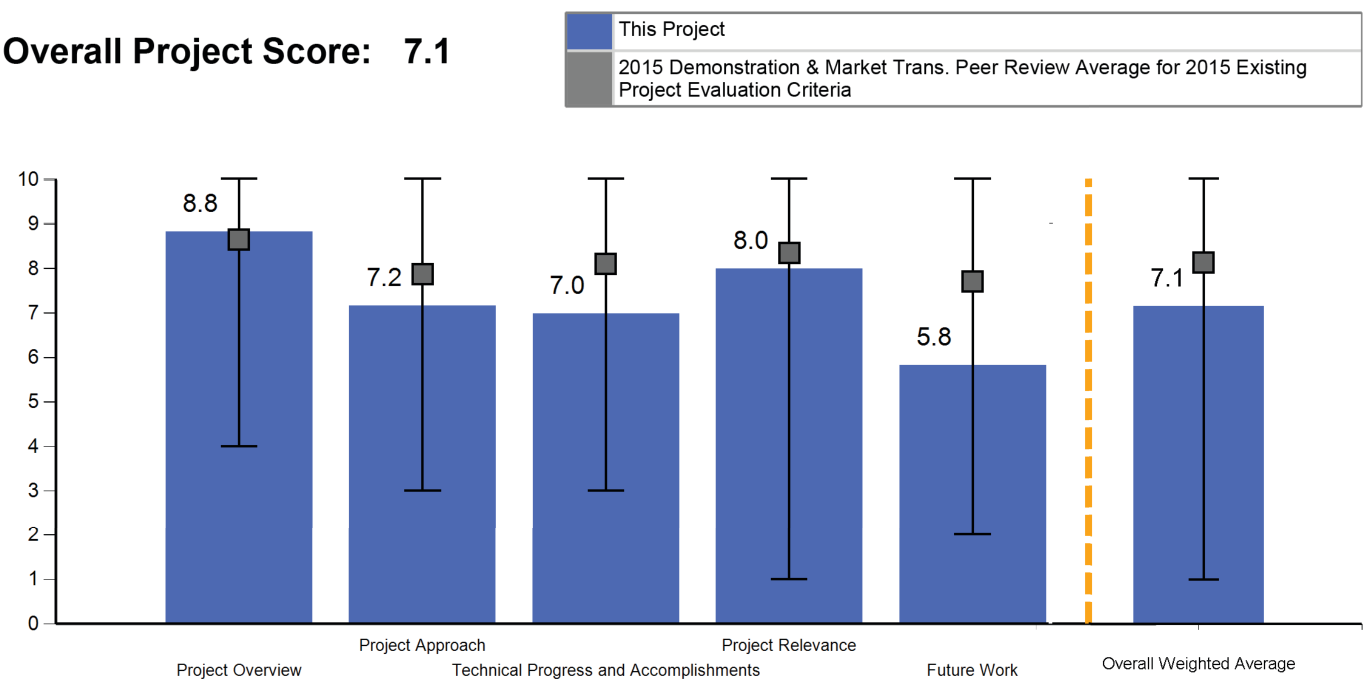
Photo Courtesy of Sapphire Energy, Inc.

Recipient:	Sapphire Energy, Inc
Presenter:	Jaime Moreno
DOE Funding FY14:	$3,515,344
DOE Funding FY13:	$712,907
DOE Funding FY10-12:	$30,386,165
Planned Funding:	$18,625,928
Project Dates:	12/29/2009 - 4/30/2015

Project Description

The overall objective of the Integrated Algal Biorefinery (IABR) project is to demonstrate the technical and economic feasibility of the process for converting algae to drop-in green crude that will form the basis for the deployment of a series of commercial-scale biorefineries. The goals of the IABR project are to: (1) deploy the algae to green crude process at pre-commercial scale; (2) integrate the key processes for the entire production chain from feedstock to transportation of final product; and (3) continue to reduce capital and operational costs through an ongoing R&D effort. The IABR's relevance remains aligned with these original project goals from early 2009. It continues to be the key step in the development of commercial-scale drop-in crude from algae, sunlight and CO_2. A fully operational 100-acre facility was constructed on time and on budget. Technically, the IABR has focused purposefully and targeted devel-

Overall Project Score: 7.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

opment of technologies to deliver a large-scale outdoor production facility that produces a crude oil suitable for refining and market use. To further success, the project will deploy next generation technologies and continue to provide tangible proofs necessary to support continued policy and investment advancements.

Overall Impressions

- The presentation did not cover the requested topics well. However, this was an excellent project for demonstrating the barriers encountered with larger-scale outdoor ponds, contamination issues, weather issues, actual costs of construction for traditional raceway ponds, and issues with upgrading of dirty algae.
- The presenter provided a good, thorough and honest summary of the project successes and impediments, which need to be addressed.
- The project made productive use of modern project management tools. There is very good use of staged pilot work, going from the laboratory, to only a few algal beds (22 acres), to what could be viewed as a small full-scale facility of 96 acres.
- Sapphire has demonstrated two years of continuous cultivation in open ponds and has produced sufficient quantities of bio-oil for transport fuels certification. Nonetheless, they were not able to achieve significantly higher productivities than have already been demonstrated in the aquatic species program of the late 70s and early 80s. The cost-to-benefit ratio of this project to DOE does not appear to be significant.

PI Response to Reviewer Comments:

- No official response was provided at time of report publication.

PILOT-SCALE MIXOTROPHIC ALGAE INTEGRATED BIOREFINERY (IBR)

(WBS#: 3.3.2.5)

Photo Courtesy of BioProcess Algae

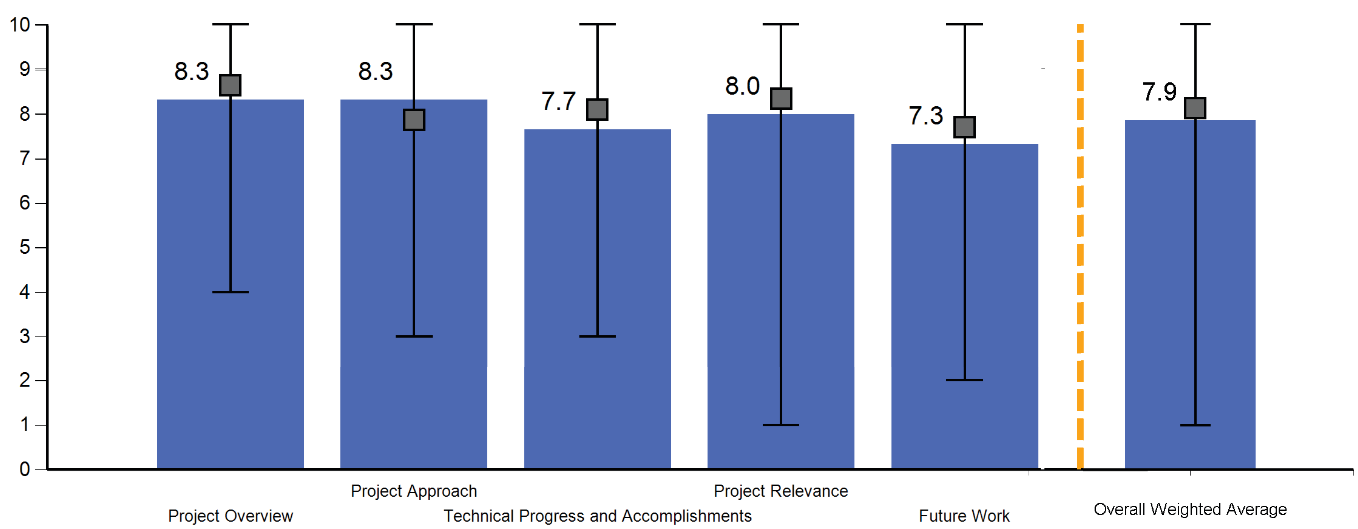
Recipient:	BioProcess Algae
Presenter:	Toby Ahrens
DOE Funding FY14:	$384,929
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$5,974,428
Project Dates:	9/30/2013 - 4/6/2017

Project Description

BioProcess Algae (BPA) will design, build, and operate a pilot-scale Mixotrophic Algae Integrated Biorefinery (Mixo-IBR), which will produce low-carbon biofuels from algae that meet military specifications (F-76, JP-5 and/or JP-8). BPA's innovative approach will be used to grow algae with renewable CO_2 from an adjacent ethanol plant, stress the algae with lignocellulosic sugars to increase lipid production, and convert extracted lipids to fuels meeting military specifications. Funds for this project will be used to: (1) expand production capacity; (2) operate the pilot facility; and (3) quantify the full environmental, economic and rural development benefits of commercializing the Mixo-IBR technology. Operation of this pilot-scale IBR in Iowa will provide the continuous operational data needed to lower the technical risks for the expansion to a commercial-scale Mixo-IBR. BPA has completed an initial budget period on time and under budget and received formal approval to proceed with the subsequent phase of the project. BPA successfully achieved all milestones in the initial budget period. The proposed approach is highly replicable, and construction and operation of future commercial

Overall Project Score: 7.9

■ (blue)	This Project
■ (gray)	2015 Demonstration & Market Trans. Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

facilities will result in high-quality job creation in rural regions throughout the U.S. Commercial deployment will directly address DOE/EERE's core goals of reducing imported oil and spurring a domestic bioindustry.

Overall Impressions

- This project appears to have a prohibitive capital cost. One could estimate $100,000 per acre at least for the greenhouses (maybe $500,000). For a 5,000-gal/acre system (20,000 acres), for a 100 million gallons/year plant, the capital cost would be $2 billion.
- This project is a good addition to the DOE portfolio. It is not clear what the benefits are of using a mixed approach of heterotrophic and phototrophic growth stages. It appears one of the hurdles of this project will be the ability to obtain quantities of cellulosic sugars.
- This is good project work to date. We need to see how costs and approach develop at higher scale up.
- A very good start so far; I would like to see more intermediate results as progress is made.
- This is a reasonable technical approach assessing multiple conversion options. Project shows innovative growth and harvesting method. More attention should be paid to the quantitative estimate of GHG impact. More information on what is being done in Budget Period 2 would have been helpful (equipment constructed and tests run).

PI Response to Reviewer Comments

- *Regarding the comment on capital cost*: BPA did not present projected capital costs nor per-acre productivity estimates during the public peer review, and assumptions in this comment are speculative and misleading. The mixotrophic approach does not translate well to a gallon/acre production assumption for the same reason that a heterotrophic/fermentation facility—such as an ethanol plant—should not be divided by its footprint to derive a per acre production value. The sugars added during the stressing period increase the overall biomass as well as the lipid content and, as a consequence, make "per acre" calculations misleadingly high. The overall investment required for a commercial facility, which was not presented as part of the public peer review, is well within the bounds considered "normal" for commercial project finance in the bioenergy sector.
- *Regarding sources of cellulosic sugars*: BPA has identified a preferred source of cellulosic sugars as well as an alternative source as contingency. The quantities needed for the proposed Mixo-IBR are within existing production capabilities for both of the potential suppliers of sugars.
- *Regarding the comment that the economic viability of the technology platform remains to be proven*: We agree. One of the primary goals of the Mixo-IBR program is to validate the proposed pathway in an integrated facility to produce sustainable and competitively priced fuels. BPA is confident about its technology and expects to continue diligent execution of the project plan in the next phases to achieve future milestones.
- *Regarding attention to the GHG impact*: BPA has performed an LCA for the Mixo-IBR approach, and per the requirements of the FOA, the results demonstrated an improvement over equivalent products derived from petroleum on a well-to-wheel (or farm-to-wheel) basis. The LCA was not presented as part of the public peer review process.

HIGH-YIELD HYBRID CELLULOSIC ETHANOL PROCESS USING HIGH-IMPACT FEEDSTOCK FOR COMMERCIALIZATION BY 2013

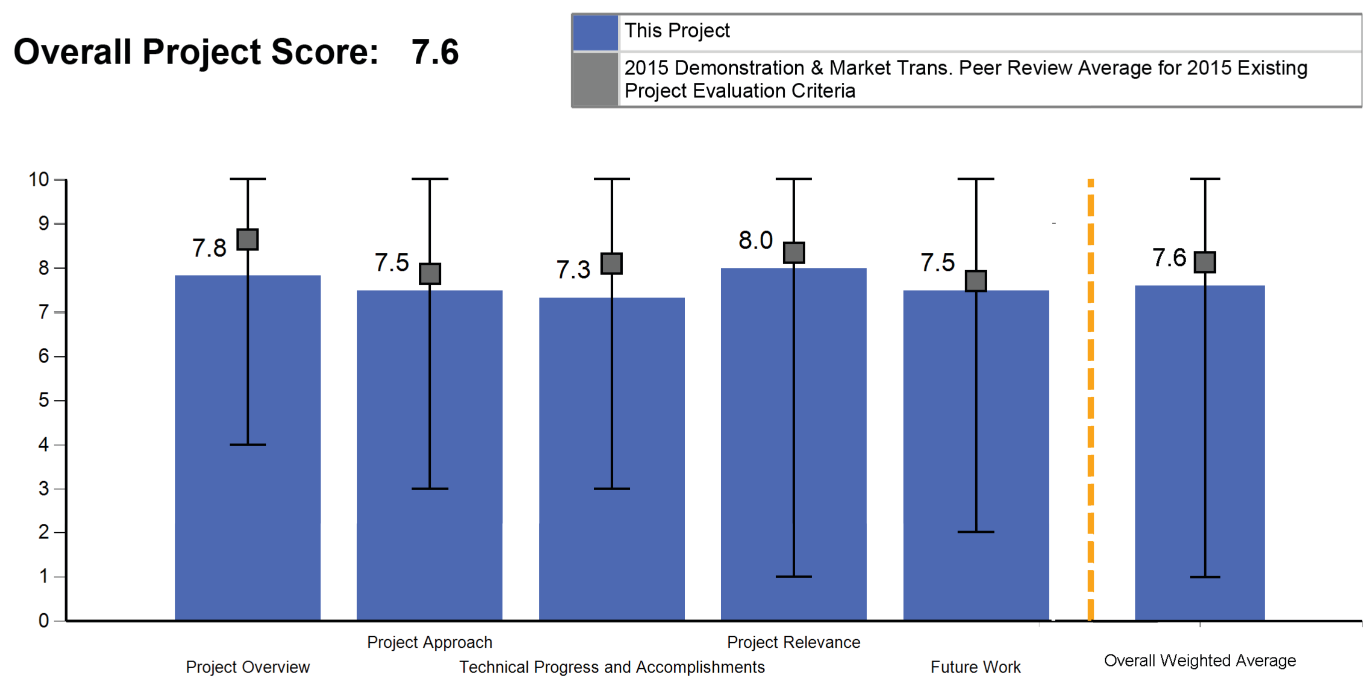
(WBS#: 3.4.1.15)

Recipient:	ZeaChem, Inc.
Presenter:	Tim Eggeman
DOE Funding FY14:	$434,731
DOE Funding FY13:	$10,129,765
DOE Funding FY10-12:	$13,365,412
Planned Funding:	$1,504,823
Project Dates:	1/28/2010 - 9/30/2015

Photo Courtesy of ZeaChem, Inc.

Project Description

ZeaChem Inc., has successfully constructed and operated a 10 tons/day Integrated Biorefinery in Boardman, Oregon, with assistance from a $31.25 million Cooperative Agreement with DOE. Cellulosic ethanol was first produced from the facility in February 2013, using hybrid poplar as the feedstock. This project is a part of BETO's DMT Technology Area and is well aligned with the mission and goals of the Multi-Year Program Plan. The project most directly addresses the barrier "It-A: End-to-End Process Integration," in that it demonstrates and validates total process integration, from feedstock production to end-product distribution. The project has completed Budget Period 2 and is ready for entry into Budget Period 3. The test run data to be collected during Budget Period 3 will be used to support ZeaChem's on-going project development efforts to finance, construct, and operate a follow-on first commercial plant. This plant is planned to be located adjacent to the existing



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

IBR facility, will use the same feedstocks as tested in the IBR facility, and produce 22 million gallons/year of cellulosic ethanol as its primary product.

Overall Impressions

- ZeaChem has done a lot of work. The question is whether it can convince investors that its technology makes sense commercially. My impression is that they have not been able to do so yet.
- The presentation was light in providing the information requested for this review. The project has demonstrated that the technology works with the use of the co-located facility to provide ester. The presenter preferred not to provide metrics around their performance other than showing they fed the required amount of feedstock as required by the FOA.
- BETO should be commended for funding demonstration-scale projects, such as this integrated project by ZeaChem. To truly deploy and expand this biochemical conversion pathway, projects such as this are necessary to help eliminate the traditional need for large-scale economies-of-scale and bring the costs down for small-scale regional projects that address regional feedstock availability. In addition, the unique acetic acid and esterification/hydrogenation pathway has distinct competitive advantages over the traditional C6/C5 ethanol production by yeast, and the ability to expand from a C2 to C3, and C4 pathways and products that will further advance the emerging biofuels and renewable biochemical industry.
- This is a tough project in these tough low-price times. There has been good diligence on the part of the investigator.
- The project appears to have been well managed and met BETO's goals. The high fraction of project costs born by DOE is probably appropriate for a small company, such as ZeaChem, but should nonetheless be reviewed to possibly develop strategies that could more effectively utilize the DOE funds.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

INNOVATIVE GASIFICATION TO PRODUCE FISCHER-TROPSCH JET AND DIESEL FUEL

(WBS#: 3.4.1.17)

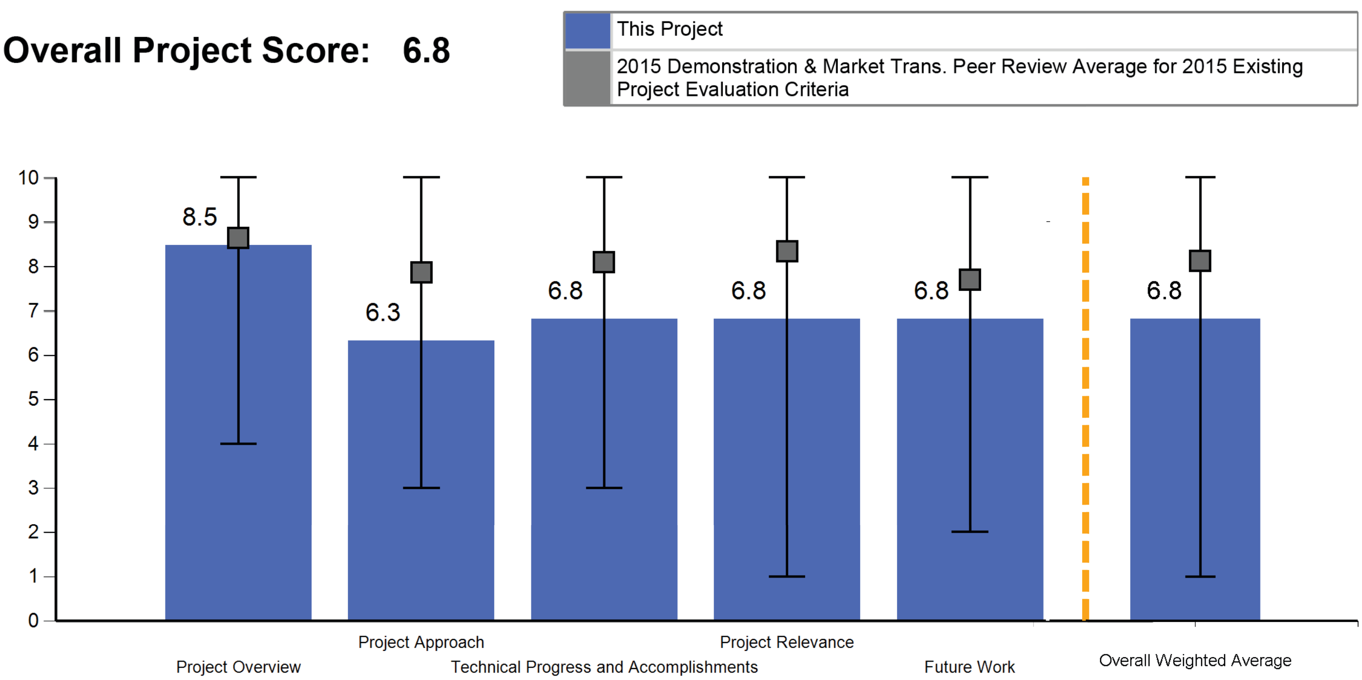
Recipient:	Frontline BioEnergy, LLC
Presenter:	Jerod Smeenk
DOE Funding FY14:	$69,769
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,057,179
Project Dates:	10/1/2013 - 12/31/2016

Photo Courtesy of Frontline BioEnergy, LLC

Project Description

Frontline BioEnergy will demonstrate the performance of an integrated biomass-to-liquids (BTL) pilot plant, utilizing innovative gasification and gas conditioning technologies coupled with a Fischer Tropsch (F-T) process. Frontline will integrate its TarFreeGas® reactor and gas conditioning processes with a 1 barrel/day F-T pilot unit. F-T product samples will be upgraded to produce representative military spec diesel and jet fuels. Project objectives include the following: (1) demonstrate the performance of the TarFreeGas® gasifier and gas cleanup; (2) successfully integrate TarFreeGas®, gas conditioning and the F-T reactor to produce F-T intermediate products; and (3) convert F-T intermediates to military spec diesel and jet fuel. This project is relevant to DOE and DOD by: (1) producing drop-in, advanced biofuels; (2) reducing U.S. dependence on foreign oil; (3) motivating growth of the bioenergy industry; and (4) integrating biomass gasification and F-T synthesis to produce useable liquid fuel products. Frontline BioEnergy leads a strong team that includes SGC Energia, Stanley Consultants, and Delphi Engineering and Construction, LLC. The project will be performed

Overall Project Score: 6.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

in three phases. The DOE due diligence phase is complete and the detailed design phase is underway. The final phase includes both construction and operation.

Overall Impressions

- Unless Frontline BioEnergy can show why its process will be dramatically cheaper than Rentech's, I do not see any reason to replicate it.
- This project's technology is a good addition to the portfolio and at an appropriate scale. It appears that this project is in the very early stage of development and needs to do additional work on developing its path forward.
- BETO should be commended for funding small-scale gasification to F-T projects, such as this integrated pilot-scale project. To truly deploy and expand the thermochemical conversion pathway, projects such as this are necessary to help eliminate the traditional need for large-scale economies-of-scale and bring the costs down for small-scale regional projects that address regional feedstock availability ("scale-down" projects and "process intensification" projects). The demonstration will also have peripheral benefits for related small-scale deployments related to converting stranded natural gas from fracking operations to alternative liquid transportation fuels, which in turn will contribute to the learning curve for small-scale biomass or distributed coal-and-biomass-to-liquids (CBTL) applications.
- This is a challenging project to get good, reliable data at this scale and in the time-frame specified.
- This is, apparently, a good project so far, but the results will have to wait until the facility is constructed and operated. The presentation content was not very clear on certain process details regarding F-T chemistry, product molecular weight distribution, catalysis, and disposition of tars.
- The project combines two "established" technologies to produce high-value products for DOD and leverages existing pilot plant facilities. The pilot plant will confirm that the technologies can be effectively integrated.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

CONVERSION OF LIGNOCELLULOSIC BIOMASS TO ETHANOL AND BUTYL ACRYLATE

(WBS#: 3.4.1.4)

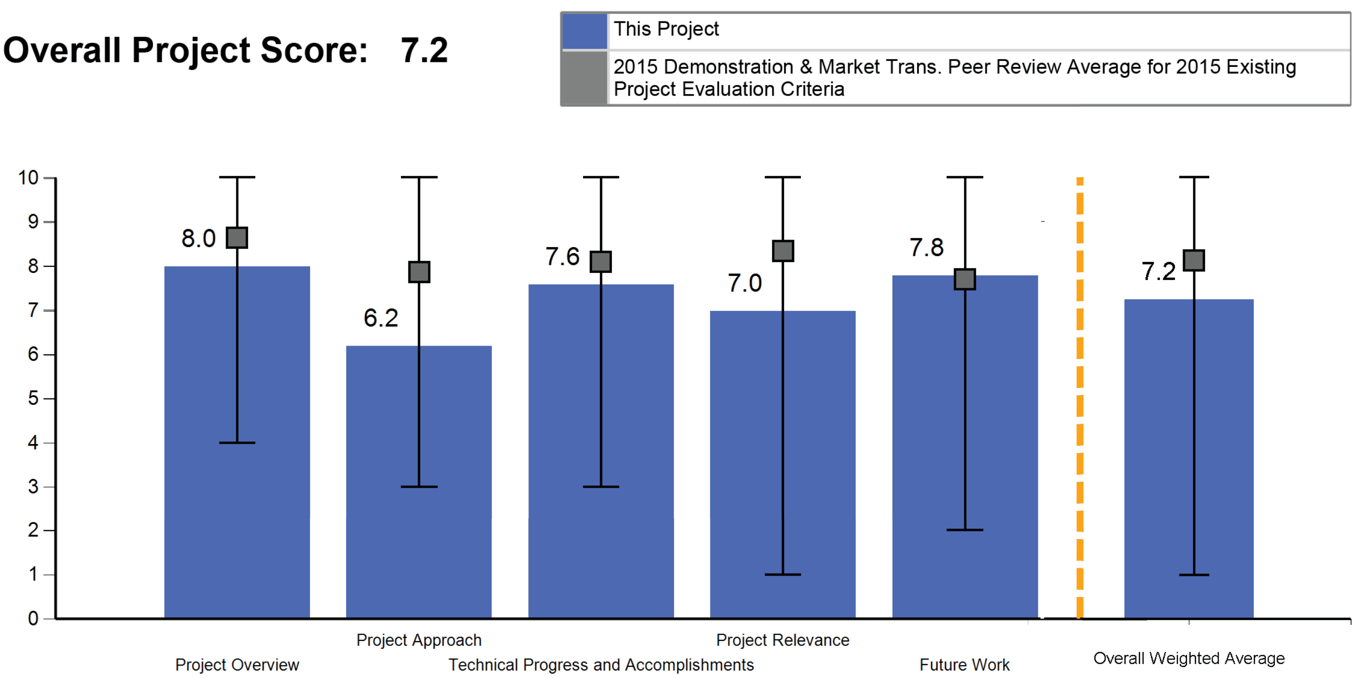
Recipient:	Archer Daniels Midland (ADM)
Presenter:	Tom Binder
DOE Funding FY14:	$1,908,209
DOE Funding FY13:	$3,646,312
DOE Funding FY10-12:	$19,280,071
Planned Funding:	$1,908,209
Project Dates:	1/28/2010 - 1/1/2015

Photo Courtesy of Archer Daniels Midland (ADM)

Project Description

The primary goal of this project is to demonstrate a process and technology to produce ethanol and chemicals from corn stover at a pilot-scale facility. The project aims to validate laboratory results on biomass conversion using acetic acid treatment and conversion of selected streams to fuels and chemicals in an integrated pilot plant. The project has demonstrated the use of enzymatic reactions to produce a high quality six carbon sugar stream that was able to be processed to both ethanol as well as industrial chemicals. The sugar profile of pilot plant material was very similar to that produced in laboratory trials. The project's current operational validations include the following: (1) all unit operations outlined in the final design have been demonstrated with materials processed from corn stover through the IBR equipment; (2) demonstration of C5 fermentation has had limited success—due to difficulties in stream purification are the main cause; and (3) demonstration of the catalytic process for butyl acrylate production has been

Overall Project Score: 7.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

successful using a reactive distillation process. This project will be viewed as a success when the optimization of the process leads to a valid economic model that will determine scale-up potential for all products from the biomass fractionation.

Overall Impressions

- The project team did a good job in completing the project and identifying technical issues.
- The project was useful in demonstrating the materials issues even for an experienced company like ADM.
- This was a very nicely done overall effort. This pilot plant would be an educational gold mine for both new employees and seasoned veterans alike.
- The technology may be good, but was not clearly proven due to gaps in engineering the pilot plant upfront. Better engineering and more focused laboratory testing could have avoided many of the problems that were encountered. DOE's funding share was excessive, considering the resources of a large company like ADM. Cost vs. benefit ratio of this project to DOE is probably very low.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

WASTE TO WISDOM: UTILIZING FOREST RESIDUES FOR THE PRODUCTION OF BIOENERGY AND BIOBASED PRODUCTS

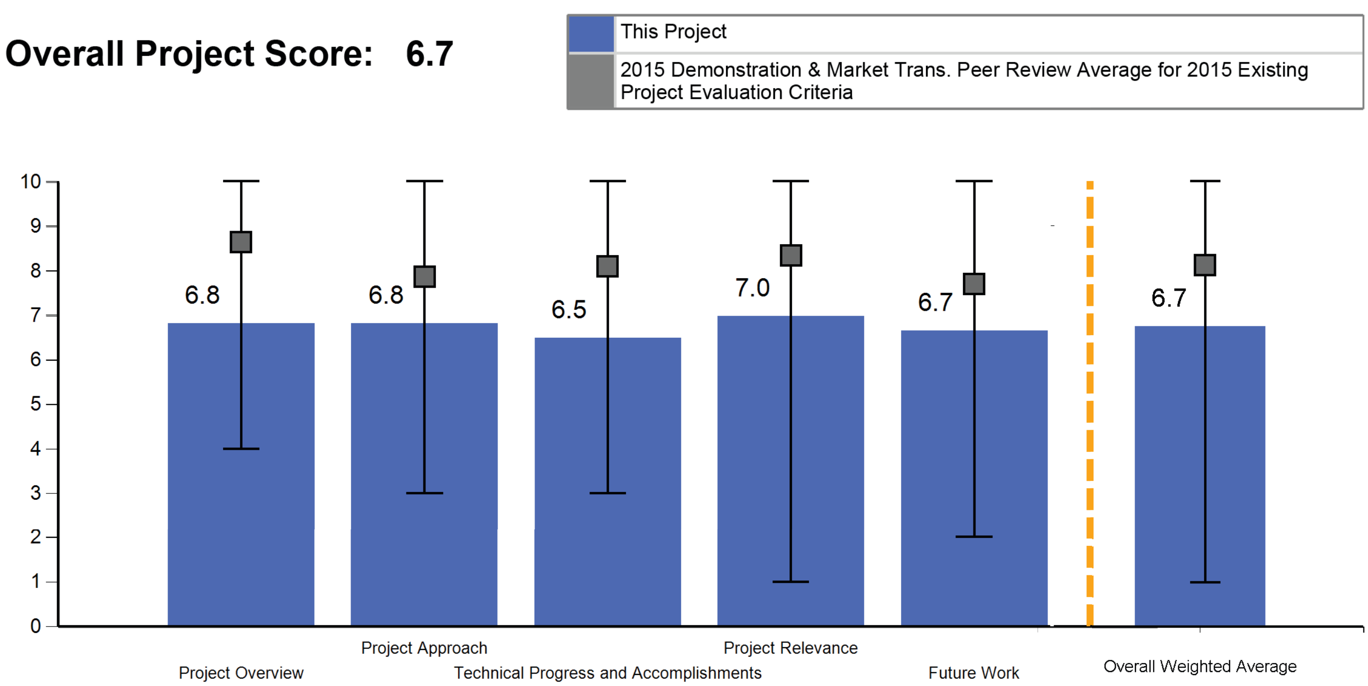
(WBS#: 3.4.1.5)

Recipient:	Humboldt State University
Presenter:	Han-Sup Han
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$5,881,974
Project Dates:	9/30/2013 - 9/30/2016

Photo Courtesy of Humboldt State University

Project Description

Forest residues can be used to produce biofuels, bioenergy, and bioproducts, but the associated costs for collecting, processing, and transporting products with low market values have been a major barrier to an increase in its utilization. This project's objectives are to: (1) develop innovative systems and logistics to produce quality feedstocks from forest residues; (2) develop three field-deployable biomass conversion technologies; and (3) perform economic and life-cycle analyses to quantify the economic and environmental benefits of utilizing forest residues. Forest residue utilization can improve air quality, reduce greenhouse gas emissions, sequester carbon, amend soil, and create employment in rural forestry-dependent communities, while reducing the nation's reliance on fossil fuels and facilitating follow-up forest management activities. Results from initial studies show that the new approach of separating stem wood from the forest residue piles during thinning and timber operations allows cost-effective production



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

of quality feedstocks. Pilot systems for converting biomass into torrefied wood chips, biochars and briquettes at a forest operations site have been developed and will be demonstrated and tested in 2015. Biochar has been applied on an old mining site to evaluate the benefits of this material in land rehabilitation. Financial and environmental analysis of an "integrated forest-to-energy system" will be continued during the next two years.

Overall Impressions

- The key to this project is the CAPEX and OPEX of the conversion systems. This needs to be the primary focus going forward.
- This project is an excellent addition to the portfolio to help address the potential cost savings of densification of the feedstock. I suggest additional work (e.g., literature search) to examine if treatment of the biochar prior to land application would be beneficial to water retention in the soil or carbon availability.
- There has been a good focus on use of forest residues. In-field conversion is an aggressive target.
- Given the various stakeholders involved, the results of this project may see widespread recognition and acceptance. Use of actual full-scale equipment lends credibility to this project. There is some concern with adherence to overall project timeline (timely use of project management tools might have helped here). The 13 co-PIs have demonstrated some planning and diligence; there is a lot to like in this project.
- This project is technically relevant and the project plan appears to be sound. The large number of PIs is a challenge that seems to be addressed effectively by the dividing the project into three task levels. However, the biomass conversion rationale of the project was not clearly articulated.

PI Response to Reviewer Comments:

- The project team would like to acknowledge the reviewers' thoughtful critique of the Peer Review presentation. Thank you for highlighting some positives aspects of the project, as well as those that may have been of concern.

GREEN GASOLINE FROM WOOD USING CARBONA GASIFICATION AND TOPSOE TIGAS PROCESSES

(WBS#: 3.4.1.7)

Photo Courtesy of Haldor Topsoe

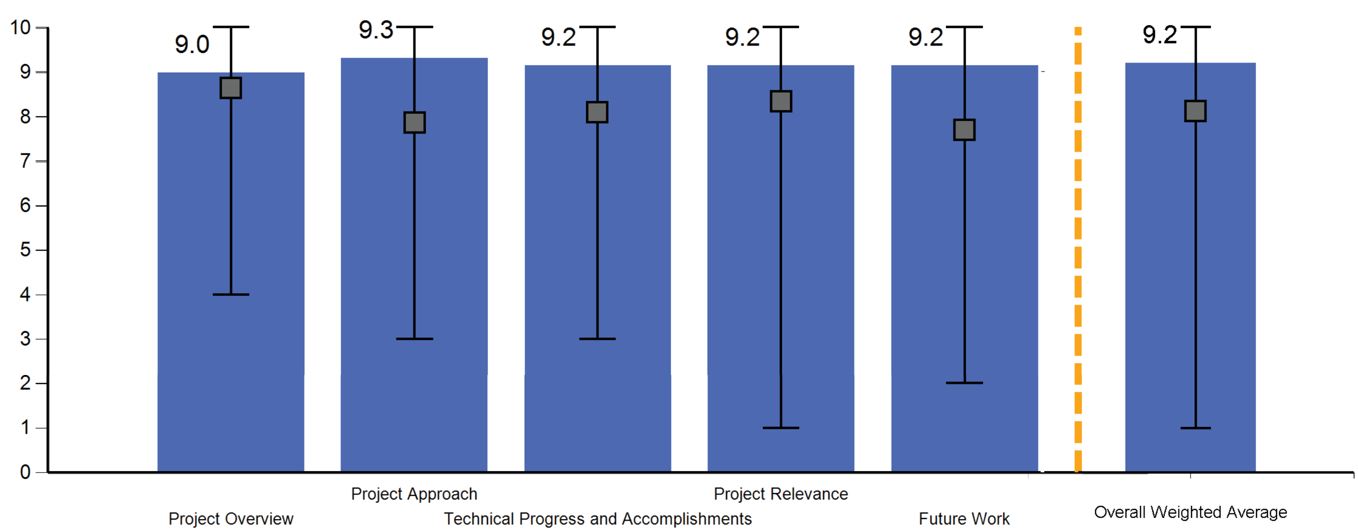
Recipient:	Haldor Topsoe
Presenter:	Rick Knight
DOE Funding FY14:	$4,383,353
DOE Funding FY13:	$11,191,577
DOE Funding FY10-12:	$9,230,762
Planned Funding:	$4,577,661
Project Dates:	12/28/2009 - 1/1/2015

Project Description

The purpose of this project is to validate the performance of a biorefinery producing drop-in gasoline blendstock from woody biomass. The process combines pressurized oxygen-blown fluidized-bed gasification from Andritz Carbona, syngas cleanup from Andritz Carbona and Haldor Topsoe, acid gas removal from GTI and Thyssen-Krupp, and TIGAS gasoline synthesis from Haldor Topsoe. The project team also includes UPM for biomass supply and Phillips 66 for product evaluation, engine testing, track testing, and EPA registration. This technology has the potential to convert available, sustainably sourced woody biomass into high-octane motor fuel that is fully compatible with existing vehicles and infrastructure. The biorefinery consumes no water,

Overall Project Score: 9.2

■ (blue)	This Project
■ (gray)	2015 Demonstration & Market Trans. Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

produces no wastes other than wood ash, and can reduce greenhouse gas impact by about 74% compared to conventional gasoline. Potential sites, including under-utilized pulp and paper facilities, could satisfy 24% of the 2022 targets of the Energy Independence and Security Act (EISA) for cellulosic biofuels. Preliminary economics show a production cost below $2.60 per gallon and attractive ROI prospects. The main challenge is to finance a capital-intensive biorefinery in light of petroleum price volatility. However, this project showed that a true drop-in gasoline can be produced reliably in substantial quantities from woody biomass using currently available technologies.

Overall Impressions

- In my opinion, this is the best project yet presented.
- This appears to be an excellent project in the DOE portfolio for evaluation of the issues surrounding biomass gasification and catalytic conversion to biofuels. The project was executed to accomplish the objectives of the project and was able to demonstrate the desired performance metrics.
- The project is an outstanding success and demonstrates exactly what BETO’s DMT platform should be doing to advance the state of the industry. The performance of the principal investigator and the sub-awardees on the project were exemplary and demonstrates superior project planning, project management, and project implementation. BETO should be commended for supporting the Haldor Topsoe project; it is an excellent example of sound project management and implementation on the part of both the performer and the BETO project officers.
- This is a very good project; it is typical of Haldor Topsoe projects.
- This is one of the better projects that this reviewer has seen. I wish all projects could be executed as well as this one has been.
- This was a well-executed project. It meets BETO's goal of drop-in biofuels. However, DOE’s share of the funding is surprisingly high considering the resources of the project partners. DOE needs to develop strategies to better leverage its funding with larger, established companies.

PI Response to Reviewer Comments:

- No official response was provided at time of report publication.

PILOT INTEGRATED CELLULOSIC BIOREFINERY OPERATIONS TO FUEL ETHANOL

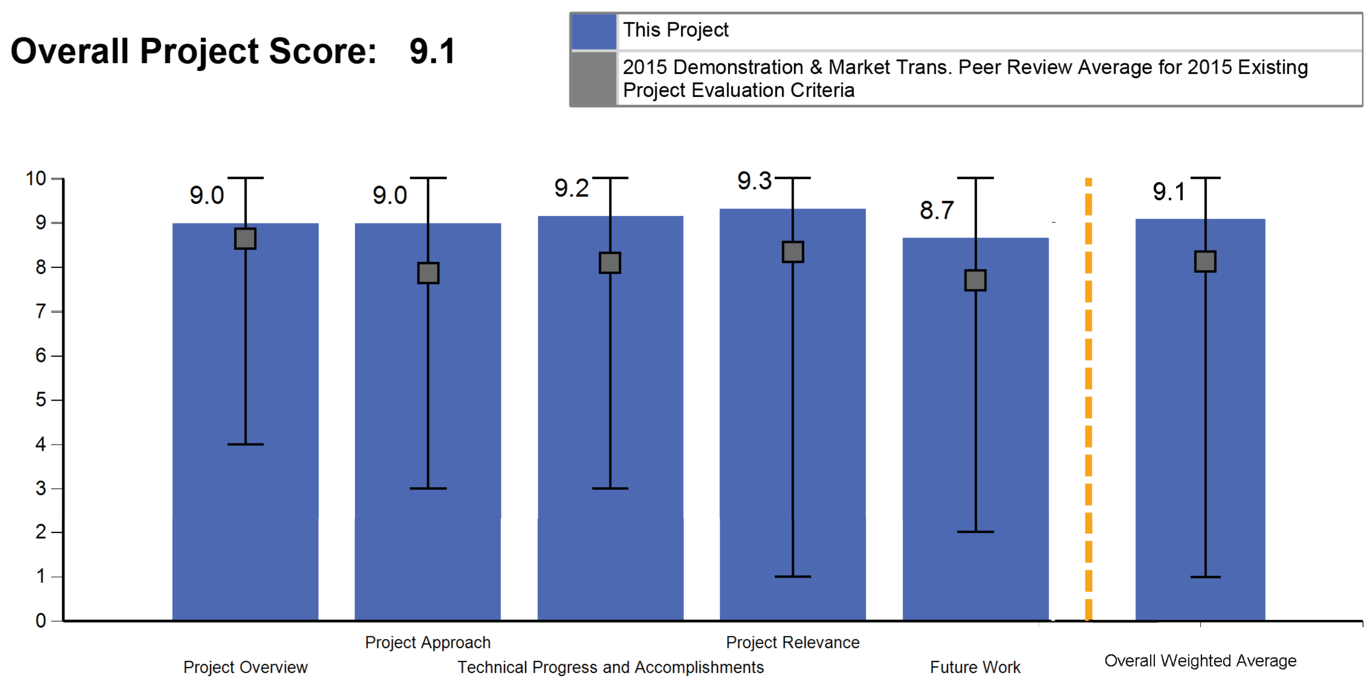
(WBS#: 3.4.1.8)

Recipient:	ICM, Inc.
Presenter:	Douglas Rivers
DOE Funding FY14:	$1,957,376
DOE Funding FY13:	$4,223,739
DOE Funding FY10-12:	$15,446,942
Planned Funding:	$3,468,117
Project Dates:	1/28/2010 - 8/31/2015

Photo Courtesy of ICM, Inc.

Project Description

ICM has modified its pre-existing grain pilot plant into a fully integrated cellulosic biorefinery capable of processing captive corn fiber, switchgrass, and energy sorghum. ICM uses an integrated biochemical platform that combines pretreatment, enzymatic hydrolysis technology, and robust C5/C6 co-fermentation to produce fuel ethanol and coproducts. Construction was completed in September 2011 and commissioning began. Pretreatment steps were modified to reduce fouling; facilitate proper level controls; pH and temperature control; and to adapt the Clean-in-Place (CIP) regimen to maintain proper operational conditions. Following adjustments to the process, ICM conducted a 1,200+ hours run during October-November 2012, using dry frac corn fiber. Later, ICM completed a run of 500+ hours using wet frac corn kernel fiber. Fermentations were run at 15,000-gal-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

lon and 585,000-gallon capacities, and proved an average increase in ethanol yield of about 10% per bushel. This scales to a potential additional 1.3-1.4 billion gallons of cellulosic ethanol for the existing U.S. ethanol industry. CAPEX is estimated at $2-$3/installed gallon of added production capacity. Subsequently, ICM has prepared to conduct two 1,000-hour campaigns using switchgrass and energy sorghum as feedstocks. The project has encountered multiple feedstock material handling challenges. After an extended time, the project team believes these challenges were solved and is currently in the midst of the switchgrass campaign.

Overall Impressions

- The project was well done. The commercial-scale demonstration is very impressive.
- This is a good project in the DOE portfolio. The work they have done has helped advance this technology path and provide understanding to the DOE. The project team appears to be capable of executing projects and addressing early operation issues.
- The ICM project is another outstanding success and demonstrates exactly what BETO's DMT platform should be doing to advance the state of the industry. The performance of the principal investigator and the sub-awardees on the project were exemplary and demonstrates superior project planning, project management, and project implementation. BETO should be commended for supporting the ICM project. This project is an excellent example of sound project management and implementation on the part of both the performer and the BETO project officers.
- This was a good demonstration of the challenges encountered in scale-up and the work needed to address them.
- There is a lot to like with this project: laboratory, engineering, construction, and operations were all conducted well. The project results indicate believable improvements were made and significant yield data was presented.
- Very successful project and serves as a case study for how to do things right.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

BEI - MYRIANT SUCCINIC ACID BIOREFINERY (MYSAB)

(WBS#: 3.4.2.1)

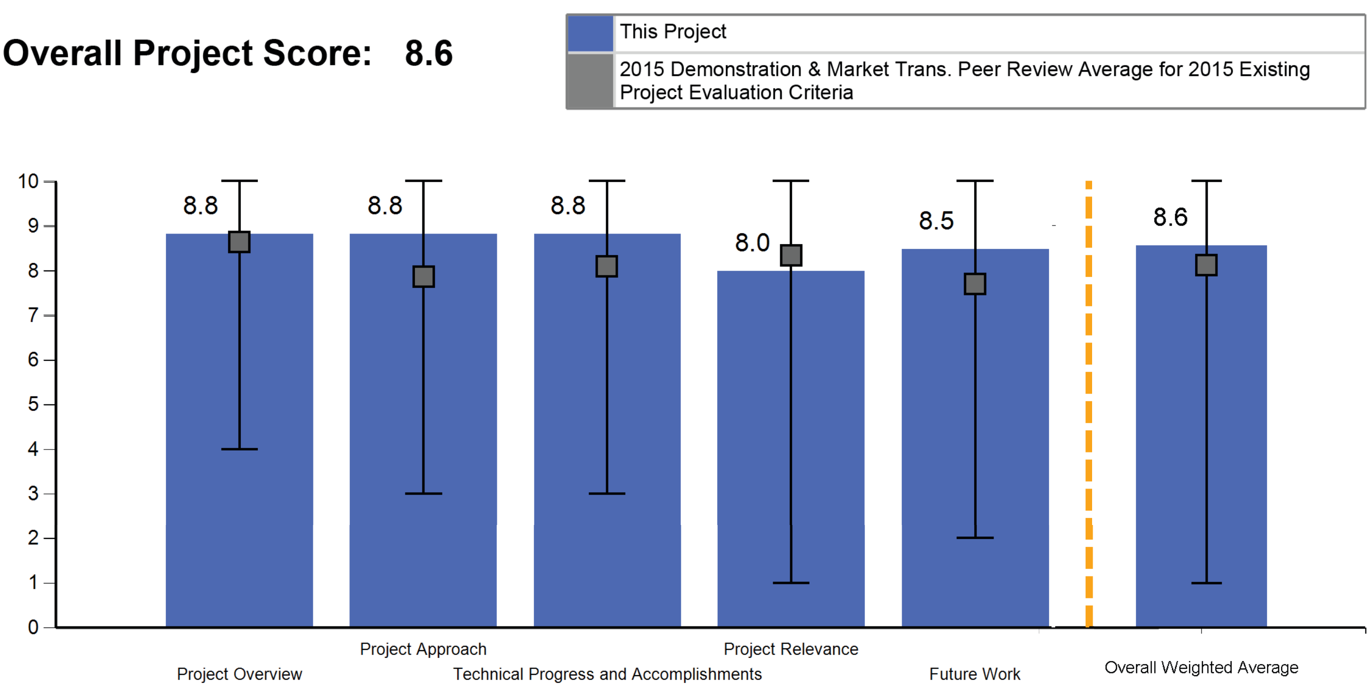
Photo Courtesy of Myriant

Recipient:	Myriant
Presenter:	Mark Shmorhun
DOE Funding FY14:	$0
DOE Funding FY13:	$12,291,887
DOE Funding FY10-12:	$37,210,358
Planned Funding:	$497,756
Project Dates:	1/28/2010 - 9/30/2015

Project Description

Myriant Succinic Acid Biorefinery (MySAB), located in Lake Providence, Louisiana, is a bio-succinic acid production facility with a name plate capacity of 30 million pounds per year. MySAB is a multi-feedstock facility built to process a variety of renewable feedstocks, including sugars derived from grain sorghum and other commercially available sugars. Myriant displaces petroleum-derived chemicals by making the equivalent replacement chemicals from renewable feedstocks with no green premium, and with reduced environmental impact. The bio-based succinic acid reduces lifecycle greenhouse gas emissions by 94% compared to petroleum-based succinic acid. Recent project accomplishments include the production of succinic acid from 95 DE, the shipment of product to customers, and the validation of ten-fold fermentation scale-up. In 2015, the project plans to run a 10-day performance test on sugars derived from sorghum grits.

Overall Project Score: 8.6



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- To meet the BETO goals, the project must employ cellulosic sugar.
- This project was well executed and it was able to build and operate a facility to convert sugars to succinic acid, exceeding its product quality specifications. A performance test is to be performed this year to quantify its technical performance. At this time, the project does not see a commercial pathway for using lignocellulic sugars.
- The Myriant project is an outstanding success and demonstrates exactly what BETO's DMT platform should be doing to advance the state of the industry. The performance of the principal investigator and the sub-awardees on the project were exemplary and demonstrates superior project planning, project management, and project implementation. BETO should be commended for supporting the Myriant project. This is an excellent example of sound project management and implementation on the part of both the performer and the BETO project officers.
- The project is a diligent and professional effort, working through construction issues to successfully demonstrate viability of bio-based chemicals.
- This is a very well executed project. The questions include: What consequence does green chemistry have in the markets for bio-based succinic acid: "Reduces lifecycle GHG emissions by 94% compared to petro-based succinic acid?" What drives customer purchasing decisions? Price only? Cost? Purity? Green chemistry?
- This is an excellent project. DOE funding is well spent.

PI Response to Reviewer Comments:

- No official response was provided at time of report publication.

INP BIOENERGY INDIAN RIVER COUNTY FACILITY

(WBS#: 3.4.2.3)

Photo Courtesy of INP Bioenergy, LLC

Recipient:	INEOS New Planet (INP) Bioenergy, LLC
Presenter:	Kelly Russell
DOE Funding FY14:	$2,760,721
DOE Funding FY13:	$2,087,212
DOE Funding FY10-12:	$45,152,066
Planned Funding:	$188,006
Project Dates:	12/28/2009 - 12/31/2014

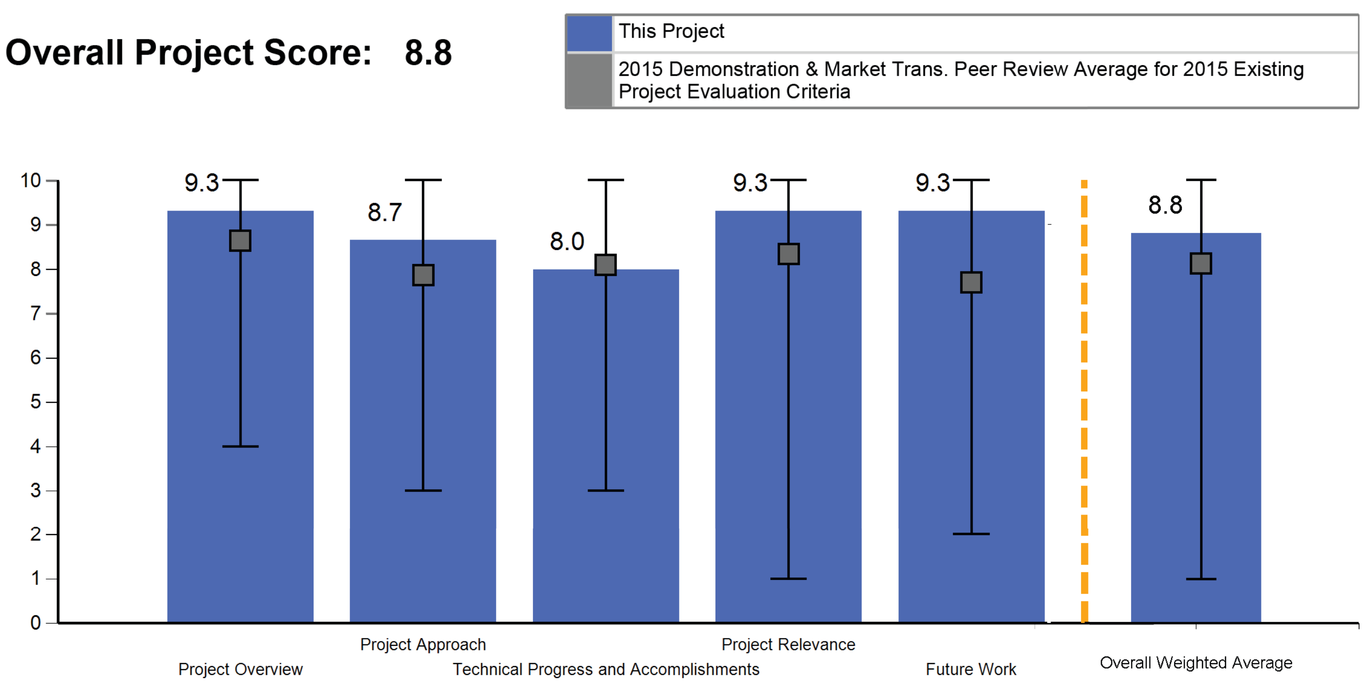
Project Description

INP BioEnergy has completed construction and commissioning and is now starting operations of the first commercial-scale facility employing the INEOS Bio bioenergy process technology on a site in Indian River County, Florida ("Indian River BioEnergy Center"). Running at full capacity, the facility will produce 8 million gallons/year of cellulosic ethanol and 6 MW (gross) of electricity at full rates. The project is demonstrating key equipment at full commercial scale, using vegetative, yard and wood wastes as initial feedstocks and post-recycled municipal solid waste as a feedstock. Learning from the demonstration will be incorporated into the design, construction, operation, and rapid deployment of future projects by INEOS Bio and its licensees. INP BioEnergy has constructed the facility on a 70-acre site located 1 mile from I-95 and adjacent to the Indian River County solid waste landfill.

Overall Impressions

- This is a good project for the DOE portfolio. This project has an excellent economic advantage where

Overall Project Score: 8.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

they are paid to take feedstock from a mature collection-and-delivery system. The long period from construction completion in 2012 and until now in 2015, where the plant is running again, is not unheard of when using new complex technology. However, this three-year period is on the extended side.

- The INEOS project is an outstanding success and demonstrates exactly what BETO's DMT platform should be doing to advance the state of the industry. The performance of the principal investigator and the sub-awardees on the project were exemplary and demonstrates superior project planning, project management, and project implementation. BETO should be commended for supporting the INEOS project. This project is an excellent example of sound project management and implementation on the part of both the performer and the BETO project officers.
- This is a well-executed project. Some technical information in the presentation was omitted and the process description was sketchy. I'm glad to see that some safety-related project performance figures were included in the presentation. The discovery of catalyst poison (HCN) was an unwelcome surprise, but the project team figured out a solution and implemented it in a reasonable time frame.
- This is an outstanding, well-managed project and innovative application of an existing technology. DOE's share of the project costs represents effective leveraging of government funds.

PI Response to Reviewer Comments:

- No official response was provided at time of report publication.

INTEGRATED BIOREFINERY FOR CONVERSION OF BIOMASS TO ETHANOL, SYNTHESIS GAS, AND HEAT

(WBS#: 3.4.3.2)

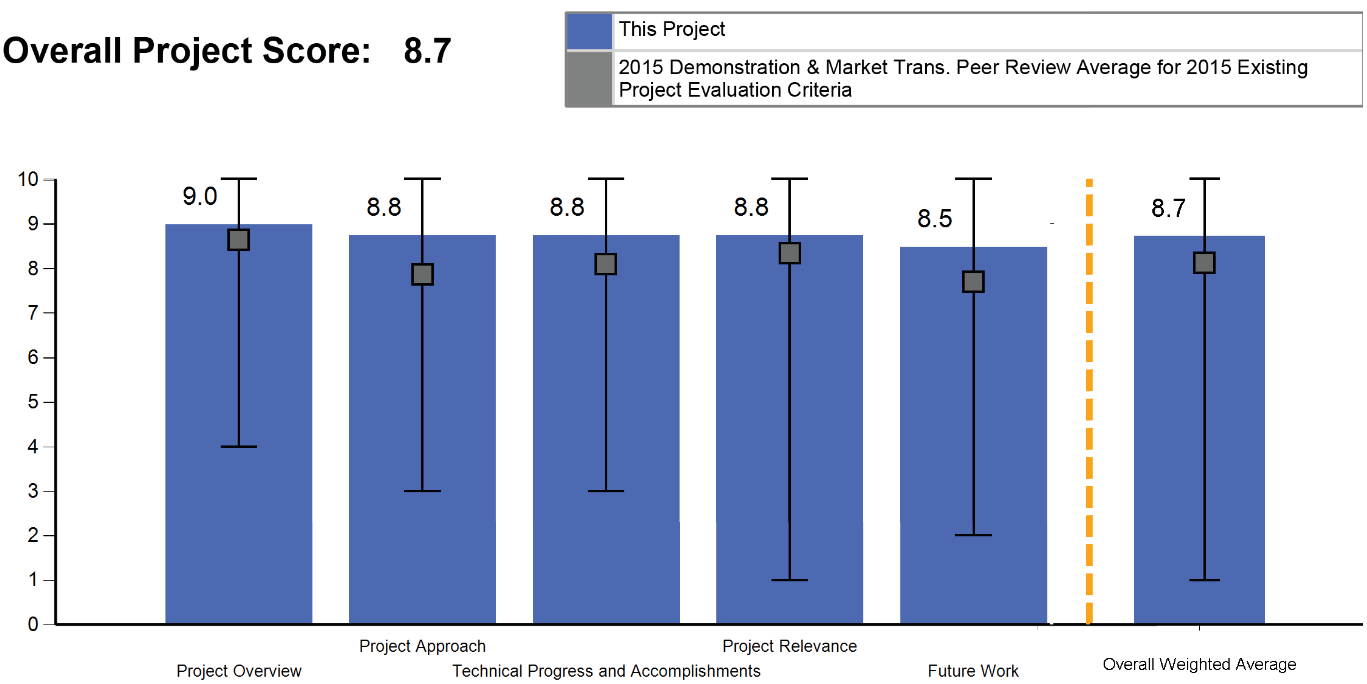
Photo Courtesy of Abengoa

Recipient:	Abengoa
Presenter:	Joseph Bradford
DOE Funding FY14:	$0
DOE Funding FY13:	$52,449,377
DOE Funding FY10-12:	$69,620,972
Planned Funding:	$2,000,000
Project Dates:	10/1/2007 - 12/31/2014

Project Description

Abengoa Bioenergy Biomass of Kansas, LLC, is currently performing final commissioning on a biorefinery facility to produce cellulosic ethanol in Hugoton, Kansas. The process utilizes an enzymatic hydrolysis process to produce ethanol, process steam, and all electrical power required to operate the facility via an integrated biorefinery and cogeneration system. Initial feedstocks that will be used are corn stover, wheat straw, and other warm season grasses. Use of multiple feedstocks will contribute to operational flexibility and will make the plant easily replicable in different geographical areas. The total biomass input for the facility will be 1,100 dry tons/day, resulting in 25 million gallons/year of ethanol production. The cogeneration system will use the ethanol process byproducts, including stillage, cake/

Overall Project Score: 8.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

syrup, biogas and sludge resulting in no planned landfill. With the facility producing all of the biomass-generated site power, plus supply remaining amounts to the grid, a high level of greenhouse gas reduction is achieved. The cogeneration plant was placed in service in late 2013 with commencement of ethanol facility commissioning beginning in the third quarter of 2014.

Overall Impressions

- This is an excellent project for the DOE portfolio. This project should allow DOE, and the industry, to benchmark the economics around this technology. This project is working through start-up issues to be able to produce commercial quantities of fuel. The water treatment technology was tested off-site and not part of integrated testing. It would not be uncommon for an extended learning curve on operating the system.
- The project demonstrates good engineering, procurement, and construction work; it needs to demonstrate operations next.
- This project is an excellent use of DOE funds. It is well executed and the focus on safety is a plus.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

LIBERTY—LAUNCH OF AN INTEGRATED BIOREFINERY WITH ECO-SUSTAINABLE AND RENEWABLE TECHNOLOGIES IN FY 2009

(WBS#: 3.4.3.3)

Recipient:	POET Project Liberty, LLC
Presenter:	Larry Ward
DOE Funding FY14:	$50,728,283
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$2,334,570
Project Dates:	10/1/2008 - 12/31/2017

Photo Courtesy of Poet Project Liberty, LLC

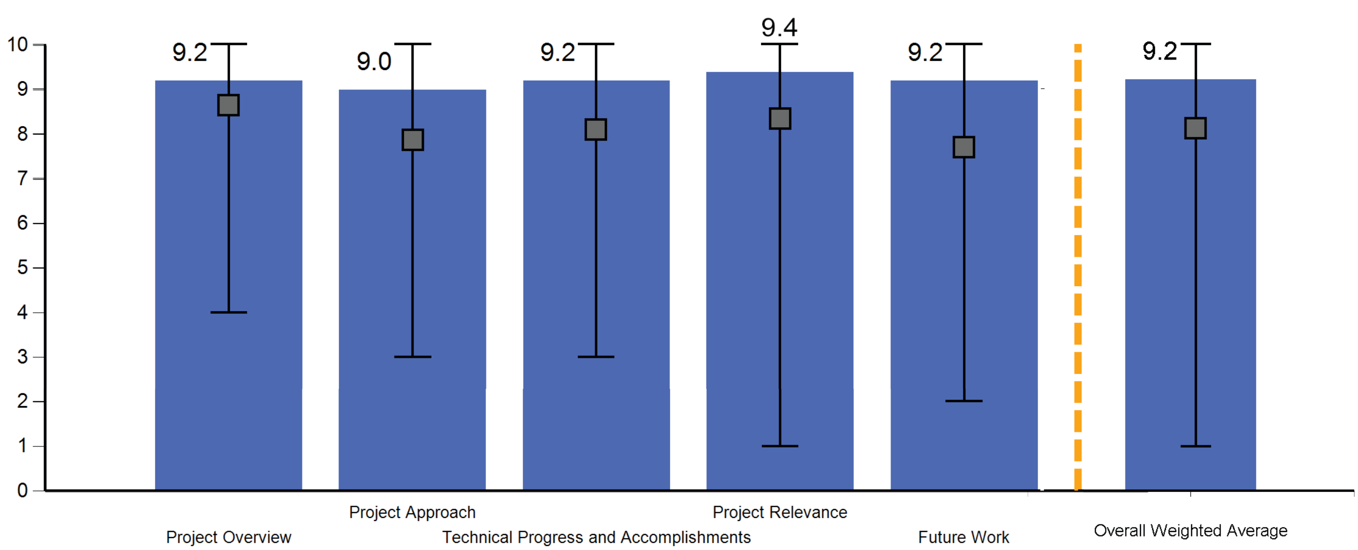
Project Description

Project LIBERTY is dedicated to the development and operation of a commercial-scale cellulosic ethanol biorefinery. The plant is co-located with POET Biorefining-Emmetsburg, an existing corn-based ethanol biorefinery in Emmetsburg, Iowa. The corn-based biorefinery currently has a name-plate capacity of 50 million gallons/year and is one of 27 POET biorefineries. At full capacity, Project LIBERTY will produce an additional 25 million gallons/year of ethanol from a feedstock of lignocellulosic material, i.e., corn cobs and high-cut material from the corn plant. Corn farmers from the surrounding area supply the feedstock to the biorefinery. The Project LIBERTY business model will enable rapid deployment of the cellulosic ethanol process across an expansive corn ethanol industry. The rollout of LIBERTY technologies will help the nation rapidly advance toward its biofuels mandates, as well as reduce its dependence on foreign oil.

Overall Project Score: 9.2

This Project

2015 Demonstration & Market Trans. Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- Well done POET-DSM!
- This is an excellent project for the DOE portfolio. There is high potential for this project to have a significant impact on the development of advanced biofuels. The start-up challenges are not unusual and generally around materials handling, separations, and biological performance.
- The POET project is an outstanding success and demonstrates exactly what BETO's DMT platform should be doing to advance the state of the industry. The performance of the principal investigator and the sub-awardees on the project were exemplary and demonstrates superior project planning, project management, and project implementation. BETO should be commended for supporting the POET project. This project is an excellent example of sound project management and implementation on the part of both the performer and the BETO project officers.
- As in 2013, the project continues to demonstrate the value of having an experienced operator/developer, with other sources of cash flow, and managing the project.
- This is an excellent example of a well-planned and executed project. The feed supply chain work is particularly impressive. I would like to see more reporting of safety indexes during construction.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

INCREASING BIOFUEL DEPLOYMENT AND UTILIZATION THROUGH DEVELOPMENT OF RENEWABLE SUPER PREMIUM

(WBS#: 3.5.1.1)

Recipient:	NREL
Presenter:	Bob McCormick
DOE Funding FY14:	$804,957
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$945,043
Project Dates:	10/1/2013 - 12/31/2015

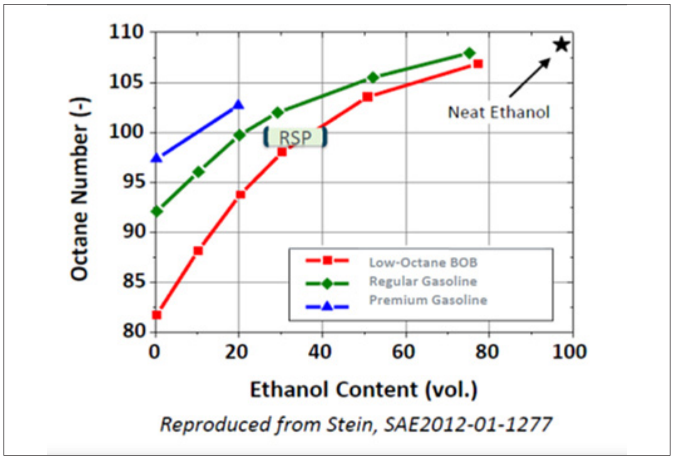
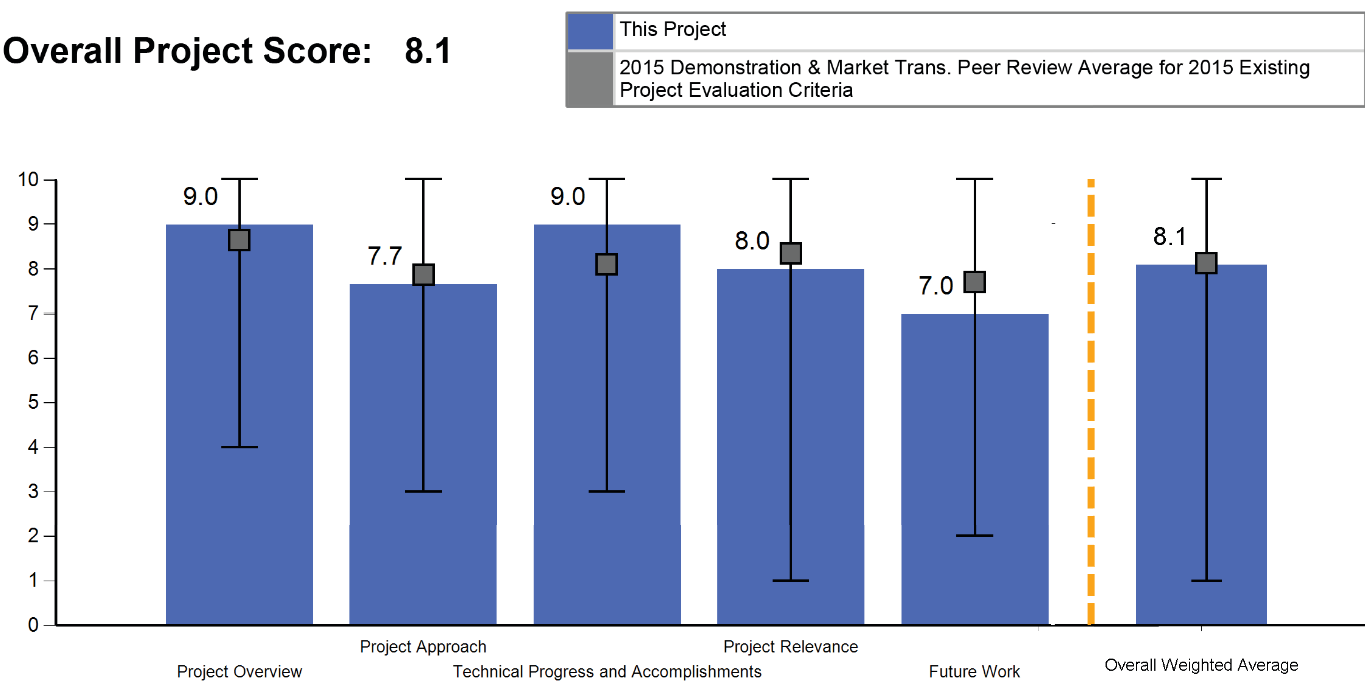


Image Courtesy of NREL

Project Description

Renewable Super Premium (RSP) fuel can create additional demand for large amounts of ethanol (move past the blend wall) and improve fuel economy in dedicated vehicles (supports biofuels and automobile industries). This project is a "scoping study" to address barriers, quantify benefits and determine if additional R&D is warranted. Research in FY14 and FY15 showed significant potential to create a new market for cellulosic ethanol via utilization of E25 to E40 blends that enable a new class of highly efficient engines. Barriers to development of this market were revealed. Tradeoffs between ethanol blend level, efficiency/GHG emissions, regulatory requirements, infrastructure cost, fuel availability, vehicle adoption, fuel prices, and the inertia that exists in the full biomass-to-biofuels supply chain are not well understood, but some of the interactions and limitations

Overall Project Score: 8.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

have been quantified. Research has been conducted in the following areas: (1) knock-resistance of ethanol blends; (2) low-cost blendstocks; (3) assessment of the ability of terminals and blenders to accommodate E25+; and (4) the influence of fuel retail infrastructure to the acceptance and distribution of RSP.

Overall Impressions

- The high-octane fuel/renewable super-premium (HOF/RSP) project, being conducted by the associated national laboratories of ORNL, NREL, and ANL, is a meritorious and potentially invaluable area of work. This effort seeks the long-term goal of combining engine design optimization with renewable fuel formulation to optimize biofuel utilization, vehicle performance, and economy for the consumer and convenience stores. This is the type of research and development DOE should be pursuing to facilitate the achievement of CAFE goals and implementation of biofuel supply chain utilization via consumer choice related to the market competition of fuels and vehicles.
- The legacy-vehicle testing conducted by ORNL, the engine/fuel optimization testing/modeling and infrastructure market assessment done by NREL, and the well-to-wheels (WTW) GHG modeling performed by ANL, are all outstanding examples of the technical expertise and capabilities available within the national laboratory system and a perfect example of the synergies and collaborative potential within the DOE system that BETO is leveraging successfully with projects like this.
- The project performers have definitely and definitively considered the importance of the potential applications of their expected outputs in the long term for engine design optimization in tandem with renewable fuel formulation to increase fuel economy, vehicle performance, and the economics of choice and competition in the marketplace for biofuels and vehicles by the consumer and convenience store operators.
- This three-part presentation contains reams of information and data, and requires some time and thought to sort it all out. Given the apparent reluctance to change fueling attitudes when driven solely by a “clean air” appeal, it becomes vital to show very clear and repeatable benefits to the individual customer, i.e., “What’s in it for me?” An agency PUSH for a new fuel and a new vehicle to burn it might result in slow or negligible market introduction, while a customer demand PULL, based on improved vehicle performance, for both new and legacy vehicles, might be more palatable to the public.
- The presentations by ANL, NREL and ORNL regarding the potential of developing a super-premium gasoline were all tightly related and, therefore, I rated them as a single project. This very promising line of research has identified a potential method to increase ethanol production incentives and decrease GHG emissions.

PI Response to Reviewer Comments

- Please see response to WBS# 3.5.1.3.

INCREASING BIOFUEL DEPLOYMENT AND UTILIZATION THROUGH DEVELOPMENT OF RENEWABLE SUPER PREMIUM

(WBS#: 3.5.1.2)

Recipient:	ANL
Presenter:	Michael Wang
DOE Funding FY14:	$153,481
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$1,296,519
Project Dates:	10/1/2013 - 12/31/2015

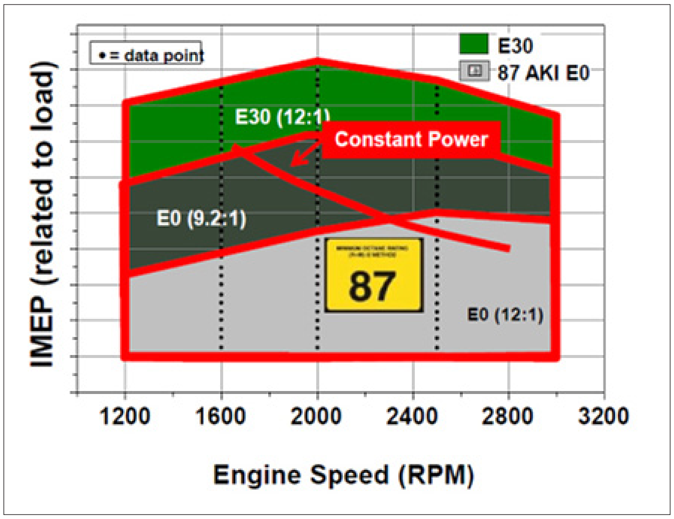
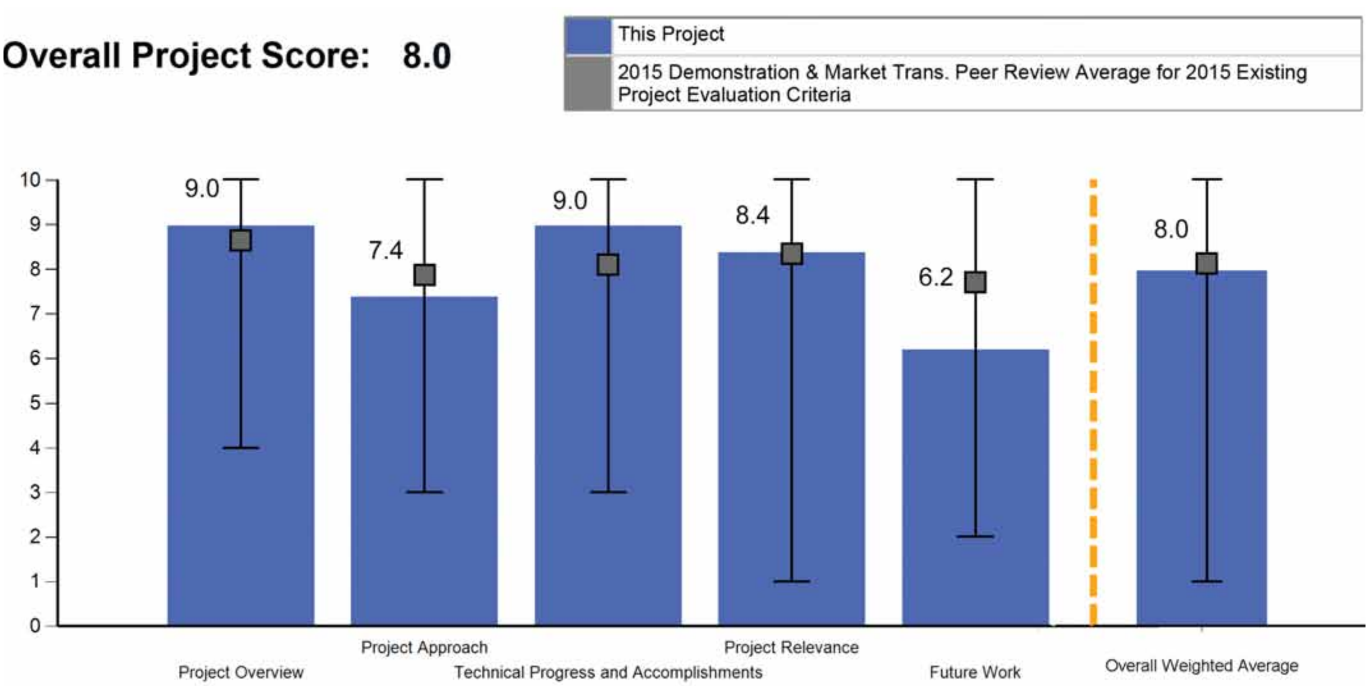


Image Courtesy of ANL

Project Description

High-octane fuels (HOFs) [e.g., Research Octane Number (RON) of 100] can increase vehicle efficiency, while producing them at refineries may result in efficiency penalties. On a well-to-wheels (WTW) basis, it has been questioned if HOFs together with vehicles have net GHG emissions benefits. This study aims to evaluate the WTW GHG emissions impacts of HOFs with RON 100 with various ethanol blending levels (E10, E25, and E40), which depend largely on refinery operation changes to produce HOFs, GHG emissions associated with ethanol production, and efficiency gains by HOF vehicles (HOFVs). The refining operation changes are examined with detailed linear program modeling of various refinery configurations and HOF market pene-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

tration scenarios (3.4% to 70%). Based on results from other studies, a miles-per-gallon-gasoline-equivalent (MPGGE) fuel economy gain of 5% for HOFVs relative to the baseline E10 gasoline vehicles was examined, with a sensitivity case of 10% MPGGE gain for E40 blends (volumetric fuel economy parity). These factors were incorporated into the GREET model to compare the WTW GHG emissions of HOFs with the baseline gasoline (E10) pathway. While the MPGGE gains reduce GHG emissions for HOFVs, additional benefits are achieved by higher ethanol blending. With 5% fuel economy gain and corn stover ethanol for blending, WTW GHG reductions of E25 and E40 HOFVs—relative to the baseline E10 gasoline vehicles—are up to 17% and 28%, respectively.

Overall Impressions

- The project needs to implement earned value management to monitor progress versus expenditures.
- The high-octane fuel/renewable super-premium (HOF/RSP) project, being conducted by the associated national laboratories of ORNL, NREL, and ANL, is a meritorious and potentially invaluable area of work. This effort seeks the long-term goal of combining engine design optimization with renewable fuel formulation to optimize biofuel utilization, vehicle performance, and economy for the consumer and convenience stores. This is the type of research and development DOE should be pursuing to facilitate the achievement of CAFE goals and implementation of biofuel supply chain utilization via consumer choice related to the market competition of fuels and vehicles.
- The legacy-vehicle testing conducted by ORNL, the engine/fuel optimization testing/modeling and infrastructure market assessment done by NREL, and the WTW GHG modeling performed by ANL are all outstanding examples of the technical expertise and capabilities available within the national laboratory system and a perfect example of the synergies and collaborative potential within the DOE system that BETO is leveraging successfully with projects like this.
- The project performers have definitely and definitively considered the importance of the potential applications of their expected outputs in the long term for engine design optimization in tandem with renewable fuel formulation to increase fuel economy, vehicle performance, and the economics of choice and competition in the marketplace for biofuels and vehicles by the consumer and convenience store operators.
- This is a very good technical work. As usual, regulatory, industry and public acceptance will be the bigger hurdles.
- This three-part presentation contains reams of information and data, and requires some time and thought to sort it all out. Given the apparent reluctance to change fueling attitudes when driven solely by a "clean air" appeal, it becomes vital to show very clear and repeatable benefits to the individual customer, i.e., "What's in it for me?" An agency PUSH for a new fuel and a new vehicle to burn it might result in slow or negligible market introduction, while a customer demand PULL, based on improved vehicle performance, for both new and legacy vehicles, might be more palatable to the public.
- The presentations by ANL, NREL, and ORNL regarding the potential of developing a super-premium gasoline were all tightly related and, therefore, I rated them as a single project. This very promising line of research has identified a potential method to increase ethanol production incentives and decreases GHG emissions.

PI Response to Reviewer Comments

- Please see response to WBS# 3.5.1.3.

INCREASING BIOFUEL DEPLOYMENT AND UTILIZATION THROUGH DEVELOPMENT OF RENEWABLE SUPER PREMIUM

(WBS#: 3.5.1.3)

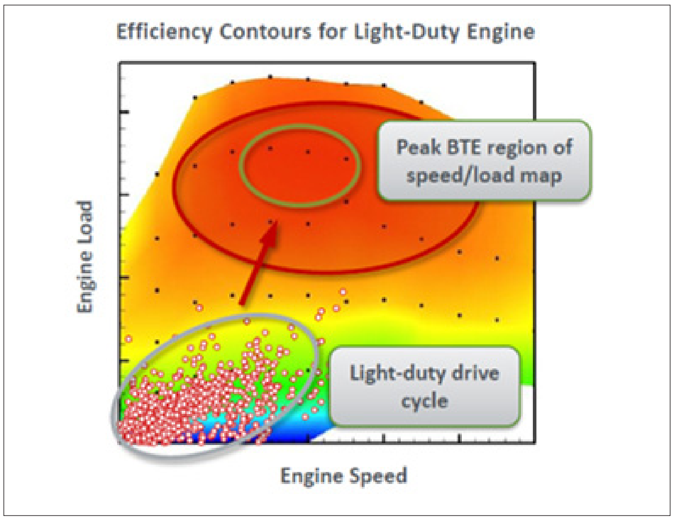
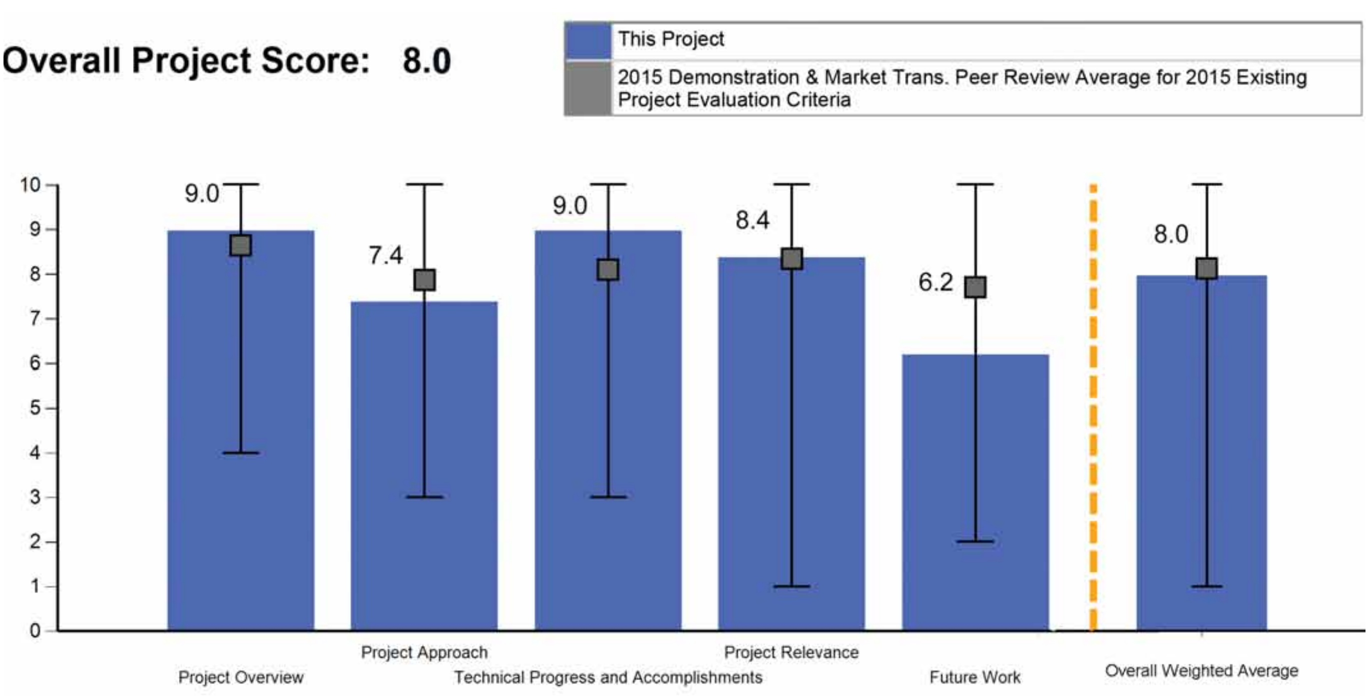


Image Courtesy of ORNL

Recipient:	ORNL
Presenter:	Tim Theiss
DOE Funding FY14:	$1,638,785
DOE Funding FY13:	$11,145
DOE Funding FY10-12:	$0
Planned Funding:	$3,731,747
Project Dates:	10/1/2013 - 12/31/2015

Project Description

Recent studies from DOE laboratories and auto makers suggest the high potential of a new high-octane fuel with 25-40 volume % of ethanol, termed Renewable Super Premium (RSP), to increase ethanol demand and lower greenhouse gas emissions. This mid-level ethanol content fuel, with a RON of near 100, appears to enable efficiency improvements in a suitably calibrated dedicated vehicle system that can possibly offset its lower energy density. There are numerous challenges to realizing this vision, as well as questions about whether such a fuel would lead to favorable fuel economy and lower GHG emissions on a life-cycle basis. The purpose of this project is to evaluate this potential opportunity



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

and assess the likelihood that RSP will be successful in the marketplace in the near- to medium-term through the following tasks: (1) quantify the efficiency and GHG benefits of dedicated RSP vehicles; (2) conduct a well-to-wheel analysis of the tradeoffs between improvements in tailpipe CO_2 emissions versus GHG emissions generated in fuel production and distribution; (3) determine the state of the legacy refueling infrastructure and compatibility with RSP; (4) examine the properties of ethanol blends with low-cost blendstocks; (5) assess whether the knock resistance of ethanol blends is adequately represented by existing octane specifications; (6) assess market barriers to the introduction and successful use of RSP; and (7) investigate the performance benefits of RSP in legacy flexible fuel vehicles (FFVs).

Overall Impressions

- A very impressive amount was accomplished by this group. Good work.
- This project is a very good addition to the DOE portfolio. The team's presentation did a very good job presenting their technical achievements, but has not demonstrated an understanding, or use of standard project management tools.
- The high-octane fuel/renewable super-premium (HOF/RSP) project, being conducted by the associated national laboratories of ORNL, NREL, and ANL, is a meritorious and potentially invaluable area of work. This effort seeks the long-term goal of combining engine design optimization with renewable fuel formulation to optimize biofuel utilization, vehicle performance and economy for the consumer and convenience stores. This is the type of research and development DOE should be pursuing to facilitate the achievement of CAFE goals and implementation of biofuel supply chain utilization via consumer choice related to the market competition of fuels and vehicles.
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- The project performers have definitely and definitively considered the importance of the potential applications of their expected outputs in the long term for engine design optimization in tandem with renewable fuel formulation to increase fuel economy, vehicle performance and the economics of choice and competition in the marketplace for biofuels and vehicles by the consumer and convenience store operators.
- This three-part presentation contains reams of information and data, and requires some time and thought to sort it all out. Given the apparent reluctance to change fueling attitudes when driven solely by a "clean air" appeal, it becomes vital to show very clear and repeatable benefits to the individual customer, i.e., "What's in it for me?" An agency PUSH for a new fuel and a new vehicle to burn it might result in slow or negligible market introduction, while a customer demand PULL, based on improved vehicle performance, for both new and legacy vehicles, might be more palatable to the public.
- The presentations by ANL, NREL, and ORNL regarding the potential of developing a super-premium gasoline were all tightly related and, therefore, I rated them as a single project. This very promising line of research has identified a potential method to increase ethanol production incentives and decreases GHG emissions.

PI Response to Reviewer Comments

- We appreciate the reviewers' inputs and positive comments about the project, its importance and the work completed thus far. We are particularly pleased that our view of the importance and potential of this fuel was conveyed. We are actively working to quantify the benefits to the consumer to encourage the use of this fuel and will provide much more information in an upcoming market analysis report.
- We have used appropriate project management tools and are tracking cost and performance metrics throughout. Because of the nature of this project, which includes individual tasks with each of the three laboratories, we have developed procedures to coordinate among tasks and among labs, including data and input/output exchanges from one task or lab to another. We also have procedures in place to review outputs from one task or lab by others. Further, we have monthly conference calls among ourselves and with BETO sponsors. Each laboratory is responsible for tracking its own budget and reporting the information to the sponsor. We coordinate milestones and deliverables among tasks and laboratories on a quarterly basis. We have regular interactions within each group, monthly calls among the team members and with the sponsor. We are deliberately maintaining a flexible management structure to expedite decision-making and making minor changes to the overall plan, as needed, based on the results from each task. We are working to provide as much high-quality technical information as possible in a short time frame to allow for informed decision-making. We acknowledge that we did not focus on the project management aspects during our presentation.

BNL BIO-OIL DEPLOYMENT IN THE HOME HEATING MARKET

(WBS#: 5.3.0.1)

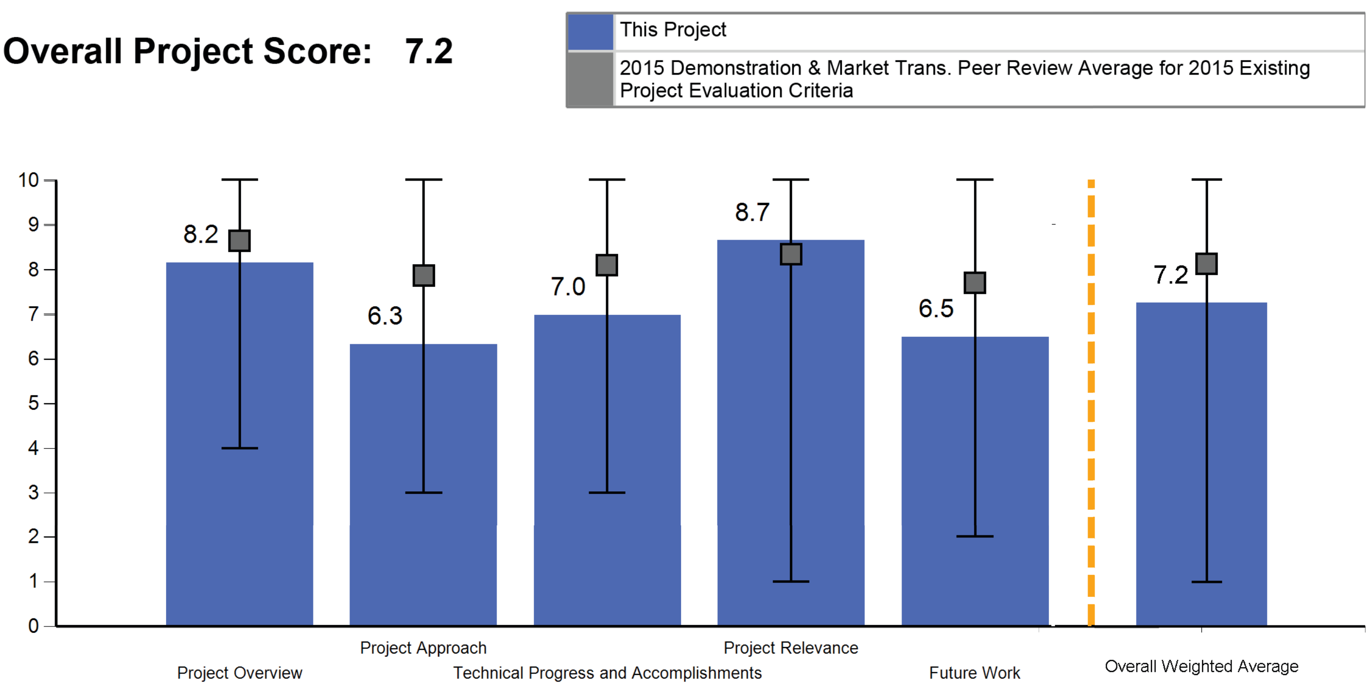
Photo Courtesy of BNL

Recipient:	BNL
Presenter:	Thomas Butcher
DOE Funding FY14:	$225,805
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$349,195
Project Dates:	10/1/2014 - 9/30/2015

Project Description

The heating oil market represents a potential early market entry point for emerging, near-commercial, upgraded bio-oils. The work for this project is focused on identifying commercial projects which may provide fuels for this market and provide technical evaluation of the use of these fuels in heating oil blends. The heating oil market includes residential and commercial buildings, mostly in the Northeast. With an estimated annual fuel consumption of 7.2 billion gallons, this market is of significant size. Relative to the transportation diesel market, the heating market includes simpler, lower-cost end-use technology; longer-term storage but at predictable temperatures; and a mixed-mode regional supply chain. The target in this effort is fuels that are fully compatible with the entire supply, distribution, and end-use system and not fuels that require major equipment changes or unique production/end-use arrangements. Work includes evaluation of fuel properties relative to this application, consideration of specifications for bio-fuels which can be used in this application, small-scale combustion and

Overall Project Score: 7.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

compatibility tests, and longer-term demonstration of the use of a selected fuel in a typical system configuration. Tests have been done to date with two candidate fuels, one of which shows outstanding promise to meet the project goals. Combustion testing shows similar ignition and flame stability characteristics and similar or better air pollutant emissions.

Overall Impressions

- The funding is not enough to cover the wide range of objectives of this project.
- This project is trying to accomplish a lot for the amount of funding it has received. This is a good start in helping the industry understand the issues and needs. I believe the development of a project management plan (to the level appropriate for this type project) would be a very useful tool to direct and measure their efforts.
- This project demonstrates the fact that BETO recognizes the value of the bio-heat market and it is commendable that BETO has started investing in this 7-billion gallon/year market that has no air pollution reduction requirements. BETO should facilitate the development of specifications and infrastructure to implement the use of biofuels broadly throughout the residential heating market. There are also a number of institutional, commercial, and industrial buildings that use heating oil as well. The participation of National Oilheat Research Alliance (NORA) is a significant attribute of the project and demonstrates the importance of including industry associations in consortia.
- It is commendable that in identifying the challenges encountered during the performance of the work, the project performer has successfully identified challenges and market hurdles in areas where they failed to achieve the anticipated targets. This should motivate BETO to encourage and support future work that would accelerate penetrating the heating oil market and establishing the specifications that will be required to address and penetrate the existing industry supply chain.
- This reviewer finds the project very significant as it truly addresses and will accelerate market transformation. The results also indicate the availability and pertinence of simplified upgrading technologies/processes that are less stringent and more easily achievable than those that must be met in the transportation market. This project makes it clear the home heating oil market is a more readily accessible and an early market entry point that BETO should be addressing to accelerate and facilitate market penetration in the transportation sector.
- Good technical work. The main limit appears to be the availability and regulatory/industry acceptance.
- Overall, this is a promising new area for BETO investigation, because it represents a biofuel use area beyond the more traditional transportation fuels market segment. Much good work has been conducted to date, but many relevant additional research and development topics remain to be investigated. Significant concerns relate to progress vs. project timeline.
- This project is important to enabling broad acceptance of bio heating oil. It is disappointing that the scope was limited by reluctance of suppliers to provide samples. BETO should consider seed money for projects of this type to enable scoping of the interest in providing samples before proceeding with the full study.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

INTEGRATED PILOT-SCALE BIOREFINERY FOR PRODUCING ETHANOL FROM HYBRID ALGAE

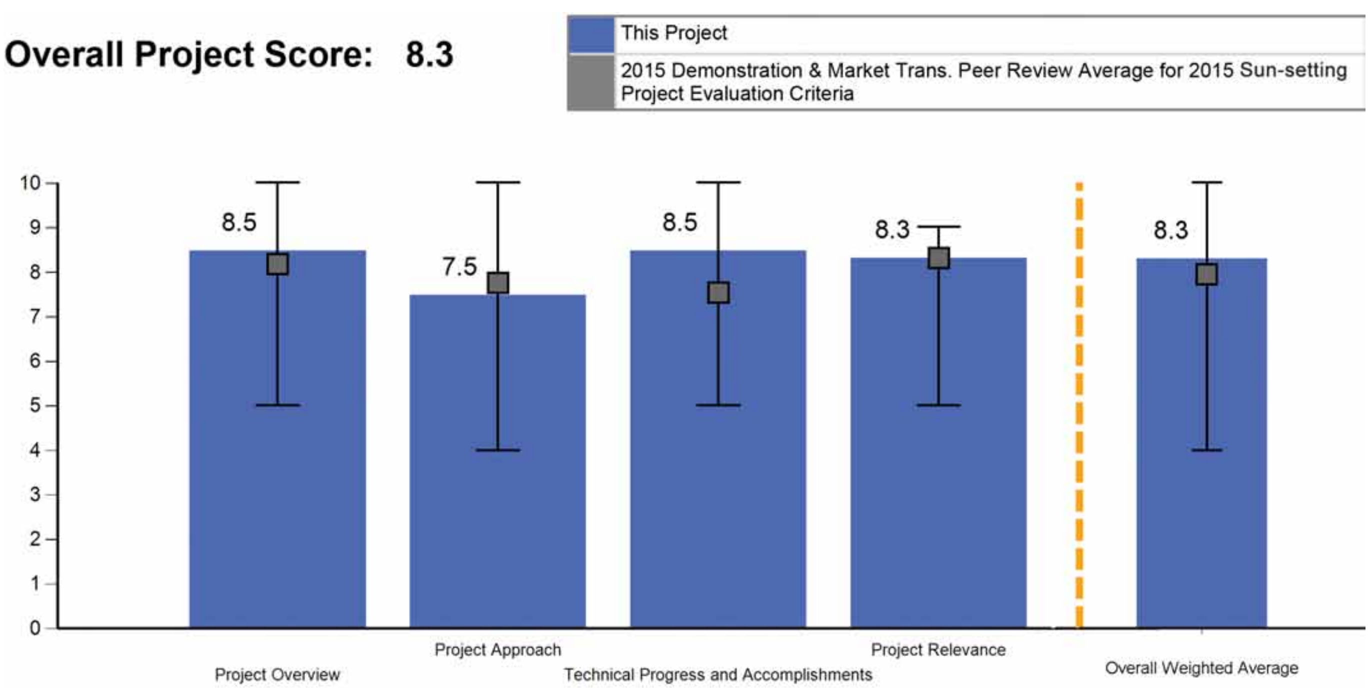
(WBS#: 3.3.2.3)

Recipient:	Algenol Biofuels, Inc.
Presenter:	Ed Legere
DOE Funding FY14:	$0
DOE Funding FY13:	$1,595,195
DOE Funding FY10-12:	$22,486,236
Planned Funding:	$250,000
Project Dates:	1/29/2010 - 4/30/2013

Photo Courtesy of Algnenol Biofuels, Inc.

Project Description

The goal of this project is to prove the commercial viability of the bioconversion of industrial waste CO_2 into liquid transportation fuels in enclosed photobioreactor (PBR) systems. The project will utilize proprietary metabolically-enhanced algae as a biocatalyst using the sun as the primary energy source. Algenol's Direct to Ethanol® technology is based on over-expressing in blue-green algae the genes for fermentation pathway enzymes found widely in nature. The resulting metabolically enhanced hybrid algae actively carries out photosynthesis and utilizes CO_2 to make ethanol inside each algal cell. The ethanol diffuses through the cell wall into the culture medium within the photobioreactor. The ethanol is then distilled from the culture medium. The ethanol-water supernatant is collected and distilled into fuel-grade ethanol. Project accomplishments include the construction of a commercial scale 2-acre PBR system that is approaching completion. There are 6,120



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

photobioreactors included in the fully integrated system. A 4,000-PBR system was operated for over 500 days and was used to develop a low cost CO_2 delivery method suitable for commercial production, as well as a robust Clean-in-Place (CIP) process that allows batch-to-batch consistency. Algenol now has all applicable licenses to commercially produce and sell ethanol and is on a path to commercialization.

Overall Impressions

- The CAPEX will be high for PBRs. What is the cost per acre? ($10,000 per acre; $1.1 billion CAPEX for a 100 million gallons/year plant (9,000 gallons per acre per day target goal). About $10 per annual gallon is the goal. That seems like a marginal value proposition.
- This is an excellent project with very innovative methods and equipment. This project has proceeded slowly, but appropriately, allowing them time to solve hurdles as they are encountered. The project demonstrated good use of go/no-go gates that led them to changing to new methods and equipment. The execution of this project was done well with good project management methods. The project team showed an excellent understanding of their algae and the needs for project development.
- Thorough work was conducted to get to this scale. CO_2 costs and number of algae units may have a big impact on future scale costs.
- This is a well-executed project. There were significant results along the way, with very good cross-fertilization opportunities to other, similar algae projects. The commercialization pathway anticipates transfer/licensure/construction of similar replicates of this plant.
- It is unclear whether closed photobioreactors will ever be a viable commercial option, but Algenol is addressing key barriers in commercializing this algae pathway to biofuels. The path to commercialization appears to be sound.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

ALPENA PROTOTYPE BIOREFINERY

(WBS#: 3.4.1.1)

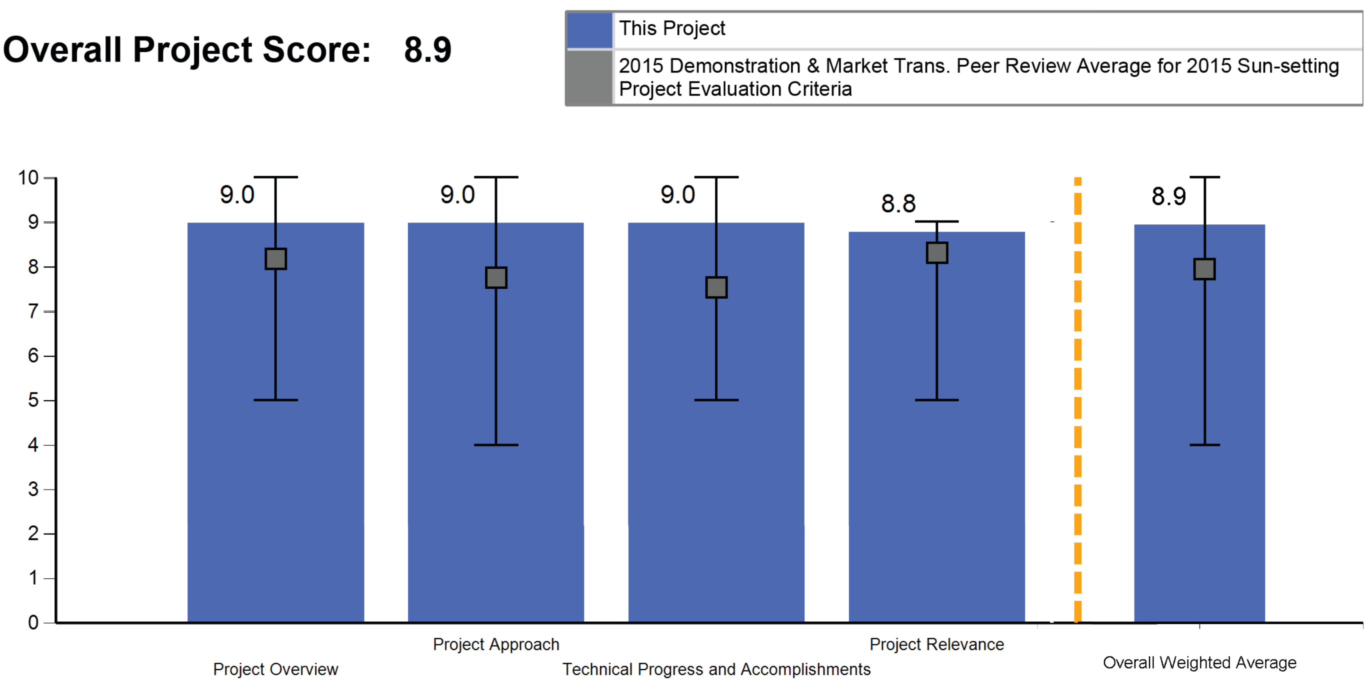
Recipient:	American Process, Inc. (API)
Presenter:	Theodora Retsina
DOE Funding FY14:	$0
DOE Funding FY13:	$0
DOE Funding FY10-12:	$17,663,395
Planned Funding:	$281,507
Project Dates:	1/31/2010 - 10/1/2014

Photo Courtesy of API

Project Description

The goal of the Alpena Biorefinery (AB) is to demonstrate a modular, technically successful, and financially viable process of making cellulosic ethanol from woody biomass extract at wood-processing facilities. The AB will produce ~800,000 gallons/year cellulosic ethanol and ~800,000 gallons/year aqueous potassium acetate deicer. The AB feedstock is wood hydrolyzate produced by co-located Decorative Panels International in the course of board manufacturing. API has completed its technology development and demonstration objectives including the generation of the first commercial cellulosic ethanol RINs from woody biomass in the U.S. API recently announced the sale of the first license for the commercial application of GreenPower+ technology. The project objectives and value proposition of the AB promote the national goals of energy independence, greenhouse gas reduction, and green job creation and retention. Objectives include the demonstration of simultaneous fermentation of C5 and C6 sugars, gathering of metrics for the construction of commercial plants, and demonstration of the business model of adding cellulosic ethanol production to wood processing facilities, such

Overall Project Score: 8.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

as biopower plants, pellet mills, and pulp mills. The top challenges the project faces include effective handling of condensed lignin and consistency of government regulations and support for cellulosic ethanol.

Overall Impressions

- This is an excellent project for the DOE portfolio. This project made excellent use of a feedstream from a co-located facility that allowed API to avoid significant costs and technical challenges around material handling.
- The Alpena project is an outstanding success and demonstrates exactly what BETO's DMT platform should be doing to advance the state of the industry. The performance of the principal investigator and the sub-awardees on the project were exemplary and demonstrates superior project planning, project management, and project implementation. BETO should be commended for supporting the Alpena Biorefinery project. It is an excellent example of sound project management and implementation on the part of the performer.
- There were several lessons learned that are particularly applicable in situations where a project's scope is still undergoing some modification while the plant is being constructed (e.g., flexibility, importance of timely communications, the value of a risk register).
- This is an excellent, well-done project, and excellent presentation. The lessons learned slide added considerable value.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

PILOT SCALE BIOREFINERY: SUSTAINABLE TRANSPORT FUELS FROM BIOMASS AND ALGAL RESIDUE VIA INTEGRATED PYROLYSIS AND CATALYTIC HYDROCONVERSION

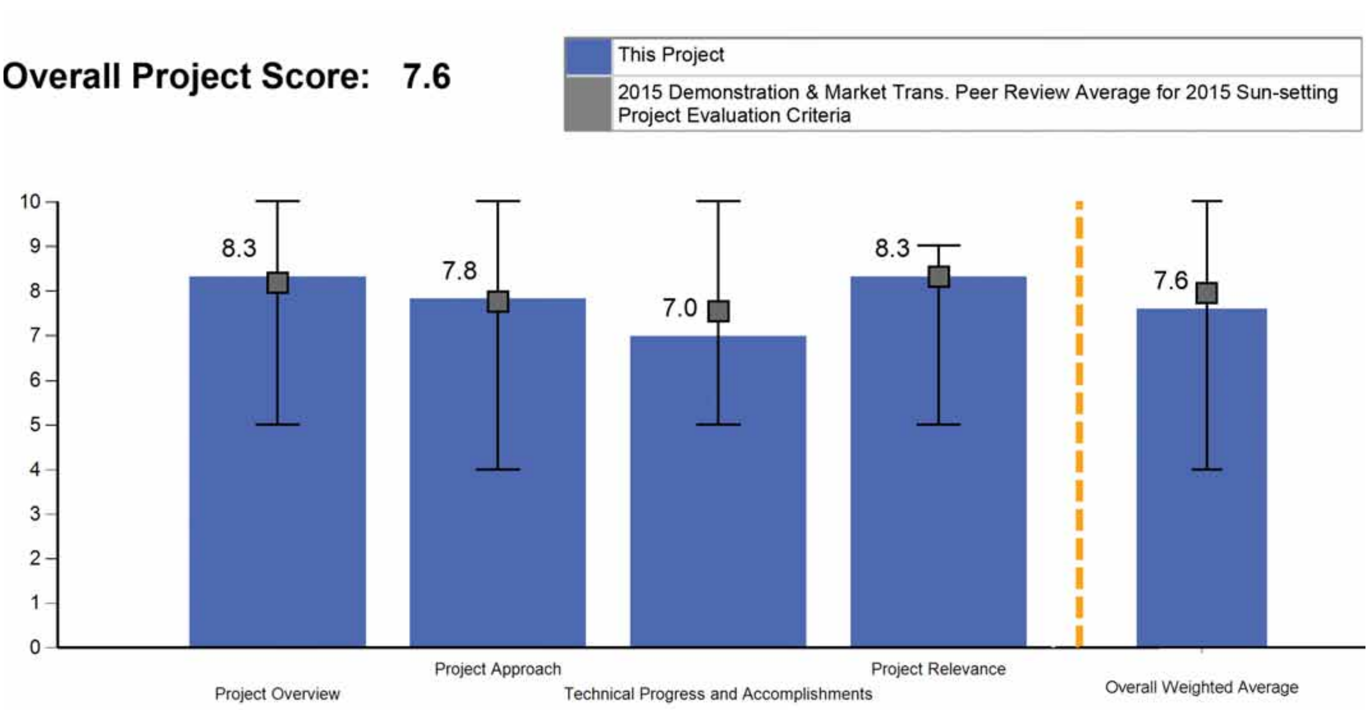
(WBS#: 3.4.1.12)

Photo Courtesy of UOP, LLC

Recipient:	UOP, LLC
Presenter:	Ray Wissinger
DOE Funding FY14:	$231,887
DOE Funding FY13:	$8,255,100
DOE Funding FY10-12:	$14,967,044
Planned Funding:	$7,780,917
Project Dates:	12/28/2009 - 9/30/2015

Project Description

UOP LLC, a Honeywell Company, is partnered with Ensyn Corporation to build and operate a pilot-scale integrated biorefinery located in Kapolei, Hawaii. The project goals are to: (1) demonstrate a technically and economically viable approach for converting renewable biomass feedstocks to sustainable and fungible transportation fuels; (2) meet the desired goal of DOE to provide a full commercial pathway for producing cellulosic biofuels from second-generation feedstocks; and (3) use non-food, non-feed cellulosic biomass to produce drop-in transportation fuels fully compatible with existing industry infrastructure. The biorefinery integrates Ensyn's Rapid Thermal Processing (RTP) pyrolysis technology with UOP upgrading technology to demonstrate a feedstock-flexible process for producing fungible transport fuels from lignocellulosic biomass. Feedstock producers sourced biomass samples and technical information used



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

for assessing the detailed life-cycle impacts. Michigan Technological University and UOP conducted a life-cycle analysis (LCA), which showed that drop-in biofuels derived from most of the feedstocks being evaluated under this project will meet the greenhouse gas emissions reduction threshold of cellulosic biofuels.

Overall Impressions

- The project team appears to be well capable of understanding and developing facilities using these technologies and addressing barriers encountered. However, it does not appear that the project was ready to build out the pilot plant. The problems encountered required re-initializing the pilot plant and R&D type trials. It is not clear to what extent UOP and its partners will continue to develop this pathway.
- The project took a rigorous approach to a tough problem, which will require more work to achieve commercial viability and acceptance.
- This is a very good start toward developing the relevant technology for pyrolysis oil introduction into refineries at minimal refinery CAPEX or refinery disruption. Coprocessing of pyrolysis oil in the refinery's fluid catalytic cracker (FCC) would allow for more rapid introduction and retrofit into existing refinery infrastructure (as compared to hydrotreating). I am not sure where this particular project is going next.
- In my opinion, DOE should review this project history and try to derive lessons regarding the pyrolysis to hydroprocessing upgrading route.
- The coprocessing concept should be supported by DOE.

Overall Impressions

- No official response was provided at the time of report publication.

RENEWABLE ACID-HYDROLYSIS CONDENSATION HYDROTREATING (REACH) PILOT PLANT

(WBS#: 3.4.1.19)

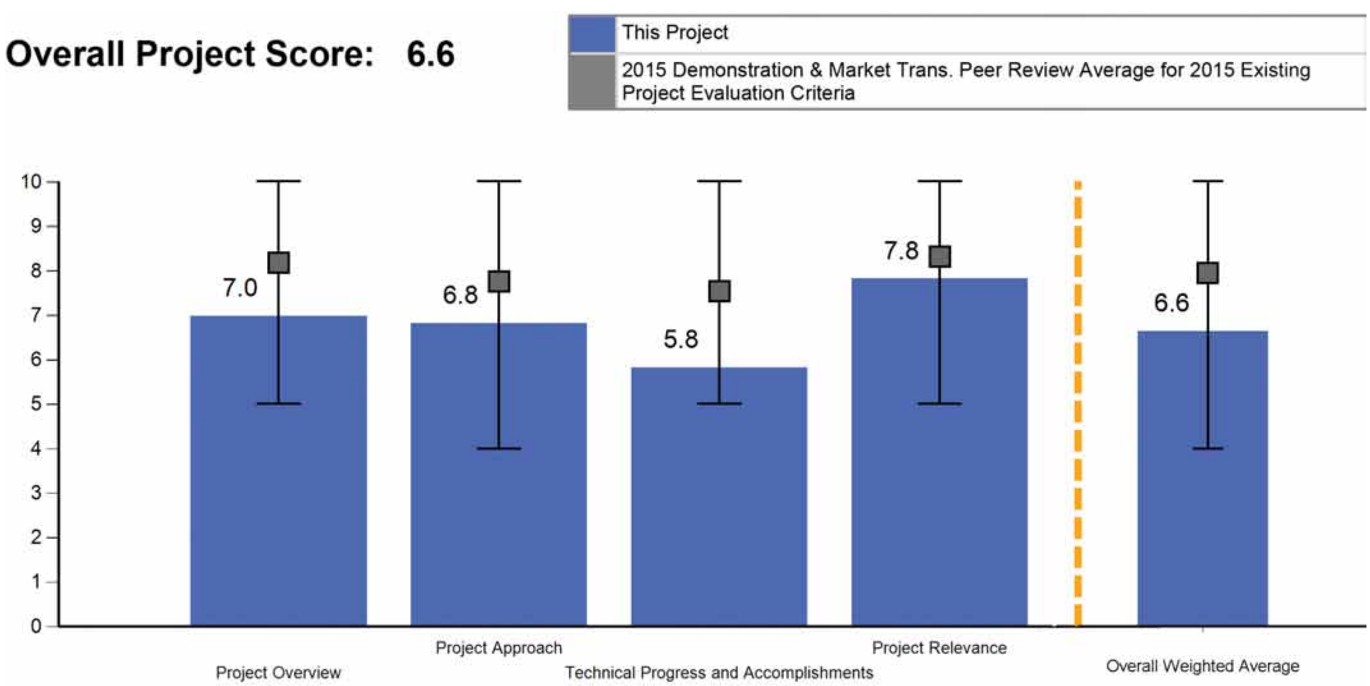
Recipient:	Mercurius
Presenter:	Karl Seck
DOE Funding FY14:	$382,923
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$4,301,696
Project Dates:	9/30/2013 - 12/31/2016

Project Description

The goals of this project are to design, build, and operate a pilot plant to scale up the Mercurius Renewable Acid-hydrolysis Condensation Hydrotreating (REACH) process. The REACH process is a novel technology that efficiently converts cellulosic biomass into drop-in hydrocarbon jet fuel and diesel. This process aims to provide an economically viable technology to start building cellulosic biofuel capacity for RSF mandates, as well as to compete with petroleum economics down to $40/barrel. The REACH technology is based on acid hydrolysis to non-sugar intermediates, such as chlormethylfurfural (converted to other compounds) and furfural. The greatest technical and non-technical challenges facing this project are acid recovery/recycle, product quality, techno-economic validation, and raising investment funds.

Overall Impressions

- This project takes an interesting approach to eliminate the need for enzymes in the conversion of biomass by using concentrated acid. The project appears to need additional R&D work prior to building the pilot plant and facing capital restrictions.
- This technology is in very early stages and fund raising difficulty may be limiting the effort.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

- My general impression is that significantly more laboratory data is required prior to engineering of an integrated pilot plant. Materials of construction were also highlighted as an engineering issue.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

SUSTAINABILITY AND STRATEGIC ANALYSIS

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Sustainability and Strategic Analysis Technology Area is one of seven key technology areas reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of 28 projects were reviewed by five external experts from industry and academia. These projects represent a total U.S. Department of Energy (DOE) investment of approximately $20 million (FY2013-FY2014), which equates to around 5% of the BETO portfolio covered at the review. The Principal Investigator (PI) for each project delivered a presentation to a panel of independent experts from industry, academia, and government. Projects were evaluated and scored for their project approach, technical progress, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Sustainability and Strategic Analysis Technology Area Project Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI. Overview information on the Sustainability and Strategic Analysis Area, full scoring results and analysis, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Kristen Johnson and Alicia Lindauer as the Review Leads for the Sustainability and Strategic Analysis Technology Area. In this capacity, Ms. Johnson and Ms. Lindauer were responsible for all aspects of review planning and implementation.

SUSTAINABILITY AND STRATEGIC ANALYSIS

OVERVIEW

Enabling long-term viability of bioenergy systems is a critical component of BETO's mission to reduce dependence on oil. The Office is focused on developing the resources, technologies, and systems needed to grow a biofuels industry in a way that protects natural resources and maximizes economic, social, and environmental benefits. To that end, the Sustainability and Strategic Analysis Technology Area is addressing the challenges related to sustainable bioenergy production and use by supporting analysis, data collection, modeling, and applied research and development (R&D) projects. This Technology Area works collaboratively with industry, academia, national laboratories, non-governmental organizations (NGOs), other agencies and international partners.

This Technology Area plays a cross-cutting role both within and outside the Office. It contributes to program portfolio planning and works with other BETO Technology Areas to develop and advance technology-specific sustainability and analysis objectives. Externally, it monitors and provides technical input to policy, scientific, and international dialogues relevant to bioenergy.

[1] More information about review criteria and weighting is available in the Peer Review Process section of the Final Report.

SUSTAINABILITY AND STRATEGIC ANALYSIS TECHNOLOGY AREA SUPPORT OF OFFICE STRATEGIC GOALS

The Sustainability strategic goal is to:

> Understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities.

The Strategic Analysis strategic goal is to:

> Provide context and justification for decisions at all levels by establishing the basis of quantitative metrics, tracking progress toward goals, and informing portfolio planning and management.

SUSTAINABILITY AND STRATEGIC ANALYSIS TECHNOLOGY AREA SUPPORT OF OFFICE PERFORMANCE GOALS

Sustainability: Sustainability activities support Office goals by providing science-based quantification of the sustainability of advanced bioenergy, and by promoting improved environmental performance and social benefits of bioenergy relative to conventional or business-as-usual energy systems. These activities enhance the scalability, public acceptance, and long-term viability of BETO's technology investments, while also equipping the Office with the necessary data, analysis, and expertise to engage in national and global dialogues on bioenergy sustainability. Example objectives include reducing greenhouse gas (GHG) emissions associated with bioenergy production and use; maintaining or improving soil quality; maintaining or improving water quality and water-use efficiency; minimizing air pollutant emissions; and promoting land-use efficiency and beneficial landscape design.

Strategic Analysis: Strategic Analysis activities provide information necessary for establishing Office goals and priorities. System-level policy, industry, and environmental analyses inform program direction, help the Office focus its technology development priorities, and identify key drivers and hurdles for industry growth. Activities address issues that cut across technology areas and are designed to support BETO decision making processes, validate decisions, ensure objective inputs, and respond to external recommendations. Complementary portfolio activities are aimed at advancing the state of the science and engineering within areas such as land use change modeling, impact analysis, and life cycle analysis.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Sustainability and Strategic Analysis Technology Area:

SUSTAINABILITY CHALLENGES
Scientific Consensus on Bioenergy Sustainability
Consistent and Evidence-Based Message on Bioenergy Sustainability
Sustainability Data Across the Supply Chain
Implementing Indicators and Methodology for Evaluating and Improving Sustainability
Best Practices and Systems for Sustainable Bioenergy Production
Systems Approach to Bioenergy Sustainability
Representation of Land Use and Innovative Landscape Design

STRATEGIC ANALYSIS CHALLENGES
Lack of Comparable, Transparent, and Reproducible Analysis
Limitations of Analytical Tools and Capabilities for System-Level Analysis
Inaccessibility and Unavailability of Data

APPROACH FOR OVERCOMING CHALLENGES

The Sustainability and Strategic Analysis Technology Area works to overcome the challenges listed by developing and disseminating knowledge, tools, and mechanisms for more informed decision making and better resource management. Key partners include national laboratories [primarily Argonne National Laboratory (ANL), Idaho National Laboratory (INL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL)], academia, NGOs, industry, and international organizations. This technology area coordinates internally and externally, working closely with other BETO technology areas, DOE offices, and federal agencies such as the U.S. Department of Agriculture (USDA), U.S. Environmental Protection Agency (EPA), U.S. Department of Defense, and U.S. Department of Transportation. Robust stakeholder engagement—through workshops, roundtables, and other means—helps advance cross-cutting objectives.

The scope of Sustainability projects includes:

- **Advancement of scientific methods** and models for measuring and understanding bioenergy sustainability across the full supply chain.
- **Dissemination of practical tools** for analyses, decision making, and technology development that enhance sustainable bioenergy outcomes.
- **Quantification of improved environmental performance and social benefits** of bioenergy relative to conventional or business-as-usual energy systems.
- **Development of landscape design approaches** that increase bioenergy production while maintaining or enhancing ecosystem and social benefits.

The scope of Strategic Analysis projects includes:

- **Resource and Technical Assessments** that provide the analytical basis for program planning and assessment of progress.
- **Market and Impact Analyses** that focus on understanding the impact of research, development, and deployment (RD&D) investments and bioenergy industry development.
- **Data Compilation** to develop and maintain tools to assist in collecting, compiling, and analyzing data.

These activities contribute to a better understanding of environmental, economic, and social aspects of bioenergy. A key priority is to analyze trends and trade-offs across multiple supply-chain components and sustainability categories.

Sustainability projects also generate new empirical data and develop novel practices to improve or maintain environmental performance and promote social benefits of bioenergy sustainability. Activities include developing frameworks to define and measure sustainability through appropriate indicators and metrics, conducting field research on best management practices for biomass production, and developing innovative approaches for spatial and multi-metric optimization.

Outcomes from Sustainability and Strategic Analysis Technology Area activities are disseminated through publications, web tools such as the Bioenergy Knowledge Discovery Framework (KDF), inter-agency coordination, and domestic and international stakeholder interactions. They are also used by the Office to inform technology research, development, demonstration, and deployment to maximize beneficial outcomes.

For more information on the Sustainability and Strategic Analysis Technology Area, please review BETO's Multi-Year Program Plan (MYPP) at: *http://www.energy.gov/eere/bioenergy.*

SUSTAINABILITY AND STRATEGIC ANALYSIS TECHNOLOGY AREA REVIEW PANEL

The following external experts served as reviewers for the Sustainability and Strategic Analysis Technology Area during the 2015 Project Peer Review.

SUSTAINABILITY AND STRATEGIC ANALYSIS	
REVIEWERS	
John Sheehan (Lead Reviewer)	Colorado State University
Stephen Costa	U.S. Department of Transportation
Jody Endres	University of Illinois at Urbana-Champaign
Michael Shell	U.S. Environmental Protection Agency
Candace Wheeler	General Motors

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: This section provides overview information for each technology area, including background information and context for the projects. Total budget information is based on self-reported data as provided by the PIs for each project.

Project Scores: The final score charts depict the overall weighted score for each project in this technology area.

Review Panel Summary Report: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. The report is based on the results of closed-door, facilitated discussions following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.

BETO Programmatic Response: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations from the Review Panel Summary Report.

Project Reports:

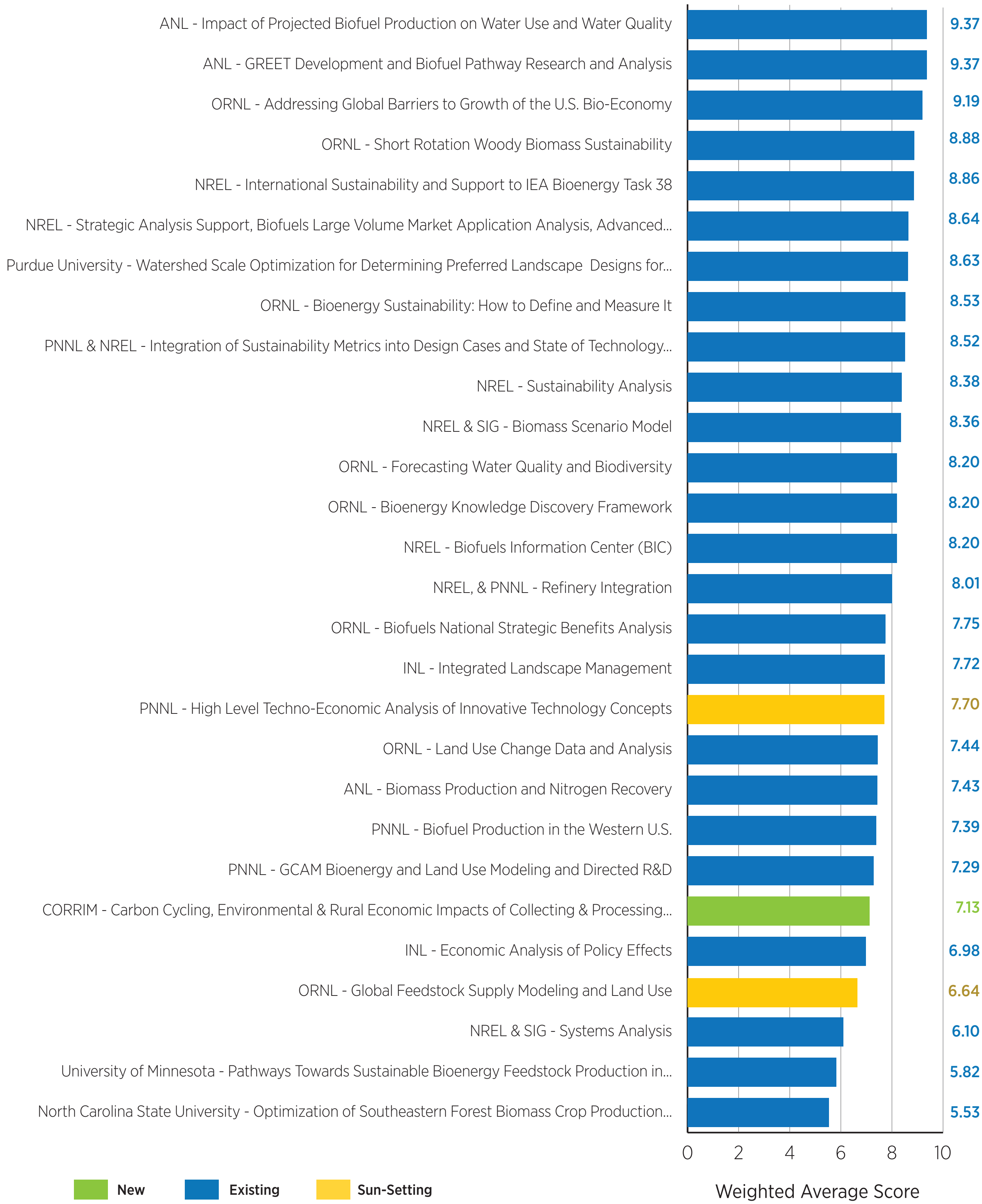
- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project (in some cases, abstracts were edited to fit within the space allotted).
- **Project budget and timeline information** are based on self-reported data as provided by the PIs for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and whiskers charts depict the range of scores for each evaluation criteria across all projects reviewed within each technology area.
- **Reviewer comments** represent the reviewers' "overall impressions" for each. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases, did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.

- **PI responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases, provided only a summary response.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Sustainability and Strategic Analysis Technology Area.

SUSTAINABILITY AND STRATEGIC ANALYSIS TECHNOLOGY AREA SCORING



REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

INTRODUCTION

The Review Panel spent three-and-a-half days immersed in presentations and question and answer sessions for projects supporting BETO's cross-cutting analysis and sustainability goals. The Panel was impressed with the breadth and depth of research, and applauds BETO's emphasis on a transdisciplinary approach to sustainability, the role that bioenergy can play in sustainability writ large, and the importance of sustainability to the successful deployment of bioenergy. In the following summary, the Panel addresses the program's five questions on the progress of the cross-cutting analysis and sustainability portfolio over the past two years. The questions include the extent to which the work is impactful, relevant, and innovative. In addition, the Panel was asked to address gaps in the project portfolio and synergies within and outside the portfolio. Finally, the Panel offers some recommendations for strengthening the portfolio in the near- and mid-term.

Review Panel Response to Key Questions

The View from 30,000 Feet: Before providing responses to the specific questions that DOE asked reviewers to consider, the Review Panel wishes to offer a few overall impressions and perspective on the work in this area. The Panel notes that the program shows great courage in tackling sustainability head-on. No doubt, the controversies that have surrounded the concept of modern bioenergy over the course of its history provide ample motivation for taking on the wide-ranging challenges embodied in setting a goal to make bioenergy sustainable.

Among the renewable technologies, bioenergy may well be the poster child for the need to address sustainability. However, there are just as many reasons to avoid the topic completely, both because it is often seen as a buzzword too vaguely defined to be meaningful, and because tackling sustainability is akin to walking straight into a buzz saw. Because sustainability touches on, and transcends, a very diverse set of disciplines, it offers challenges not seen in any other aspect of BETO's overall research portfolio. Given these challenges, the progress made in this area shows a leadership rarely seen in the scientific and technological arenas.

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum? Why?

Strengths of the Portfolio

First, among the strengths of this portfolio is how well it operates as the "eyes and ears" of the program. Its projects, for the most part, excel in delivering pertinent high quality information to catalyze a pathway toward the optimally sustainable use of bioenergy. The portfolio has done a particularly good job of measuring and linking both economic and environmental components of sustainability for bioenergy. The project portfolio in this technology area operates at several critical levels within the program. There are projects designed to address strategic input at the highest program levels, and others that are rigorously connected to project-level and technology area-level activities across the BETO portfolio.

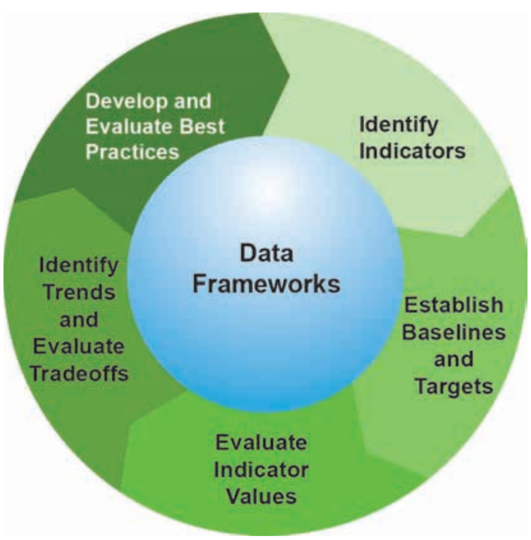
The Panel would also like to highlight the quality of the teams engaged in this area. It is clear that the Sustainability and Strategic Analysis Technology Area has invested several years of effort to assemble groups of experts across a variety of disciplines at several of the national laboratories. The laboratories have been given the time and resources to develop critical models and tools. The work of these projects over the past two years shows that BETO is now reaping the benefits of this commitment. This cross-laboratory expert community is also a valuable resource for BETO in dealing with both quick turn-around issues that arise, as well as producing long-term assessments that shed light on fundamental strategic direction for the program.

Another key strength that runs through most of the projects in the portfolio is the transparency in assumptions, approaches, and data. This is vital not only for ensuring the highest quality outcomes from the project, but also the credibility of the work—without which any effort to promote and enhance sustainability of bioenergy will fail. That transparency extends internally across projects in the program, as well as externally to the broader public through mechanisms such as the Bioenergy KDF.

Project "Standouts" in the Portfolio

Four groups of activities stand out as examples of high quality work.

ORNL Defining Sustainability: From the Panel's perspective, this project has essentially functioned as the cornerstone of BETO's effort to integrate sustainability into its plans and activities. The Panel repeatedly saw the kind of adaptive management framework developed in this project (see exhibit) in many of the other projects—evidence that this mindset has been successfully transferred across the program.



Defining Sustainability project brings critical coherence

Biomass Scenario Modeling (BSM): Like the "Defining Sustainability" project at ORNL, the impact of the BSM project on BETO's program is to integrate and bring coherence to much of the work being done—not just in the Sustainability and Strategic Analysis Technology Area, but across the BETO program. The example below illustrates how this model can bring together marketplace, technology development, and policy influences to create a vision for how the biofuels industry could evolve. It is a powerful tool for strategic decision making and holistic thinking.

Techno-economic and Life Cycle Analysis (TEA and LCA): The program has a long history of conducting high quality techno-economic and life cycle analysis. Both have become standards for assessment of renewable energy technology. The Panel observed that the projects involved in TEA and LCA over the past two years have shown an improved and much tighter integration of the two tools, which greatly increases their impact.

International Engagement: The Review Panel commends BETO for bringing an informed and influential voice to several ongoing international debates. In particular, ORNL and NREL have played major roles in establishing an international standard for sustainable bioenergy, and have contributed to efforts by the Roundtable for Sustainable Bioenergy, the International Panel on Climate Change, and the Scientific Committee on Problems of the Environment.

Weakness of the Portfolio

There is always room for improvement in a set of activities as complex as those managed under the Sustainability and Strategic Analysis Technology Area. The Panel highlights a few here, recognizing up front that some of these represent trade-offs as much as they represent genuine weaknesses. Thus, addressing these weaknesses, in some cases, will come at the cost of other benefits and strengths.

A key example of these types of trade-offs is BETO's decision to create a largely insular team under the Sustainability and Strategic Analysis Technology Area. The projects in this technology area continue to be dominated by DOE's national laboratories. We acknowledge the trade-off between the benefits of an internal team that brings long-term consistency in the quality and availability of expertise and models, and the need to bring in outside perspectives. Subcontracting more of this work would clearly reduce BETO's capability to be flexible and nimble in an area that often faces rapidly changing external issues and requires quick turn-around responses. It might also reduce the ability to maintain a stable pool of high quality talent. Nevertheless, this is an issue that the Sustainability and Strategic Analysis Technology Area should revisit.

A second area for improvement is the need to increase connections with stakeholders and key decision makers outside the program. As it stands, much of the program's efforts in this area focus on what might be called "outreach and education." The Sustainability and Strategic Analysis Technology Area does an excellent job of communicating with both the general public and the research community. However, this one-way flow is not enough. More importantly, the Panel sees a missed opportunity to take advantage of the powerful modeling tools that have been developed in this area. Not all models are suitable tools for interacting with a broad range of stakeholders; however, the Panel feels that the life cycle assessment and system dynamics modeling tools are not only ideally suited for such interaction, but by their very nature, are at their most valuable when used in an interactive setting with stakeholders. The Panel can only imagine just how powerful these tools would be when policy makers, citizens, and politicians have an opportunity to experiment with new ideas using these tools.

Finally, the Panel acknowledges that engaging so directly with stakeholders, and especially policy makers, comes with some risk. It will require maintaining the proper distance between the Office and the broader political system that it serves, and will require a mutual trust that the policy-driven modeling tools will not be misused or used to misrepresent official government positions or predictions.

RELEVANCE

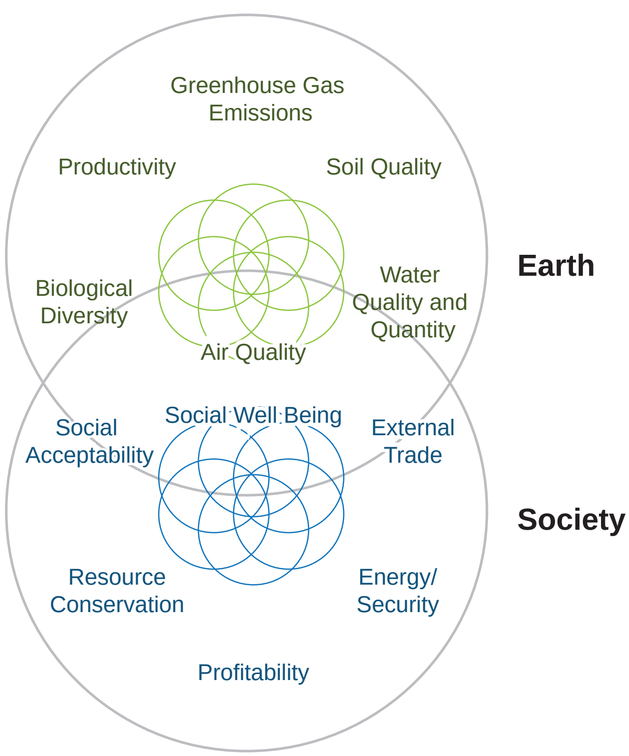
2 Are the projects in this program relevant to achieving BETO's broader goals? Are the projects well aligned with what is needed by industry for successful commercialization of an advanced bioenergy industry? How can the impact of BETO on the emerging industry be amplified?

All of the projects are clearly identified and aligned with the goals and milestones of the program. As noted earlier, these projects are designed to provide feedback on the effect of BETO's various technology pathways on the realization of a robust and sustainable bioenergy industry. Per the previous section on impacts, the Panel feels that the impact of BETO's program—and the Sustainability and Strategic Analysis Technology Area, in particular—could be greatly amplified by increasing accessibility and availability of its modeling tools and expertise. More importantly, these tools should be used in the context of authentic interaction with, and engagement of, stakeholders at all levels and areas of interest.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The Sustainability and Strategic Analysis Technology Area's projects represent a very aggressive targeting of environmental sustainability. The Panel applauds BETO's willingness to take risks in assessing and ensuring sustainability in its broadest possible context. This wide-ranging approach puts this work at the "bleeding edge" of industry thinking on sustainability. Its metrics of environmental and social sustainability (see Venn diagram) constitute an ambitious framework for benchmarking sustainable bioenergy.



Nevertheless, the Panel feels that, in the social context of sustainability, its approach is too narrowly focused. There is a tendency to focus on the more easily measured and manageable aspects, such as profitability and resource conservation. The Panel encourages BETO to step outside its comfort zone (in science and technology), and engage more deeply in addressing the societal challenges of sustainability.

Project "Standouts" in the Portfolio

The Panel previously mentioned the BSM-related projects as standouts in terms of impact, but it also deserves a mention for its innovative "systems thinking" approach. The Panel specifically highlights the work being done to combine system dynamics modeling with more traditional economic modeling to develop a better understanding of the behavior of the Renewable Identification Number (RIN) market. Such combined modeling is also being used to better understand energy security as a metric of sustainability, and the role that bioenergy plays in it.

In the life cycle assessment arena, the Panel would like to highlight the innovative efforts to expand the geospatial and temporal capabilities of LCA, both particularly important in the challenges of minimizing air and water impacts of bioenergy.

Deserving special mention as standouts are the innovative approaches to assess sustainability of bioenergy at the landscape level. Several projects in the Southeast and the upper Midwest are applying the sustainability methodology developed by ORNL to landscape-level systems. The process embodies the Panel's meaning when it states that the portfolio's powerful tools can be used to even greater effect in a setting where stakeholders are fully engaged.

4 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation? Why?

While this question may be more pertinent to other technology areas in BETO's program, the Panel notes that the Sustainability and Strategic Analysis Technology Area portfolio covers the gamut from high level market analysis and new technology pathway development, to detailed economic and environmental assessments of more fully developed technology pathways at the landscape scale. Ultimately, what makes this portfolio well positioned to support successful commercialization is its emphasis on aspects of sustainability, which the emerging industry is unable to take on in the face of the more immediate challenges of technology deployment and market penetration.

5 Are there any gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals? Are there any areas in the existing portfolio that need more or less emphasis?

GAPS

Gaps in the portfolio mainly reflect issues mentioned in previous sections of this report. Specifically, they include:

- An insufficiently broad or deep understanding of the social aspects of sustainability for bioenergy. The program needs to tackle the less readily quantified and analyzed social issues such as rural development and environmental justice. This will require recruiting other groups and institutions with the skills and experts to deal with what is now commonly referred to as the "human dimensions" of sustainability.
- Related, though somewhat distinct, is the issue of how to engage stakeholders, not just communicate to them. In fact, the social processes involved in engaging all manner of stakeholders are critical to social acceptance and to obtaining a proper understanding of the societal goals for sustainability in general, and sustainable bioenergy in particular. BETO's work on life cycle assessments, similar to 90% of published research, is largely missing this component. The International Organization for Standardization (ISO), recognizing the importance of stakeholders in defining and assessing sustainable options, has standards for life cycle assessment that require such engagement. The Panel would argue, too, that market and systems analyses and resource assessment projects in this portfolio also need to strengthen this aspect of their work.

SYNERGIES

6 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies?

There are obvious synergies among the projects in this portfolio, as there are bound to be in a highly interconnected subject area such as sustainability. The Panel was struck by the high degree of synergy, and the degree to which BETO has encouraged it. The Panel sees the BSM as one place where almost all of the projects have some need to (and are) interfacing in a way that allows it to build an integrated understanding of a path forward for evolving a sustainable bioenergy industry. Similarly, the life cycle assessment projects take good advantage of opportunities for connections among projects. In these areas, the Panel thinks BETO has established strong and collaborative relationships among its projects. Overall, BETO is to be commended for the high priority its researchers give to communication across this portfolio.

Some of the synergies among projects are being leveraged more explicitly than others. The Panel encourages BETO to consider a workshop in which all of the research, analysis, and models might be mapped in a way that more specifically shows their linkages and overlaps. This will not be an easy task, but may well lead to identifying new activities focused on building connections and increasing synergies among the projects.

7 Does this program appear to be appropriately leveraging breakthroughs from the DOE Office of Science, ARPA-E, the National Science Foundation, and/or other DOE Offices or federal agencies?

The Panel sees the strongest linkages in the portfolio with USDA and EPA, but cannot speak with much confidence as to how successful the program has been in leveraging the efforts of these and other agencies in a meaningful way. For example, though it is clear that USDA and BETO researchers have important collaborations in the area of feedstock development, the Panel would like to see stronger connections with USDA on research related to sustainable feedstock production. Anything that will increase the available funding in this area would greatly enhance this portfolio. Its need for resources to support an understanding of feedstock sustainability far exceeds the funds available.

RECOMMENDATIONS

8 What are the top three most important recommendations that would strengthen the portfolio in the near- to medium-term?

1. Strengthen the linkage of sustainability to decision making. In effect, the Panel is suggesting that sustainability is not a subset of analysis, but it is the overarching *focus* of analysis. There is an implicit paradigm in BETO's MYPP that distinguishes economics versus sustainability. This is an artificial separation that treats sustainability as an environmental issue. The result is that the connections between market and economic analysis and high-level program management decision making are more explicit, while the goal of sustainability becomes subservient to these. At the project level, there is clear recognition that this is a line that should be erased, as evidenced, for example, by the effort to merge life cycle and techno-economic analysis in all the technology pathway design reports.

- A related recommendation is to pursue a workshop in the near term in which all of the research, analysis, and modeling activities in the portfolio are mapped out to identify connections among the projects and to clarify the linkages of these activities in a hierarchical structure that ultimately connects to decision making at the BETO program level. As the Panel indicated at the outset of this report, the Sustainability and Strategic Analysis Technology Area portfolio serves as the "eyes and ears" of the program, and should likewise have strong links to the brain.

2. Continue the effort to integrate the science and knowledge generated by BETO in the international dialogue on bioenergy's sustainability. The successful deployment of a sustainable U.S. bioenergy industry is inextricably tied to global issues and international policies. The Panel sees tremendous progress in this area, but senses that funds for this area do not match the need, given the fast pace of international activity. At the same time, stronger connections are also needed in providing holistic analysis of bioenergy that reaches from the global scale to the local scale.

3. Strengthen the effort to understand the human dimensions of sustainable bioenergy. This has two facets:

- As mentioned in this report, the Panel feels that more research and analysis is needed for the more intractable and less measurable social challenges for sustainable bioenergy (e.g., environmental justice and basic quality of life issues).
- But more research projects that address these questions are not, in and of themselves, sufficient. Tackling these social challenges requires a fundamental shift toward a stakeholder-led analysis and modeling effort that inherently brings the social dimension together with the science. Findings related to sustainability without such deep connections are, in the end, meaningless.

BETO PROGRAMMATIC RESPONSE

We thank the Peer Review Panel for their time, active engagement, and constructive review of the Sustainability and Strategic Analysis portfolio. The Peer Review Panel referred to the Sustainability and Strategic Analysis Technology Area as the “eyes and ears” of the Bioenergy Technologies Office. We interpret this to mean that the Technology Area is effectively staying in tune with the status of the advanced bioenergy industry, paying attention to issues across the bioenergy supply chain that influence the commercial viability and public acceptance of bioenergy, and acting as a channel of information flow between the external stakeholder community and other areas within BETO. The Peer Review Panel recommendations will be used to further enhance the effectiveness of the Technology Area’s activities and contribution to the Office’s goals.

The 2013 Peer Review Panel provided a number of recommendations for the Sustainability and Strategic Analysis Technology Area to act on, and the 2015 Peer Review Panel recognized the progress that the Technology Area has made on those recommendations. This year’s reviewers specifically called out improvements in transparency, leadership in the sustainability community, leadership in international dialogues, sustainability at the landscape and community level, and a high degree of synergy within the Office and with other agencies. We are pleased that we have been able to continue to build an effective portfolio and that our efforts to implement feedback since 2013 have been fruitful.

The reviewers praised the improved integration of environmental and economic sustainability, which was recognized by the 2013 Review Panel as an area for continued emphasis. The reviewers at the time noted that environmental sustainability was not sufficiently accounted for in BETO’s technology pathway assessments. Since 2013, the Sustainability and Strategic Analysis Technology Area created a coordination group of analysts and researchers from multiple national laboratories involved in sustainability and techno-economic analysis of advanced biofuel pathways. This group has worked to create more consistency and integration across these analyses. For example, all design cases and state-of-technology assessments that the Office conducts on advanced biofuel pathways now include key sustainability metrics (such as GHG emissions, energy consumption, and water consumption) for the conversion stage. These efforts and publications provide a quantitative understanding of the trade-offs and complementarities between economics and environmental performance, enabling BETO and researchers to balance these objectives. The national laboratories also coordinate to develop supply chain sustainability analyses in order to facilitate comparison of life-cycle energy and environmental impacts across biofuel pathways in BETO's R&D portfolio.

Reviewers provided feedback on each project within the Sustainability and Strategic Analysis Technology Area portfolio and, in response, PIs are working to address this project-specific feedback to strengthen their future work plans. The reviewers also provided feedback to the overall Sustainability and Strategic Analysis Technology Area, which was organized into three general recommendations. BETO Technology Managers for the Sustainability and Strategic Analysis Technology Area greatly appreciate these recommendations and are already incorporating these suggestions into priorities for FY2016 and beyond.

Recommendation 1: Strengthen the linkage of sustainability to decision-making

The effort to integrate environmental metrics and economic metrics to evaluate technologies has progressed immensely since the 2013 Peer Review. To build on these accomplishments, the 2015 reviewers felt that the effort could go further. For example, the reviewers noted that BETO's MYPP illustrates how market and economic analyses influence program management decision making, but stated that BETO could do more to present economic, environmental, and social sustainability goals in an integrated manner.

The Sustainability and Strategic Analysis Technology Area appreciates the reviewers' feedback that all dimensions of sustainability should be more visible and tied to BETO decision making. In the next MYPP revision, we will work to better represent the equal importance of economic, environmental, and social sustainability. In response to the reviewers' recommendations, we will also ensure that the portfolio's powerful tools more directly feed into BETO's strategic planning and, more broadly, to the policy dialogue. As part of this effort, we will pursue the recommendation of having a workshop to map linkages between analysis and modeling activities and how those are feeding—or could more strongly feed into—BETO decision-making.

Recommendation 2: Continue to integrate BETO-generated knowledge into the international dialogue

The reviewers observed that BETO is making valuable contributions to global dialogues on bioenergy sustainability. We are encouraged that the reviewers saw tangible benefits for the U.S. bioenergy industry resulting from our international efforts, and that they see value in continued involvement. Examples include involvement in the Intergovernmental Panel on Climate Change (IPCC), the Global Bioenergy Partnership (GBEP), ISO, and the International Energy Agency-Bioenergy. Balancing resources for international engagements and domestic-focused activities continues to be a challenge. Nonetheless, we will continue our level of involvement in a strategic way, focusing on efforts that benefit the U.S. industry. For example, we will prioritize efforts that accelerate R&D on sustainable bioenergy production through mutually beneficial technical exchanges; enable the Office to stay informed of international market developments that affect the U.S. bioenergy industry; and help ensure that the U.S. perspective and scientific contributions are represented in international arenas.

Recommendation 3: Strengthen effort to understand human dimensions of sustainable bioenergy

The reviewers noted that research and analysis are needed for the more intractable, less measurable social challenges for sustainable bioenergy. They specifically called for stakeholder-led analyses and modeling efforts that bring societal considerations together with the technical aspects of bioenergy development.

We will continue to look for ways to advance understanding of the social aspects of sustainable bioenergy in a way that is consistent with BETO's mission space. For example, BETO will continue to encourage community-level engagement as part of the landscape design approach to integrating bioenergy into existing agricultural and forestry systems; involving diverse stakeholders in the landscape design process is critical to achieving sustainability goals and effectively addressing human dimensions at the local and community level. We also agree that social aspects, such as human health, environmental justice, and rural development, are important aspects of bioenergy sustainability, and we view these areas as ripe for collaboration with USDA and EPA. We will work to integrate these topics into our interagency planning on bioenergy sustainability.

These three recommendations underscore the value of the peer review process; external reviewers provide valuable insights that enable us to improve activities that benefit the industry and affirm the investments that Congress and the taxpayers have entrusted to the Bioenergy Technologies Office.

INTEGRATION OF SUSTAINABILITY METRICS INTO DESIGN CASES AND STATE OF TECHNOLOGY ASSESSMENTS

(WBS#: 4.X.X.X)

This presentation merges cross-cutting work from several projects supporting the Sustainability and Strategic Analysis and Conversion Technology Areas (i.e., 2.1.0.100, 2.1.0.301, 2.1.0.302). The budget and timelines for those projects are covered in their respective presentations.

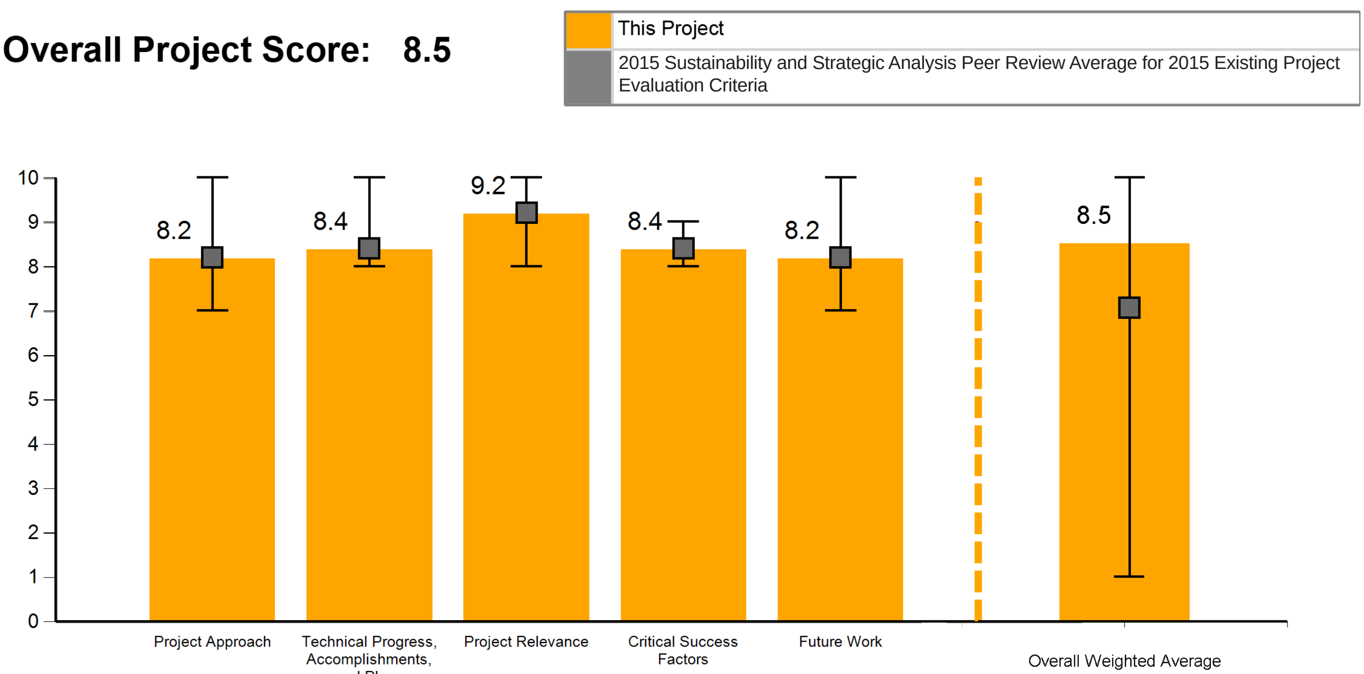
Recipient:	PNNL and NREL
Presenter:	Lesley Snowden-Swan
DOE Funding FY14:	N/A
DOE Funding FY13:	N/A
DOE Funding FY10-12:	N/A
Planned Funding:	N/A
Project Dates:	N/A

Photo Courtesy of PNNL and NREL

Project Description

The integration of sustainability metrics into Design Cases and State of Technology (SOT) assessments is directly aligned with the Bioenergy Technologies Office's programmatic goals to develop sustainable and economically viable biomass-derived fuels. This work is supported by projects in both the Sustainability and Strategic Analysis and Conversion research platforms. Techno-economic analysis (TEA) is a tool used by BETO to assess technical progress and, through concerted efforts, has been coupled to sustainability analyses for the development of biorefinery designs. The overall aim of this cross-cutting research is to minimize the cost and sustainability impact of potential biofuels. Over the past several years, this work has included the development of five design cases for hydrocarbon biofuel production pathways and the corresponding annual SOT reports that summarize both cost and sustainability metrics.

Overall Project Score: 8.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

In addition, sensitivity analyses have been utilized to investigate cost/GHG trade-offs and synergies for design modifications (such as feedstock impacts). The results of these analyses are published in the MYPP and support additional sustainability projects by providing key inputs to both the ANL-led GREET and water modeling efforts. This research requires multi-lab collaborations among the analysts and investigators at NREL, PNNL, INL, and ANL to ensure a consistent basis for the data, methodology and assumptions.

Overall Impressions

- This project supports the development of biofuels that are both sustainable and economically viable through the novel integration of techno-economic modeling and life cycle analysis work. The consistent use of assumptions across studies helps enable better comparisons across pathways. The results of these analyses have enabled researchers to focus on critical issues which inform future process and design choices. The project shows great progress in not only applying the research to several critical pathways but also expanding the depth of the analysis beyond the basic metrics. I would encourage incorporating a more extensive use of sensitivity analysis to understand tradeoffs. It was good to hear that all new design cases will include a section on sustainability. This research will have a positive effect on future commercialization by enabling data-driven choices that improve both the economics and sustainability of the system. Understanding both the techno-economic assessment and the impact on sustainability will lead to modifications on process execution and design. The hydrocarbon pathway work is critical as we move toward these drop-in fuels, but I would also recommend looking at biochemical production.
- The project PIs addressed the 2013 Peer Review comments well. There is really nothing more I can add from the 2013 comments, or how the PIs responded.
- The approach outlined here to integrate environmental and economic metrics represents an excellent start to achieving a comprehensive assessment of bioenergy technologies' sustainability. The project team has chosen to build off the critical linkage between the material and energy balance components of the traditional techno-economic analysis and life cycle assessment. They have chosen to focus on a subset of sustainability metrics, and it is hoped that they will eventually expand these metrics. They have further demonstrated the true value of this integration by using these new sustainability metrics directly in design choices and design optimization. The main weakness of their approach is the reliance on commercial software (SimaPro) for the life cycle analysis work. Actually, this is both a strength and a weakness. Its strength lies in the ability to access a consistent and comprehensive life cycle inventory database and in the ability to rely on software-encoded consistency in tracing life cycle flows. The weakness in this software choice is that it will limit transparency and access to data and models both because the commercial license restricts publication of the proprietary data and the cost of a license limits access to models. But overall, the project team is to be commended for forging this important linkage between economic and environmental metrics.
- This project fits into BETO's portfolio nicely by offering comprehensive TEA/sustainability analysis of different conversion pathways. The sensitivities explored on GHG/cost tradeoffs are a valuable contribution to researchers and decision makers. The expansion of the project to incorporate additional pathways will provide additional value going forward.

PI Response to Reviewer Comments

- We thank the reviewers for their helpful insights, comments and suggestions. We will strive to incorporate this feedback to improve these efforts going forward. We thank the reviewers for their views on the utilization of commercial software for the development of our analysis and the challenges associated with transparency. We would like to re-emphasize that one of our goals is to be as transparent as possible in all of our analyses, for both economic and sustainability evaluations. For sustainability efforts, this includes documenting the basis of our assumptions (including the version of the software and database utilized) in our public design reports and in the references within the MYPP. We also work to find public and citable information for key LCIs utilized for our analyses and cite them when appropriate in these public reports.

- With respect to expanding the current sustainability metrics, we work in collaboration with other tasks within the Sustainability and Strategic Analysis Technology Area platform to broaden the impact of this analysis and to provide key data needed to develop detailed analysis around air quality and key criteria air emissions. We also thank the reviewer for the helpful suggestion on incorporating a more extensive use of sensitivity analysis to understand trade-offs. We will continue to explore opportunities to understand how routes toward improving biofuels costs by design and process modifications will impact the sustainability of an integrated design. We have begun these efforts in the catalytic conversion of sugars to hydrocarbon fuels design case by considering the implications of natural gas-derived hydrogen compared to biomass-derived hydrogen; in the gasification of biomass to high octane design report, by considering the opportunities for co-processing natural gas to improve fuel yields; and in the biological upgrading of sugars to hydrocarbon fuels, by considering the case for lignin conversion to chemicals rather than electricity.

OPTIMIZATION OF SOUTHEASTERN FOREST BIOMASS CROP PRODUCTION: A WATERSHED SCALE EVALUATION OF THE SUSTAINABILITY AND PRODUCTIVITY OF DEDICATED ENERGY CROP AND WOODY BIOMASS OPERATIONS

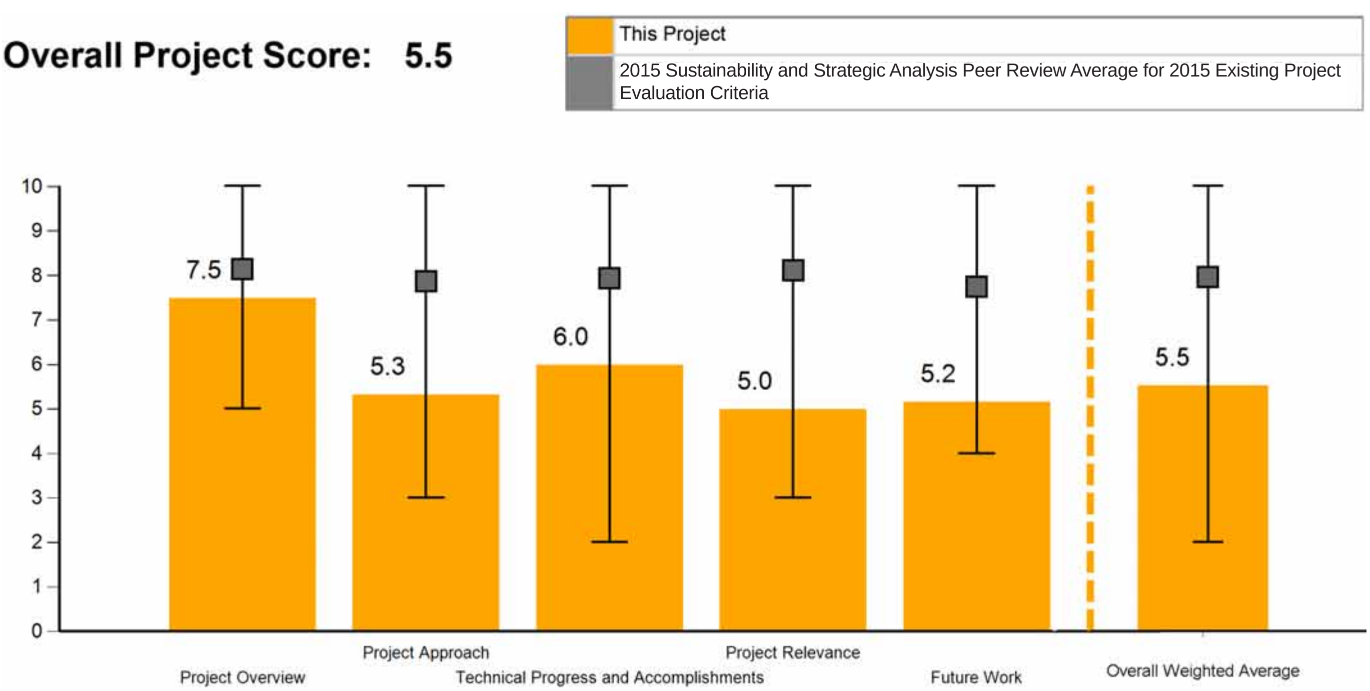
(WBS#: 1.7.1.5)

Photo Courtesy of North Carolina State University

Recipient:	North Carolina State University
Presenter:	George Chescheir
DOE Funding FY14:	$288,439
DOE Funding FY13:	$468,583
DOE Funding FY10-12:	$664,237
Planned Funding:	$671,633
Project Dates:	9/30/2010 - 9/30/2016

Project Description

The goal of the project is to develop and disseminate science-based information for sustainable production of biofuel feedstock in a forestry setting in the Southeast. The project evaluates the environmental and economical sustainability of a potentially viable biomass production technology that will not compromise availability of food, fiber, and water, and can utilize over 15 million hectares (37 million acres) of pine plantation forests in the Southeast. The project seeks to quantify the impacts of different energy crop production systems on hydrology, nutrient dynamics, soil quality, flora and fauna populations, and habitat quality using watershed and plot-scale experiments. In addition, the project uses watershed and regional scale models to evaluate environmental sus-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

tainability of multiple biofuel scenarios. As an outcome, the project will develop and evaluate Best Management Practice guidelines for environmental sustainability.

Overall Impressions

- The project is examining a unique application of bioenergy production; in this case, bioenergy value may be supplemented by the ecosystem service value of cover-crops during particular stages of conventional forest rotations. The project design will make drawing general conclusions difficult. The plots and watersheds are more case studies than replicated or controlled installations.
- The objective of this project, to develop a system for the sustainable production of biomass in a forestry setting, is a worthy goal and could have great impact if utilized across the Southwest. However, the project was limited in scope to switchgrass and encountered significant difficulties in getting the switchgrass established initially. Good progress had been made since the last review with the collection of good quality data on sediment loads and the impacts of site preparation on soil properties such as compaction as well as soil moisture levels and the accumulation of biomass under the various conditions. It remains to be seen if the level of switchgrass production is economically viable or if an alternate crop would be better suited for intercropping. While this work is coming to an end, understanding the potential of intercropping over a range of crops, geographies, and landscape conditions remains an important goal for future work.
- This is not a criticism of this project, but more a question with regard to BETO strategy: why didn't BETO fund a project that harvested residues and other forest materials for the pellet market, like ORNL is studying? I understand that BETO probably could get a large industry match for this, but I have heard for a while, in the long run this type of interplanting project is not economically viable. Why not choose the feedstock model that is an already viable model and has been causing a lot of controversy, particularly in Europe? Are water quality conditions so affected by the areas previously not planted in perennial grasses that such a study was thought to bring about great improvements in water quality? Perhaps the presenter could have made that clearer from the beginning: what water quality problem was meant to be addressed by this silvicultural model?
- It is difficult to assess the value of this project. While progress has been made in establishing the plot tests for interplanting of switchgrass in pine plantations, the conclusions and observations reported thus far seem disjointed with no context as to the overall implications for the sustainability of the switchgrass/pine intercropping scheme. Furthermore, the relation between the plot studies and the watershed studies is unclear. Perhaps what is needed is a more detailed and comprehensive review of the project by DOE management before further investment is made.
- While this effort is interesting from a hydrology and soil quality perspective, without simultaneous consideration of the economic viability of such a bioenergy system, it lacks greater applicability to BETO's goals of identifying and developing sustainable feedstock supplies. Without investigating the preparation, harvesting, and transport costs of interplanting switchgrass in pine stands against estimated returns, it is impossible to assess the biomass supply potential from these projects' simulations. The economic viability of such a system would be crucial to whether it would be implemented. Absent viability of the system being evaluated, the substantial data and environmental insights gathered from this project are diminished. This reviewer recommends the immediate assessment of economic conditions surrounding this operation and the testing of different site options to improve economic favorability (e.g., variable rotation length, residue collection, harvests coinciding with pine thinnings) to bolster the utility of this project.

PI Response to Reviewer Comments

- We would like to address the primary reviewer concerns which include the lack of treatments and treatment replication, the unclear definition of water quality problem, and the perceived lack of economic analysis.
- The overall goal of this project is to develop and disseminate science-based information for sustainable production of forest biofuel feedstock in the southeastern U.S. We proposed to develop that information based on data collected from field measurements made on operational-scale watersheds as requested in the original FOA. This type of approach had seldom been used for evaluating the environmental sustainability of biofuel crop production. The lack of such studies was likely due to the expense, longevity and complexity of conducting watershed-scale research, as most researchers opted for plot studies and modeling studies. The high cost of conducting these studies and the difficulty of finding multiple suitable watersheds within a specified area make blocked replication of watersheds impossible. However, the approach we used is the highest standard in watershed-scale studies and is used wherever possible in forest hydrology.
- We established three watershed study sites with four or five treatments each. We are currently reporting each of our three watershed-scale studies as a paired study and then we will report observations made across all of the groups. We have found that reviewers of our manuscripts recognize this design and they fully appreciate the value of results coming from field studies being conducted at an operational scale as opposed to plot scale or modeling results. Many studies are conducted with paired watersheds in one site; having similar studies in three states adds to the power of the overall analysis, not detracts from it.
- We hypothesized that adding switchgrass to a forested system would degrade the typically good water quality from forested lands. Additional operations needed for switchgrass could increase nutrient and sediment loads. These operations include: additional site preparation and planting to establish switchgrass, and the annual fertilization and harvesting of the switchgrass. Best management practices (BMPs) developed in this study will be related to these operations and involve the timing and intensity of site preparation for switchgrass planting after tree planting, and the timing of fertilization and harvesting. BMPs also address the field conditions (i.e., soil moisture and land slope) when and where these operations can be performed. Development of these BMPs requires the understanding of the hydrological, nutrient cycling, and sediment transport processes that will be affected by the operations.
- Our field studies are designed to give us valuable information about how the additional operations affect hydrology, nutrient cycling, and sediment transport processes. Thus far, we have documented the effect of various site preparation procedures on sediments and nutrient loading. We have also quantified the amount of soil compaction that occurs from site preparation and switchgrass harvesting operations. Very recently, we have documented the increase of nitrate nitrogen loads due to fertilization. We have also quantified the effect of tree shading on switchgrass production. All of this information is very important for developing BMPs that assure environmental and economical sustainability of interplanting switchgrass between pine trees.
- We are also collecting economic information about the costs and returns of the system to produce switchgrass in this forested setting. Additional information is also available about the transport and processing of the biomass. This information will be used to perform a life cycle analysis of the entire system; however, this analysis depends on productivity data collected in our studies. We will collect and analyze this once more after this growing season before we calculate the results.

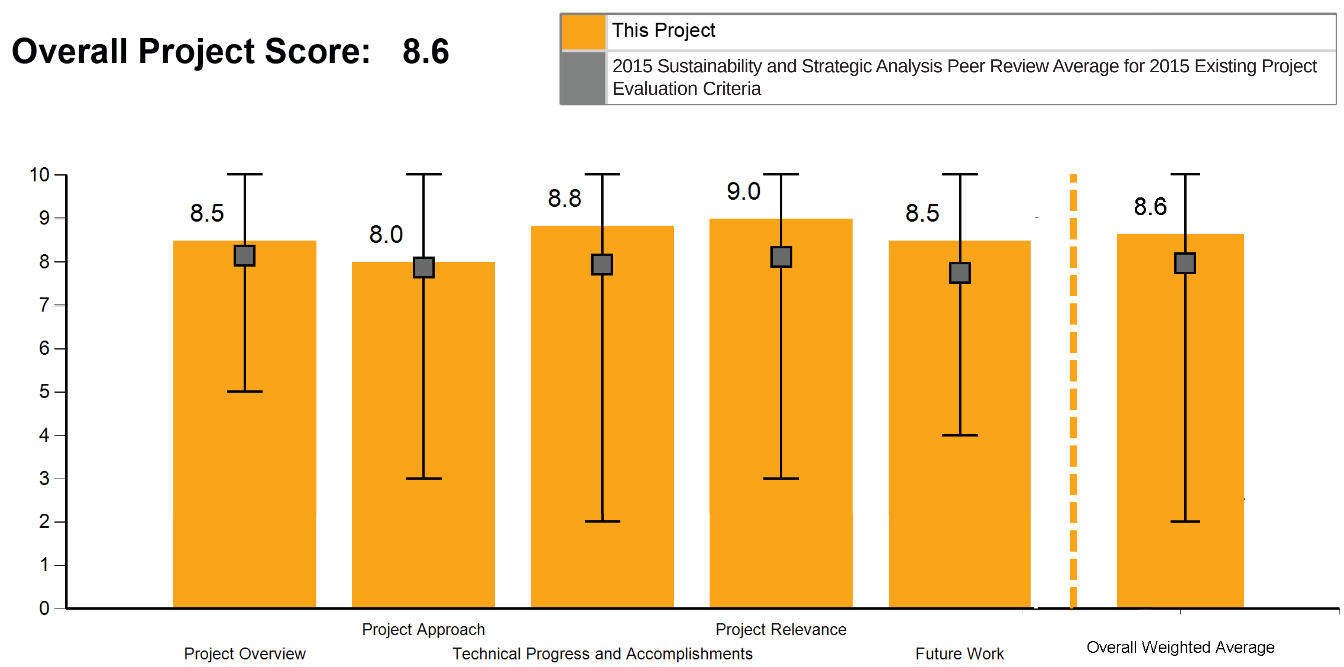
WATERSHED SCALE OPTIMIZATION FOR DETERMINING PREFERRED LANDSCAPE DESIGNS FOR SUSTAINABLE BIOENERGY FEEDSTOCK PRODUCTION SYSTEMS AT A WATERSHED SCALE

(WBS#: 1.7.1.6)

Recipient:	Purdue University
Presenter:	Indrajeet Chaubey
Total DOE Funding:	$1,592,385
DOE Funding FY13:	$343,055
DOE Funding FY11-12:	$888,226
Planned Funding:	$0
Project Dates:	9/2010 - 9/2015

Project Description

This project conducted a watershed-scale sustainability assessment of multiple species of energy crops and removal of crop residues within two watersheds representative of conditions in the Upper Midwest through the following four tasks: Task A: Collected 4,275 plot-years of bioenergy production data and have utilized the data to improve a Soil and Water Assessment Tool (SWAT) model for simulating impacts of bioenergy crop production on hydrology, water quality, and environmental sustainability. The improved model codes have been incorporated in the official SWAT model (version 612) distributed to model users globally. Task B: Developed watershed landscape scenarios and have evaluated their sustainability using SWAT model simulations, economic analyses, and ecosystem impact models under current and future climate change scenarios. The results indicate that bioenergy crops generally improve water quality and environmental sustainability in the Midwest. Task C: Developed methods to optimize selection and placement of various energy crops and have optimized bioenergy crop production strategies using both environmental and economic objective functions. The project method and results have been communicated through 8 peer reviewed journal articles, 5 thesis/dissertation reports, and 61 presentations at various meetings.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This is a good project and a good investment of DOE research effort to improve models for bioenergy applications. This is a fundamental investment and it would be good to extend this work to truly validate the improved SWAT model in other areas.
- The goals and approach to improve the SWAT model, to use the baseline to understand impacts at the watershed scale, and then to optimize the landscape scope of the project were clearly stated and well executed. Substantial progress has been made and is relevant to the rest of the BETO portfolio. Continued improvements to the SWAT model and validation of the tools were critical and relied on the data collected. The project has demonstrated significant improvements and used the model to look at potential impacts across various eco-systems. In the future, by using the tool, researchers will be able to better understand how a particular energy crop grows under various environmental conditions, under different management practices, and what eco-system benefits could result. Improvements to the model were made to make it more user friendly, but more needs to be done to get this work out to the potential users. This project is almost complete, with work to understand the impact of optimizing the current system and the integration of economics to be completed this year.
- I hope that the project does not miss the opportunity, in the final phases of the project, to translate this work to the stakeholder community, in particular the regulatory community that deals with water quality. I would have liked to have seen the project directly address why this was missing, given that the same request was made in the 2013 peer review.
- The approach taken by the project performers is excellent. It is designed to deliver outcomes that will be useful to other researchers working with models like SWAT to be able to extend the findings of the specific field trials conducted as part of this project. Thus, the flow of the work is from collection of data to improve models, followed by use of the models to optimize a range of scenarios for using energy crops. The amount of data collected in this project is truly impressive. Findings include data that has been used to enhance and extend existing models, and results include a broad range of agronomic, economic, and environmental performance data. These results have already found their way into 8 published peer review journal articles and 5 completed dissertations, with at least as many now under preparation. Overall, the project should serve as an exemple for the BETO Program in terms of its comprehensiveness and efficiency.
- This project includes an impressive amount of data collection. The quality of the database is excellent due to frequency of observations (daily) and range of variables considered. It offers a strong foundation for further assessment of environmental impacts and site optimization. The climate sensitivities considered and the simulations performed through this project offer a comprehensive analysis of bioenergy systems, and the capabilities developed through SWAT to fit a variety of crops and land types are an excellent feature. The comprehensive approach taken to integrate techno-economics, environmental impacts, and sensitivities would serve well as an example for other projects.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

PATHWAYS TOWARDS SUSTAINABLE BIOENERGY FEEDSTOCK PRODUCTION IN THE MISSISSIPPI RIVER WATERSHED

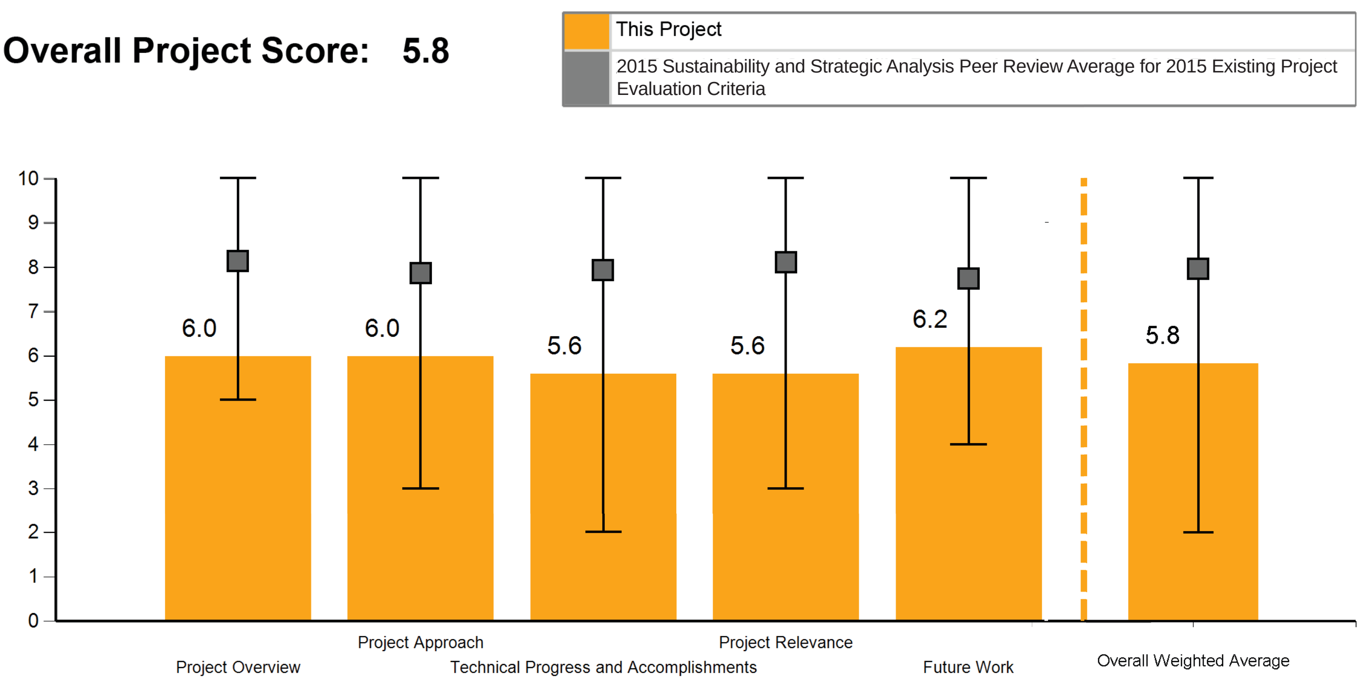
(WBS#: 1.7.1.7)

Recipient:	University of Minnesota
Presenter:	Jason Hill
DOE Funding FY14:	$146,854
DOE Funding FY13:	$95,663
DOE Funding FY10-12:	$121,280
Planned Funding:	$427,146
Project Dates:	9/30/2010 - 9/30/2015

Project Description

The overall goal of this project is to use an ecosystem service framework to evaluate the environmental impacts of various biomass production options and their placement on the landscape so as to guide the bioenergy industry toward greater sustainability. To this end, the project team is evaluating the biophysical and socio-economic tradeoffs of bioenergy production to provide results useful to a broad range of stakeholders including farmers, investors, the bioenergy industry, policymakers, regulators, and the general public. The modeling domain is the Mississippi River Watershed, which has been identified as having the potential to support a diversity of biomass feedstocks ranging from dedicated crops and crop residues, both herbaceous and woody. Analytical tools being used include the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) and Agro-IBIS (Integrated Biosphere Simulator) models. Future work will include expanded model runs to cover the entire Mississippi River Watershed, and the continued addition of likely biomass feedstocks given market conditions and end goals for environmental benefit. The outcome of this project will be an actionable set of recommendations for guiding sustainable growth of the bioeconomy by assisting stakeholders in making informed decisions about what bioenergy feedstocks to use, where to produce or collect them, and what environmental impacts they will have.

Overall Project Score: 5.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project has veered from its original mandate, which was to use an ecosystem framework to assess the impact of bioenergy feedstock production in the Mississippi River watershed, and is currently seeking to advance the quantification and valuation of ecosystem services, with a particular focus on air quality. Overall, the project was strong on the science and technical aspects but weak on project management. Crisper objectives and associated milestones would have helped to steer the project forward on a clearer path. The project showed significant progress and excelled at publishing and achieving visibility of the results. The work was innovative and introduces issues not previously raised. Looking at the health implications of different vehicle types and the fuels used on the changes in air quality is a novel approach and worth pursuing. The lack of information provided does not allow me to comment on the results. However, understanding the net return to society is important. Unlike many of the other projects, it is more of a stand-alone project so the impact on other BETO projects is minimal. However, future plans include integration with GREET. I also applaud the future work on the air quality for perennial grasses.
- I think it's telling that none of the other PIs cite this work, or their collaboration with this project. "Ecosystem services" goes beyond air quality. If this project ends in 2015, how much more time/capacity can be devoted to the important question of nitrogen/water quality? What about biodiversity? If one looks at the objectives of the 2013 Peer Report, what was achieved on those since then? Air quality work. There are other academes (e.g., UC-Berkeley) doing this same type of air quality work, so what was gained? A completely missed opportunity to synergize with ANL and ORNL, and to leverage USDA/AFRI work.
- The overall approach for this project involves assessing sustainability for biofuels in a consistent ecosystem services framework that translates these metrics into a common metric of dollars. This approach has pluses and minuses. On the positive side, attempting to put all of the metrics on a common economic basis could lead to a much simpler and consistent way to compare different pathways and technologies for biofuels. On the negative side, the translation to a common dollar metric is fraught with difficulty and subjectivity, leaving such an analysis prone to hidden bias and open to criticism. Nevertheless, such approaches to valuing ecosystem services are quite popular, and do carry weight in the research community. Unfortunately, this project's technical progress and accomplishments bear little resemblance to the goals and approach of the project. While future work appears aimed at getting back to the goals and approach originally established, performance to date does not bode well for its success.
- This project takes the approach of assessing the climate and air quality impacts of bioenergy production on a monetary basis. This comparative method, combined with the regional resolution of modeling outcomes, produces localized impacts, an effective means of communicating results. Further, the uncertainty analysis of bioenergy feedstock profitability with and without ecological service payments is interesting and informative to landowners. Opportunities for collaboration with other BETO projects analyzing air and water quality should be explored to capture synergies between similar efforts.

PI Response to Reviewer Comments

- Our most recent paper from this project has been viewed nearly 44,000 times since its publication in mid-December 2014. Its Altimetric impact score puts it in the 99th percentile of papers of a similar age in the Proceedings of the National Academy of

Sciences (PNAS), the 99th percentile of all articles in PNAS, and the 99th percentile of all articles ever tracked by Altimetric. It was widely covered by national and international media, including the Associated Press and The Economist. Furthermore, this paper passed peer review under the editorial service of the executive director of the Joint Institute for Strategic Analysis at NREL.

The paper described above is just one example of the high-impact work this project has generated. We also published a major policy piece that was featured on the cover of Environmental Science & Technology. This paper received widespread attention from federal agencies because it pointed out serious discrepancies among future biomass production scenarios produced by DOE, USDA, and EPA. We received many positive comments from employees of these agencies thanking us for providing this analysis. Overall, our project has had substantial impact, which is particularly notable given that it is one of just three Sustainability and Strategic Analysis Technology Area awards made to external academic partners in a competitive process, and it is by far the smallest of those three.

We have not veered from our original mandate, but rather we have focused in the middle of this project (Years 3 and 4 of 5) on effects on air quality because of the emerging realization of the importance of clean air as a critical ecosystem service, as well as our being well positioned to develop the tools necessary to assess it. Our future work will add on additional ecosystem services to our current suite of impact categories that includes air quality, climate change, and nutrient loss. We plan to continue our existing close collaborative relationships with the national laboratories, including ANL, NREL, and ORNL.

GREET DEVELOPMENT AND BIOFUEL PATHWAY RESEARCH AND ANALYSIS

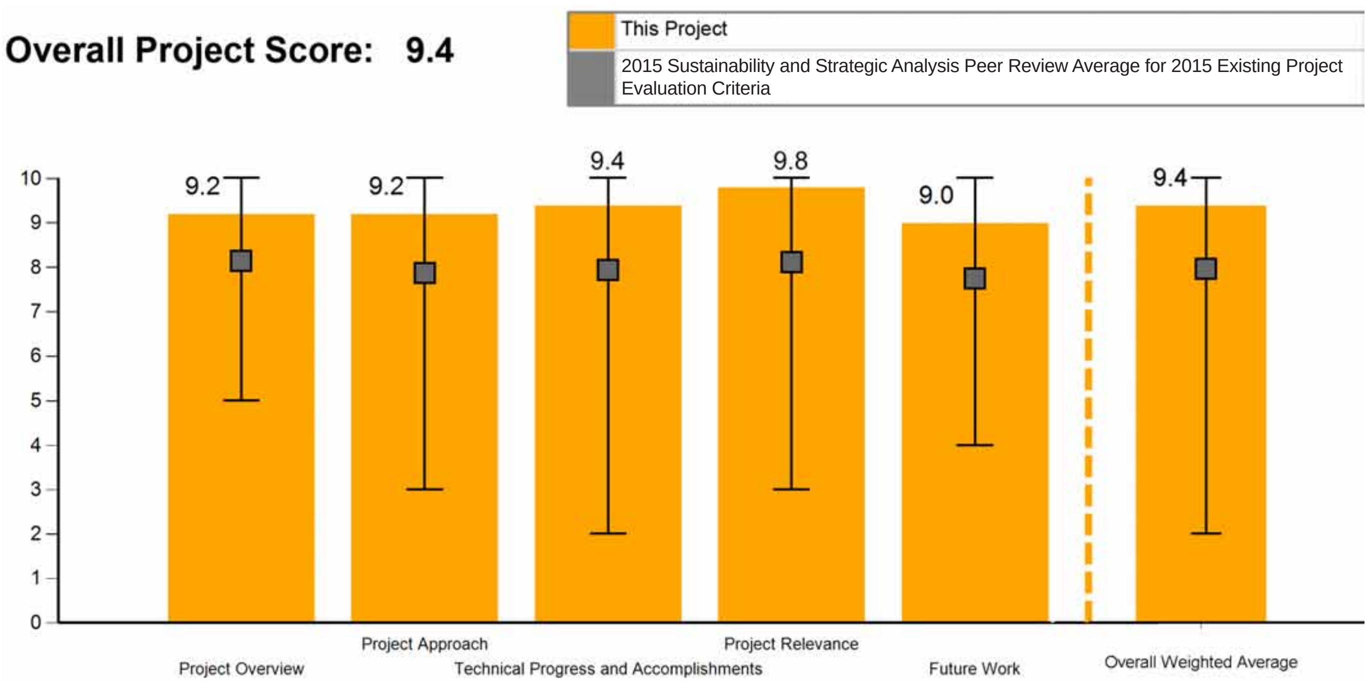
(WBS#: 4.1.1.10)

Recipient:	ANL
Presenter:	Michael Wang
DOE Funding FY14:	$214,692
DOE Funding FY13:	$415,809
DOE Funding FY10-12:	$204,455
Planned Funding:	$3,980,043
Project Dates:	10/1/2006 - 9/30/2017

Image Courtesy of ANL

Project Description

The first project objective is to develop a life-cycle analysis (LCA) model that supports BETO Sustainability and Strategic Analysis. This model, called Greenhouse Gas, Regulated Emissions, and Energy use in Transportation (GREET), quantifies the energy and water consumption and air emissions impacts (including GHG emissions) of biofuels. A second objective is to conduct LCAs and publish peer-reviewed studies. A third project objective is to engage and interact with external stakeholders including agencies, industry, and academia. Recent key accomplishments include: (1) refining analysis of baseline petroleum fuels, expand GREET to include black carbon emissions and water consumption; (2) expanding algal fuel pathways; and (3) developing supply chain sustainability analyses (SCSA) for key BETO pathways. This latter activity enables BETO to gauge full supply chain GHG emissions of priority pathways (e.g., pyrolysis) and identify the most critical directions for research and development to lower pathway emissions. Additional activities include the expansion of GREET to include modules for bioproducts, pretreatment technologies, rail transportation, and catalysts. Finally, improving estimates of carbon stock changes in domestic lands as a result of biofuel production has been another key area of activity. Overall, GREET-based LCAs of biofuels mitigate the lack of comparable and transparent LCAs and address key questions regarding the life-cycle impacts of these alternative fuels.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- GREET provides a consistent and rigorous tool to advance the understanding of biofuel sustainability by providing a consistent way to quantify the energy and environmental impacts of biofuels. It serves as a foundation of numerous projects and analyses. Its acceptance and use by the LCA community at large shows the relevance and impact the tool has had. It currently serves as an enabler of policies such as the Renewable Fuel Standard and Low Carbon Fuel Standard where assessing the greenhouse gas benefits of the various new fuel pathways is critical to the mandates. Great progress has been made since the last review. The expansion of GREET to include water consumption, black carbon emissions, and algal pathways was critical. Also, adding the ability to look at coproducts and biochemicals/bioproducts will be important as we move to a more integrated biorefinery approach in the future. Data is the key, and a rigorous attention to detail has made the model the success it has become. Efforts should be taken to ensure that the model's continued growth in scope and complexity does not come at the expense of transparency and utility. Another key to the success and impact of GREET is that it is open for public use. Current efforts are underway to make the model easier for users. Finally, because GREET has become the foundation for so many studies, further expansion will require the researchers to prioritize and focus on the overarching and most critical issues.
- There is absolutely no doubt that this project is used extensively by the policy community. Other reviewers expressed some concern about mission drift. In my opinion, however, if there is a vacuum within other entities that should be doing LCA work, then DOE should be a strategic leader and fill that vacuum. In this regard, as outreach, the group, and BETO, could pursue dialogues about how to create and harness systematic efforts to provide comprehensive LCA analysis for the entire policy space.
- Like the Biomass Scenario Model, the GREET model is a critical tool for providing environmental perspectives on bioenergy at a holistic, that is systems, level. One issue that should be considered as this tool grows in scope and complexity is how to maintain and even increase its transparency. Transparency and user access may have become more problematic as the tool has moved to a .net format and away from its spreadsheet roots. This is not to say that the tool should remain confined by the obvious limitations of a spreadsheet model. But as this new approach to GREET progresses, the project team should give deliberate thought to the balance between transparency and complexity. The life cycle assessment activities continue to expand into new areas of interest for the bioenergy program. In addition to new fuel pathways, life cycle activities have expanded to include products and even economy-wide assessments. New factors incorporated in the model include more robust assessments related to land use, change, carbon debt, and water usage. Finally, it is important to note that the GREET team continues to play an important cross-project role, acting as an important glue among economic and environmental activities.
- GREET continues to build upon its status as the standard for LCA data by enhancing user-friendliness, updating existing capabilities, and building new features (e.g., added representation of water consumption, black carbon emissions, and bioproducts), and regularly incorporating additional feedstock pathways. As GREET grows more complex, the creation of training tools to assist new and returning users is a valuable offering. The future incorporation of woody biomass pathways will be a considerable addition.

- GREET is so widely and heavily leveraged and relied upon, that the importance of continued transparency of the model and its assumptions cannot be overstated. Continued and even increased peer exchange and review between fellow federal agencies (EPA, USDA, DOD, DOT, etc.), as well as states (e.g., California), is highly desirable.

PI Response to Reviewer Comments

- The reviewers raised important concerns about model transparency multiple times in their comments. We share the concern that as the GREET model grows in scope and complexity, transparency may be compromised and the model could become unwieldy.

- As we responded in the Project Approach, we take several steps to maintain transparency. First, data sources, methodology, and assumptions that underpin the data within GREET are documented in technical reports and journal articles that are peer reviewed and maintained on the GREET website. In the GREET.net platform, as pathways are added to GREET, the model is annotated with the report or article URL such that it is easily located. Second, the availability of the Excel platform enables users to see deep into the model and access the raw data and formulae. Third, complex LCA issues such as land use change (LUC) are addressed in a standalone module in GREET so that users can readily follow the analytical steps to address LUC and deeply dive into critical issues affecting LUC. Fourth, we periodically conduct GREET user workshops to demonstrate new GREET features and to seek user input. Additionally, we maintain communication channels with users and stakeholders on their priorities and issues they encounter in understanding our LCA results and using the GREET model to refining our research approach and GREET design.

- Reviewers raised a concern that not all aspects of biofuel LCA could or should be analyzed in GREET. While we understand this concern, we have approached this somewhat differently. As the biofuel community has observed, some researchers have raised and analyzed some additional issues that the biofuel community did not. These have changed the biofuel sustainability debate considerably (and unfortunately resulted in serious setbacks of biofuel policy and R&D developments). From these experiences, we decided to address some emerging LCA issues proactively. In some cases, our LCA research shows that certain issues are not important and some issues are too uncertain to determine biofuel sustainability. We often get into detailed issues in order to shed light of their impacts on LCA results. For example, in the context of analyzing soil organic carbon, we collaborate with subject matter experts at the University of Illinois at Champaign Urbana. Further, to maintain its LCA focus, we keep some elements of our analysis outside GREET, such as the economy-level analysis, which is conducted in a new tool called Bioeconomy AGE that uses GREET and other data sources. Also, we maintain open lines of communication with BETO to identify gaps in the field of biofuel LCA and the role the GREET project team should have in addressing that gap versus other researchers internal or external to the BETO portfolio. We will stay mindful of excessive scope expansion and will target high-impact areas for research.

- Finally, reviewers encouraged increased stakeholder engagement and peer review with federal agencies (EPA, USDA, DOD, DOT, etc.) and state agencies. We agree that exchange with and review by other federal agencies besides DOE on our LCA research and the GREET model are critical to make Argonne National Laboratory's LCA research and the GREET model relevant and useful to R&D and policy developments. We will strive to maintain and increase these interactions with the aim of receiving feedback on existing analyses and input as to future direction in model development and research. As we stated above, we will have a GREET user workshop in the summer 2015 to demonstrate new GREET features and seek user inputs.

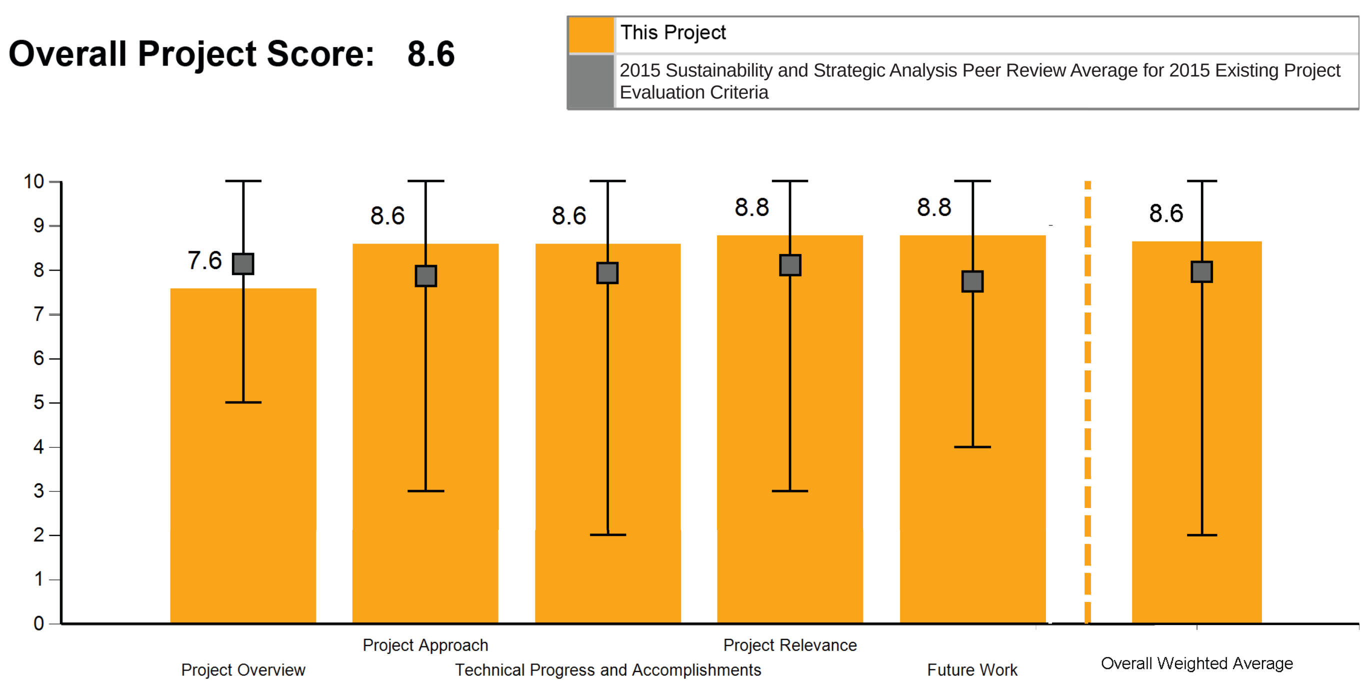
STRATEGIC ANALYSIS SUPPORT, BIOFUELS LARGE VOLUME MARKET APPLICATION ANALYSIS, ADVANCED BIOFUELS AND BIOPRODUCTS MODELING

(WBS#: 4.1.1.30, 4.1.2.30, 4.1.3.3)

Recipient:	NREL
Presenter:	Mary Biddy
DOE Funding FY14:	$700,000
DOE Funding FY13:	$900,000
DOE Funding FY10-12:	$2,000,000
Planned Funding:	$2,000,000
Project Dates:	10/2010 - FY15 - FY17

Project Description

The NREL strategic analysis project portfolio encompasses a wide set of analytical tools and expertise in support of the Bioenergy Technologies Office. Strategic analysis projects develop models and methodologies to understand the technical, economic, and societal impacts of the development of bioenergy. These models serve as an analytical basis for program planning and assessment of progress. Specifically, these efforts include: (1) the techno-economic analysis of the strategic expansion of hydrocarbon fuel technologies including to jet fuel production; (2) a market analysis to identify key drivers and hurdles for near-term industry growth of bio-derived chemicals; (3) optimization of an integrated biorefinery; (4) assessment of the value of bio-derived blendstocks to petroleum refiners; (5) a comparative analysis of the economics of energy production on a levelized cost basis; and (6) an estimation of job growth and economic impacts of bioenergy production. Critical to the success of these tasks is the utilization of high-quality data that is thoroughly documented and vetted. Key stakeholders (e.g., policy makers, bioenergy technology developers, and investors) are actively engaged in developing and reviewing the results of these analyses. Uncertainties associated with the analysis efforts are clearly defined and quantified.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project was not as innovative as some of the other projects but was instead very responsive to the direct requests of others. The results led to overall tool development and novel applications. In this time period, the focus was on biomass-derived chemicals, the economics of various jet fuel pathways, a look at optimal biorefinery economics, and finally, estimating the number of jobs created by the biorefinery industry. These are all critical questions and well worth pursuing. Significant progress was outlined for each of these areas. The project also showed good coordination with other models and groups as well. Transparency was key. Future goals include completing the biochemical analysis, expanding the jet fuel pathway work, looking at refinery logistics, and vetting other novel conversion concepts. The continued support by this project of other work going forward is essential.
- The 2013 Peer Review noted the general value of the project, and I agree. It aligns with the Sustainability and Strategic Analysis Technology Area by providing pathway, economic, and other analyses that form the foundation of particularly exciting, emerging uses of energy biomass. I do not see that the PIs fully implemented the advice in the 2013 report to "broaden its focus to answer other economic, social, and environmental questions, barriers, and showstoppers in a consistent, robust, and prioritized manner." Explaining and understanding the strategy in directing this research in one direction or another, and how feedback loops from the research contribute to strategy development, are so key to coordinating BETO research and ensuring integration, but this was not emphasized. The 2013 Peer Report states that the work "does not have the feel of a set of tasks actively engaged in the process of setting strategic direction." Despite the plenary's effort in explaining the strategic direction, this research's tie to that strategy in terms of driving it and being directed by it was not clear. This is unfortunate because connections and opportunities may be missed.
- This project represents a collection of projects with different goals, but all support high-level decision making for BETO. The first of these projects was based on work done in collaboration with Iowa State and ConocoPhillips. This project seems ill-conceived and its approach was not consistent with how other economic analyses are done within the BETO Program. This work is coming to an end and much of this work is transitioning to NREL's design report approach. The latter has a long history and is well developed. Of particular value in the design/TEA approach is its incorporation of both nth plant and pioneer plant costs. The approach underlying the BIOREFINE modeling and JEDI modeling is more difficult to assess, based on the relatively brief presentation provided for the peer review. The relevance of this project is very high, as the kind of analysis done here directly influences management decisions made by BETO. Here again, the TEA work has the greatest relevance. The refinery and blending optimization work is also important, but its value is hard to judge based on what has been presented thus far.
- This project makes strong contributions to the techno-economic analysis of multiple overshadowed bioenergy systems dynamics. In particular, estimating the market potential of bioproducts is an important effort for assessing the economic attractiveness of bioenergy options. The TEA approach is rigorous; the transparency of the methods and data along with sensitivity analysis offer great opportunity for continued exploration of bioproduct market opportunities. The JEDI model offers an opportunity for stakeholders to estimate the employment impacts of a given bioenergy system. The tool is limited in its ability to evaluate indirect impacts or endogenous response, but the direct impacts offered are still of value and clearly in demand given the number of public downloads the tool has had in recent years.

PI Response to Reviewer Comments

- We thank the reviewers for their helpful feedback and comments. We will continue to strive to develop analyses and modeling tools that support the strategic goals of the BETO program. We will work to further publish the results of our analyses in order to provide credible results to assist in decision making in bioenergy investment, as well as to address key questions and provide critical data needed for the strategic direction of BETO. We also thank the reviewers for their suggestions that this effort should "broaden its focus to answer other economic, social, and environmental questions, barriers, and showstoppers in a consistent, robust, and prioritized manner." We will continue to develop new analysis approaches and studies to broaden the focus of these projects. Further, we will continue to collaborate with and provide data to other BETO-supported analysis and sustainability projects, thereby allowing for a broader, multidimensional analysis to explore economics, sustainability and socio-economic impacts for the developing bioeconomy.

REFINERY INTEGRATION

(WBS#: 4.1.1.31, 4.1.1.51)

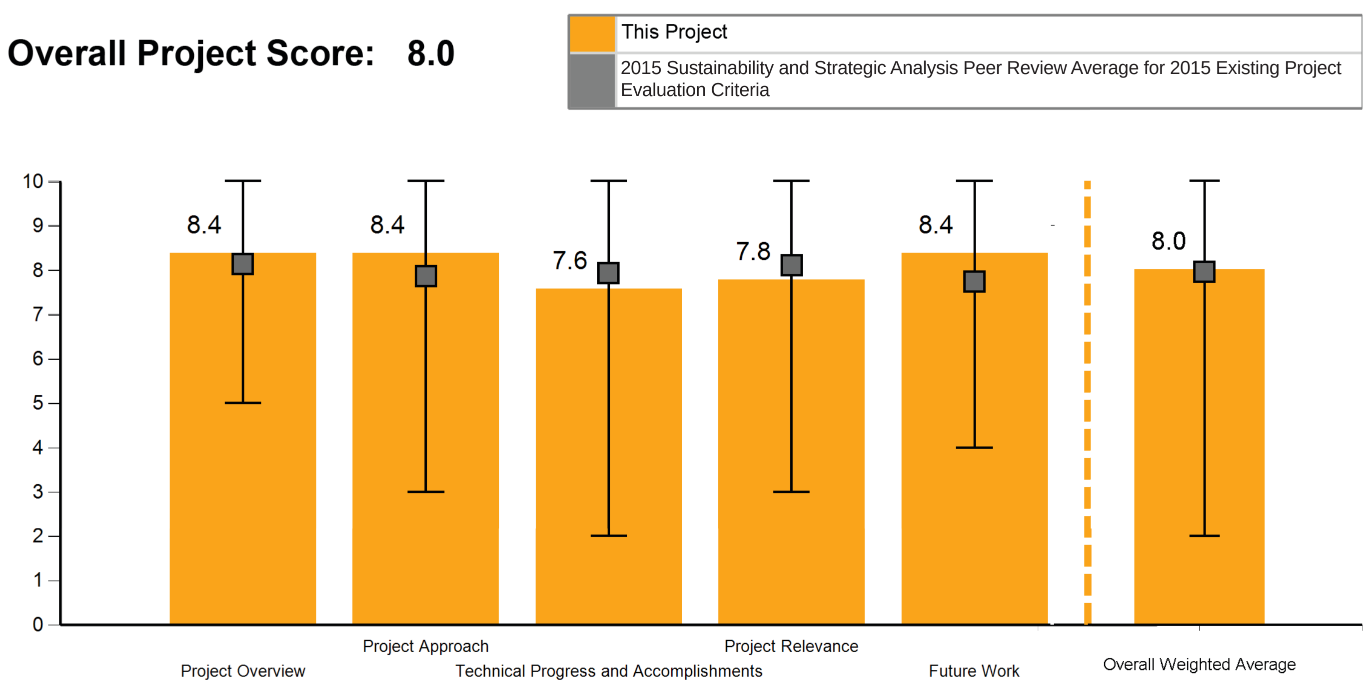
Recipient:	NREL, PNNL
Presenter:	Mary Biddy
DOE Funding FY14:	$339,396
DOE Funding FY13:	$192,722
DOE Funding FY10-12:	$65,295
Planned Funding:	$925,588
Project Dates:	10/1/2012 - 9/30/2016

Project Description

The project purpose is to evaluate and understand the economic incentives and key cost drivers associated with use of existing refinery infrastructure to produce biofuel hydrocarbon blendstocks. All biofuel design cases are based on standalone plants processing biomass to produce a finished fuel blendstock. However, use of existing infrastructure through integration with petroleum refineries is a means to reduce biofuels production costs. Currently, no tools are available to assess the impact of co-processing bio-intermediates with conventional petroleum. The project builds upon separate PNNL and NREL efforts to identify and develop synergistic opportunities for integration of biomass-derived hydrocarbons into existing petroleum refineries. It directly addresses barrier "Petroleum Refinery Integration of Bio-Oil Intermediates." At completion, this project will identify risks, key hurdles, uncertainties and further R&D needed for co-processing. Completed to date are preliminary Aspen models for hydrocracking and fluidized catalytic cracking, with and without bio-intermediates. Modeled results and preliminary costs were reviewed by refining contacts and refining catalyst vendors. Incorporating feedback is ongoing.

Overall Impressions

- The goals of this project were to look at what value bio-oil has at the refinery. Specifically, the approach was to model various insertion points in a refinery to co-process bio-oil intermediates. The researchers selected pyrolysis oil for their initial modeling. They had good stakeholder engagement, which helped to provide added information and feedback. As part of this research, they were able to model several parts



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

of the refinery, such as the hydrocracker and fluidized catalytic cracker, which allowed them to begin to understand the issues involved in co-processing. Because bio-oil could play a significant role in the biofuels industry in the future, it will be important to look at other oils such as algal oil, etc. Having done the initial modeling should make looking at these additional fuels easier. Getting good stakeholder engagement was key to making this project successful and continued discussions with refiners will be important going forward. Moving forward, it will be important to determine where the bio-oil can be added in the refinery process but also the key specs or requirements (oxygen content, acidity, etc.) of the bio-oils themselves. There is also a need to determine best practices, optimal bio-oil characteristics, the changes required at the refinery, impacts on refinery equipment such as metal and seals, etc., as well as whether or not the added bio-oil generates a RIN and the economic impact of adding bio-oil will have. Good start on a complex issue.

- BETO appears to have heeded the comments of the 2013 Peer Review. The project has the right partners and direction. It isolated two processes for the development of process models. I am not quite sure why hydrocracking and fluid catalytic cracking (FCC) were chosen, however, over other processes. The economic analysis of the value of bio-oil outputs seems very important in order for refiners to choose alternative feedstocks. I would like to see the sustainability LCAs of these outputs compared to conventional oils. Thus, it will be important to incorporate collaboration with GREET in future work.
- The project offers potentially important insight into the economics of integrating pyrolysis oil intermediates directly in a petroleum refinery. The effort to perform rigorous bio oil characterization and process modeling of its impact on unit operations within a petroleum refinery is commendable. It seems that the research team has made good progress on the modeling, and obtained good technical feedback on their approach from experts within the petroleum refining industry. However, it was disappointing not to see any actual results presented before the peer review panel. Did this first round of analysis and modeling suggest that there is an economically viable path to bio-oil integration in the refinery?
- This project addresses an important research area of bio-oil integration into refinery processes. The PIs have focused heavily on stakeholder engagement with refiners, a vital approach considering the technological precision of refining operations. While there is a lot of work still to be done, outcomes from this project could have significant implications for future bio-oil integration.

PI Response to Reviewer Comments

- Thank you for your helpful feedback and comments. The original modeling methodology was based on the difference in heating values between the feed and the products (including the unconverted feed) for blends as compared to a 100% petroleum-based feed (VGO). This was done because, at the time, we had little confidence in the densities calculated by Aspen—a result of using estimates and user defined compounds for the bio-oil. Industry feedback clearly impressed upon us the fact that refiners use volume swell, and only apply that to the converted portion of the feed. Thus, we were uncomfortable publishing cost results that will likely be changed. To address this, we now are working on a method that will overcome the density issues and will enable us to use a more traditional approach for estimating the cost differences.

  FCC and hydrocracking were chosen initially for a number of reasons. First, the identified biomass-derived intermediates are feedstocks with a broad boiling point range that require a reduction in the molecular size to produce fuels and precursors in the gasoline and distillate boiling range. Second, per EIA's 2014 Annual Energy Outlook (AEO) report, the transition of the fuel pool to a higher diesel and lower gasoline demand has a large impact on petroleum refinery operations. The utilization of FCCs is expected to decrease due to lower gasoline demand, which provides an opportunity to supplement this processing availability by using biomass-derived intermediates. Alternatively, hydrocracking demand is expected to increase, which would allow biomass intermediates to potentially supplement the petroleum feedstock. Further, both NREL and PNNL have processing equipment capabilities to perform detailed experiments and explore the utilization of these two process units for the co-processing of biomass-derived intermediates with petroleum.

- We agree that sustainability issues are important to any bio-fuels production scheme and we will consider co-processing implications on sustainability to the extent possible in this project.

SYSTEMS ANALYSIS

(WBS#: 4.1.2.1a)

Project Description

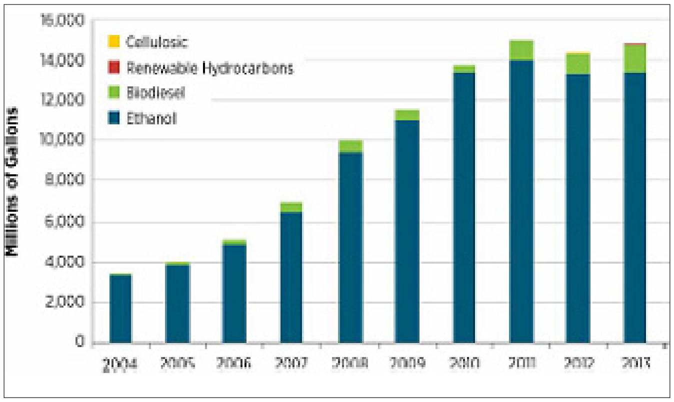
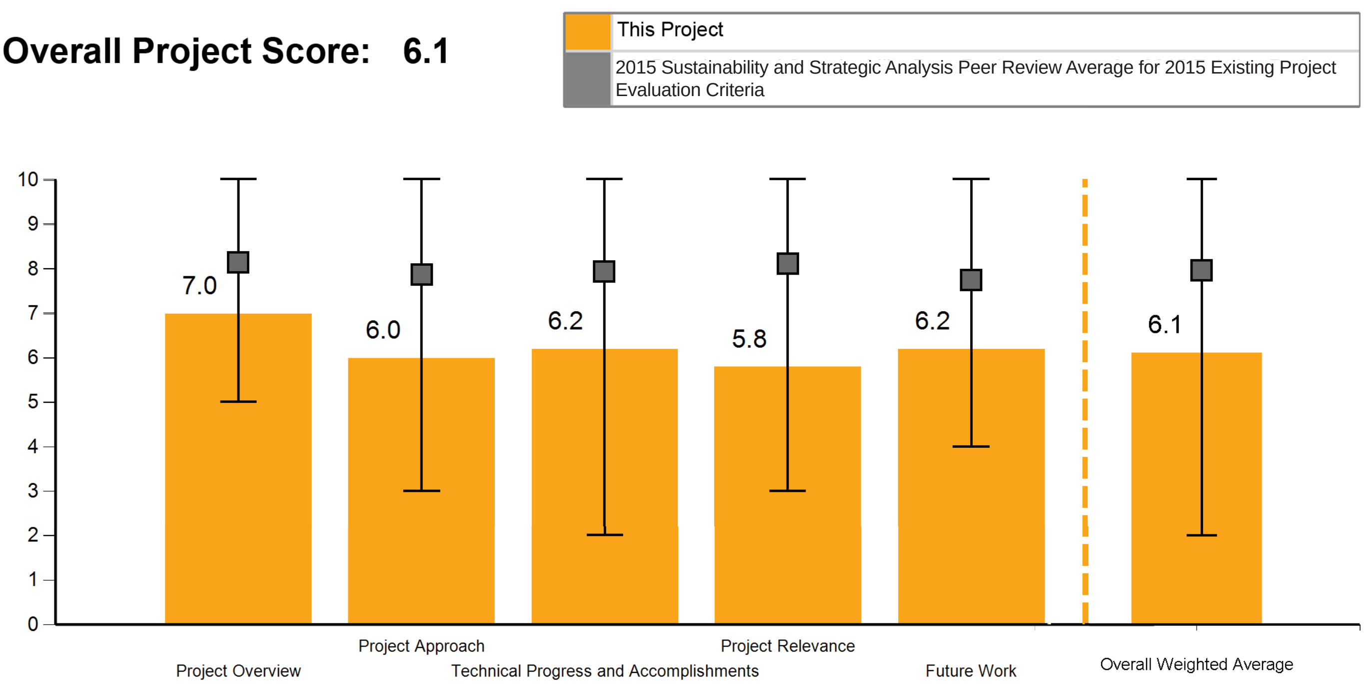


Image Courtesy of NREL-SIG

Recipient:	NREL-SIG
Presenter:	John Lewis
DOE Funding FY14:	$2,968,133
DOE Funding FY13:	$956,646
DOE Funding FY10-12:	$1,438,578
Planned Funding:	$9,731,153
Project Dates:	10/1/2013 - 9/30/2017

The development of domestic biorefineries faces several market barriers including feedstock availability, production costs, investment risks, consumer awareness and acceptance, and infrastructure limitations. Developing a sustainable, commercially viable national bioenergy industry will require understanding cross-system and cross-sector trade-offs and impacts, analysis of external factors on accomplishment of goals, and analysis of possible unanticipated effects. This project utilizes a systems integration approach to provide a systems-level perspective on the domestic bioenergy market and supply chain (from feedstock supply to bioenergy infrastructure). Key outcomes of this project include: documenting the status and development of the domestic bioenergy industry; tracking the commercialization of viable bioenergy technologies that enable sustainable, nationwide production of biofuels; and timely systems-level analysis on topical issues relevant to the bioenergy industry. The results of this project have been published through a series of internal reports, technical reports and journal articles.

Overall Project Score: 6.1



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The overall objectives of this project are to supply an annual update and analysis of the bioenergy market and provide insight into the state of commercialization of new bioenergy technologies. The approach is a worthy one and centers around aligning and integrating efforts across the various BETO projects. The researchers showed great progress on a number of different project initiatives. One such project was an annual survey of advanced biofuels in 2013. My concern is that this work is duplicative as there are many other "lists" out there, which highlight this type of information. Since this is a specific request, it might be useful to discuss the value the work brings and if there is a way to streamline the work, making it more efficient and more current. I also question the U.S. focus and would argue that it should be global rather than U.S.-centric. I applaud the plan to add bioproducts to the report. Co-products have proven to be an enabling technology for corn ethanol plants. Identifying new opportunities to support BETO's projects concerning new conversion pathways or bioproduct development would also be valuable.
- Whether or not this work is repetitive of other efforts is a burning question. BETO and the PI should definitely explain the motivation for this project.
- There is definitely value in regularly updating the status of the biofuels industry and the marketplace in general. But BETO management should rethink the approach taken here. Producing a new survey of the industry seems redundant relative to the efforts of many other groups.
- While the objectives of this project are admirable, and the information being gathered useful, there are multiple private services that collect and report similar information. Therefore, absent the development of significant analytic capabilities, this project does not seem to provide much value to BETO.

PI Response to Reviewer Comments

- The PI would like to highlight that the market report was a specific request from Assistant Secretary Danielson. The goal of the report was to provide a document similar in scope to market reports produced by other offices within DOE. Moving forward, the PI and BETO will investigate opportunities to streamline the project scope to leverage related reports and minimize redundancy of efforts.

BIOMASS SCENARIO MODEL

(WBS#: 4.1.2.1b)

Recipient:	NREL-SIG
Presenter:	Brian Bush
DOE Funding FY14:	$950,000
DOE Funding FY13:	$800,000
DOE Funding FY10-12:	$2,400,000
Planned Funding:	$2,700,000
Project Dates:	10/1/2006 - 9/30/2017

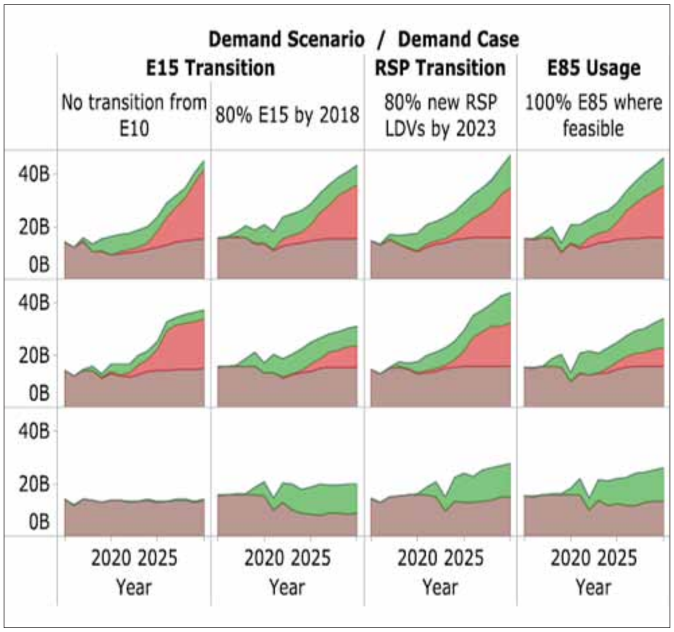
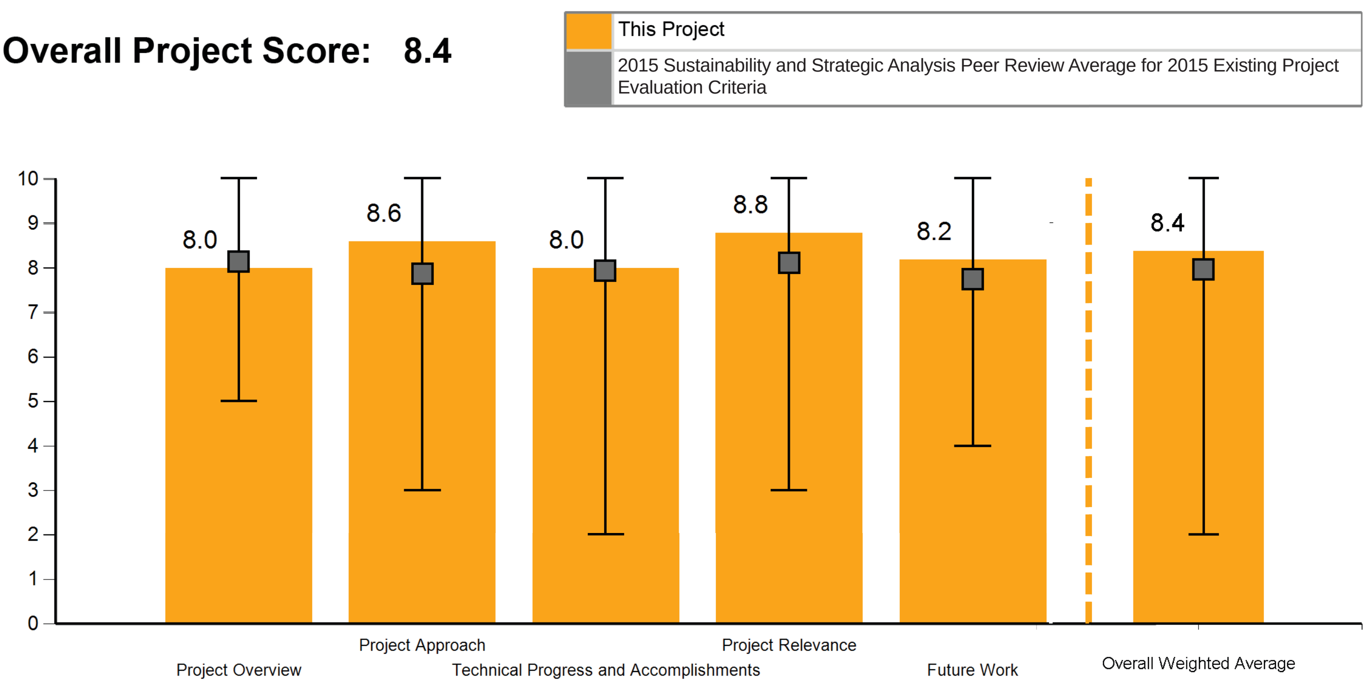


Image Courtesy of NREL-SiG

Project Description

The Biomass Scenario Model (BSM) is a unique, carefully validated, state-of-the-art, fourth-generation model of the domestic bioenergy supply chain which explicitly focuses on policy issues and their potential side effects. It integrates resource availability, behavior, policy, and physical, technological, and economic constraints. The BSM uses system-dynamics simulation to model dynamic interactions across the supply chain; it tracks the deployment of biofuels given technological development and the reaction of the investment community to those technologies in the context of land availability, the competing oil market, consumer demand for biofuels, and government policies over time. It places a strong emphasis on the behavior and decisionmaking of various economic agents. The model treats the major infrastructure-compatible fuels. Scenario analysis based on the BSM shows that the biofuels industry tends not

Overall Project Score: 8.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

to rapidly thrive without significant external actions in the early years of its evolution. An initial focus for jumpstarting the industry typically has strongest results in the BSM in areas where effects of intervention have been identified to be multiplicative. In general, policies which are coordinated across the whole supply chain have significant impact in fostering the growth of the biofuels industry and that the production of tens of billions of gallons of biofuels may occur under sufficiently favorable conditions. Near-term future work will focus on select feedstocks (clean pine, whole tree pine, hybrid poplar, switchgrass, and corn stover) and blends of these feedstocks to perform comprehensive conversion and upgrading experiments from which predictive, multivariate conversion models will be built.

Overall Impressions

- BSM offers the rare opportunity to stimulate thinking and generate insights across the biofuels value chain. The present focus is on the deployment model analysis which looks at how rapidly biofuels could be deployed across the U.S. and what the major obstacles are to getting high volumes of renewable fuel into the market place. This review focused on scenario analysis interactions between the government and the marketplace. While this model is complex, it does enable discussion around these issues, which is good. The project approach appeared to be thorough and carefully cautious. This level of detail is important in a model like this since complete validation is not always possible. The current approach includes a move to a more flexible and modular architecture. The BSM is well integrated into BETO's objectives and brings all aspects into one model. The question is how can we use the tool to have an impact? The key will be performing analyses that can inform decision makers. Making the model accessible to the public would be a start, and plans are underway to release it to the public in three years. Adding biogas and bunker oil to the model, as well as adding bioproducts, are all good additions. I would encourage strengthening the alignment with other models as you have done with the vehicle choice model and Polysis, etc. Good communication between team members and with other researchers is key here. This is great work. You just need a way to get the message out and make it more accessible.
- The value of the project is clear and the work has been translated well, except to the extent where the BSM model is difficult to use for a layperson not familiar with tableau. Could you publish some exemplary results using nice graphics, which could then be used to understand the elements of the scenario builder and how to run it? You could also create a YouTube video. Why not build a webpage on the NREL site to introduce the work, and then link to KDF? There are so many neat ways to interface this with the public. You should bring on, either into this group or in BETO, communications professional(s) to make this better translated and usable to the public.
- System dynamics is a powerful tool for combining quantitative and qualitative elements of behavior in a holistic context. It thus offers a tremendous opportunity to assess sustainability of bioenergy in its most complete sense. Done properly, it can also be a powerful learning tool for unraveling the complex web of assumptions that underlie our mental models about what hinders and what helps move bioenergy forward along a sustainable path. For these reasons, the Biomass Scenario Model can and should serve as a capstone in the collection of analytical tools in this program area. The BSM has clearly become a central connection point for much of the analysis conducted in this program area. Its ability to tie together the disparate pieces of analysis that comprise this program area is a tremendous asset to the program. The project team should make more effort to open the model up to others outside the internal management team within BETO. Doing so will achieve a number of important things: (1) it will introduce fresh thinking into DOE's strategic and tactical planning; (2) it will raise the level of

thinking among policymakers (something desperately needed given the unfavorable consequences of the major policy efforts involving bioenergy over the past few years); and (3) it will educate a broader audience, including the general public, which remains confused by the contradictory expert claims about bioenergy that hit the mainstream press. Finally, a simpler version of the model (referenced in the response to reviewer comments) should be made more publicly available. While there is concern that use of the BSM by outsiders may inadvertently bring DOE's imprimatur to ideas and views of others, access to the simpler model separate from the tool used by DOE management may mitigate this concern. Further, the added insight and transparency of such a move will pay huge dividends.

- The BSM helps build understanding of bioenergy and system dynamics in a holistic manor. This is an important contribution to policy makers and stakeholders. The model's flexibility, complexity, and openness offer a strong platform to root analysis of important policy and data questions. There is a fair amount of uncertainty regarding the data and inputs (naturally), but the transparency of BSM combined with the detailed set of inputs offers quality means for investigating data, assumptions, and policy scenarios. Further, the superb functionality of the model offers opportunity for rapid and thorough investigation of uncertainties. The integration of BSM results into KDF is an excellent arrangement that provides broader exposure for the tool.
- Increasing the open availability of the products of this project would greatly benefit the bioenergy industry and research community.

PI Response to Reviewer Comments

- The project has contributed to a significant body of published literature available to all interested audiences. Please see the "Major BSM Publications" slide of the project presentation and *https://www.zotero.org/groups/bsm_publications/items*. Among publications about the model, we recommend Peterson (2015) as a summary that is relatively accessible to audiences interested in modeling. However, the format and content of these publications may not be as transparent nor as broadly accessible as the reviewers' comments recommend. We appreciate the reviewers' suggestions that the BSM model and results could be better translated and usable for lay audiences, the bioenergy industry, and the research community. Reviewers offered detailed and insightful rationales for outreach and engagement beyond academic publications and analytic support to BETO. Publications alone do not accomplish all of the important objectives that the reviewer outlines for a more open outreach effort. We also recognize that we can do a better job in conveying the strategic importance of scenario analysis to all audiences. Selecting target external communities for engagement, and designing appropriate engagement and communications strategies are a challenge, and ongoing need for the project remains a topic of discussion within the project team and with BETO.

Reviewers highlighted the value of public dissemination of the BSM or of a simplified version of the model. The idea of model simplification is especially important in light of transparency and accessibility goals, which are critical to the potential role of the model as a learning tool. We are pursuing publication of a learning model that is based on learning in the BSM and have developed a model of the competition among different uses of biomass resource uses (E. Newes, et al. 2012), which could be a precursor to a simplified model for public release. We agree that a simplified version could be a valuable contribution to the public domain, while noting the concerns about the potential for a model to be used in ways that neither we nor BETO might condone. The three-year project plan aims for public release of the full model, but that decision may be modified based on consultation with BETO. We are actively engaged with BETO to further realize the potential of BSM to enable holistic learning and understanding of system complexities and contribute to advancing biofuels sustainability.

Reviewers noted that the project has addressed timely and interesting topics, and they suggested additional topics that would expand the model's scope (including biogas, bunker oil, and bioproducts) and increase its impact (including analysis of risks and policy impacts). We continually evaluate the boundaries of the BSM and endeavor to address important questions that are deemed within the scope of the model, and analyses of additional products can often, but not always, be accommodated within our resource constraints. Risks and policy impacts are topics of considerable interest, and we continue to seek productive analytic context for contributions to these questions, while noting the limits of analytic approaches to political questions.

We appreciate the numerous positive comments that the reviewers offered, and are grateful to the reviewers for their time, consideration, and support. In particularly, we are glad that the reviewer found useful the overview of project history, accomplishments, and connection to BETO's mission. We are pleased that our attention to collaboration, outreach, adaptability, and defensibility of inputs is apparent. We thank the reviewers for pointing out the tremendous potential of the BSM to serve as a capstone analytic tool for holistic analysis and powerful systems insights. We appreciate that our project approach, planning, and success factors are deemed logical, well-defined, and well-communicated. We are happy to hear that the reviewers find BSM analyses timely and interesting.

ECONOMIC ANALYSIS OF POLICY EFFECTS

(WBS#: 4.1.2.20)

Recipient:	INL
Presenter:	Jake Jacobson/Jason Hansen
DOE Funding FY14:	$239,959
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$660,041
Project Dates:	10/1/2013 - 9/30/2017

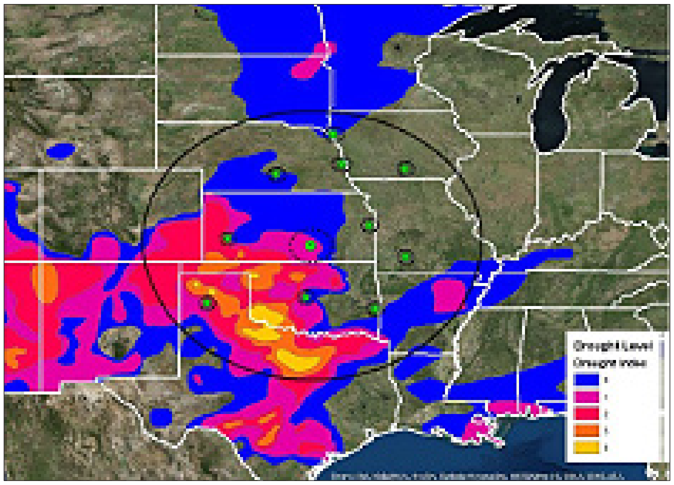


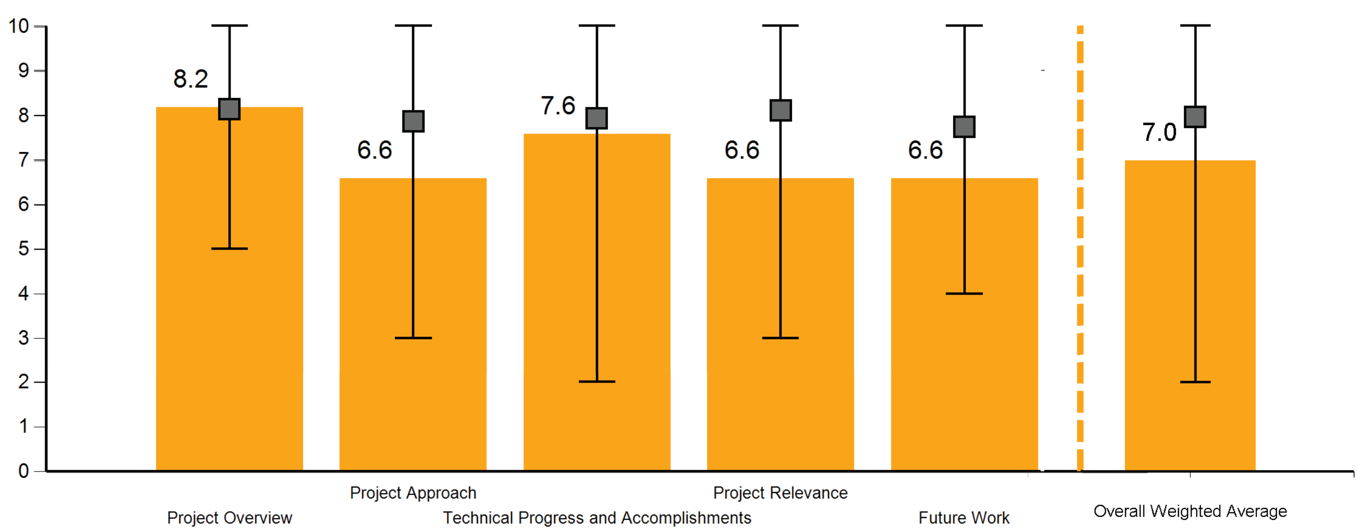
Image Courtesy of INL

Project Description

The goals of this project are to identify the risk factors inherent in the biofuel supply system, translate risk factors to cost and supply implications, and identify polices and strategies to minimize market and supply chain risks. The supply system is sensitive to market and supply chain disruptions. “De-risking” the bioenergy industry means knowing what points in the supply system to leverage to mitigate market and other risks. This work analyzes market risk implications and co-product competition on the success of the biofuels industry and on its supply chain, focusing on policy and strategies to minimize risks. In FY14, this work surveyed the bioenergy industry to identify a set of critical risk factors and analyzed the policy impact of RFS2 on the RIN market. In FY15, it examines bioenergy co-product markets, analyzing risks and opportunities. The project identified market and technology drivers, statutes and policies, then analyzed impacts in terms of risk to the industry. Project success is determined by relating costs and risks, developing risk reduction strategies and informing on policy implications. Experts from industry and academia validated the importance of market and policy analysis, and the relevance of risk analysis on success of the bioenergy industry. Building on the types of models

Overall Project Score: 7.0

(orange)	This Project
(gray)	2015 Sustainability and Strategic Analysis Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

used in this project, we will develop a policy analysis capability that BETO can use to ascertain quick insights and understanding for various policy, market or program decisions.

Overall Impressions

- The project involved identifying strategies to reduce risk in the biofuel supply system, understanding the implication of those risk factors, and then identifying strategies or policies that could mitigate that risk. While the approach is relatively straightforward, the challenges will be in understanding the interactions and being able to understand individual effects in the complex system. While still early in the project, the researchers have been able to identify a number of risk factors and gather data on the implications of these risks such as the economies of scale at biorefinery scale and the uncertainty around the quantity of corn stover available due to drought and other extreme weather events. These and other results have led the researchers to look at mitigating risks with diversification and a depot approach. The depots would cost money but could lead to considerable cost savings in other areas such as better access to capital and reduce financing risk, etc. The depot idea is innovative and worth exploring. Due to the issues around the density of agricultural residues, having local depots to preprocess and densify the material prior to transport to larger regional refineries makes sense. This project should help direct future development once it is completed.
- Overall, economic analysis of policy choices is very important. The areas prioritized make sense, but the PIs need to explain more specifically why those areas are of most risk. The project needs to demonstrate that a comprehensive literature review has been conducted, and collaborations with the many academics working in this area have been established. The project needs to do a much better job of surveying the field of risks and demonstrating a methodology for why one is prioritized over another. Otherwise, the choices look haphazard. BETO definitely needs to consider, in light of all the policies that may contribute or alleviate risk, how a project could ever comprehensively take these into account at this budget level. Other institutes/efforts put much more capacity into these types of economic analyses of policy projects. The "policy interest of the day" approach is otherwise haphazard and it's unclear how it ties into other BETO projects. I do like the depot analysis, but again, there are other academics considering this and collaboration should be tight with those.
- On a superficial level, the findings from this project vis-a-vis the effects of risk and policies on the supply chain for biofuels and byproducts make sense. But they seem to add little new insight to inform program managers in BETO. There is no information about the nature of the dynamic computer model used to garner insights about market and supply chain behavior. In addition, the work seems somewhat unfocused. BETO should rethink the value of this task, particularly with respect to other analysis platform activities.
- This is an interesting project, addressing a long-standing concern of bioenergy with a novel approach. There are seemingly promising collaboration opportunities between this project and others in BETO's portfolio that assess the air quality impacts of bioenergy systems. The bioenergy community would benefit from deeper, integrated assessment of the economic and environmental costs and benefits of traditional supply versus depot systems.

PI Response to Reviewer Comments

- The reviewers brought forth a valid, general concern; the project's attempt to analyze policies that impact the bioenergy industry have led the project, as one reviewer notes, "all over the map." We acknowledge this concern and are now redirecting the project's focus to be a clearer analysis on supply chain risk to biorefineries. To reflect this change of focus, the title of the project has been changed.

The project's goal is to develop a methodology for quantifying supply chain risk such that supply chain designs can be certified based on cost and risk. Within the supply chain, probabilistic challenges create excess cost and thereby increase the probability that logistics costs will exceed the established Feedstock Platform target logistic cost of $80/dry matter ton. Uncertainties in unit processes within the supply chain potentially increase costs of feedstock supply, waste treatment, and disposal to name a few. Engineering-based optimizations then underestimate cost because cost increases from variability in supply are not included, thus limiting a biorefinery's certainty of business feasibility. Developing methods to quantify probabilistic supply chain challenges will enable accurate, quantitative comparisons. For example, comparing minimalist supply chains to advanced technologies where controls can be put in place to manage variability will be based on accurate representation of cost and risk. This will enable well-informed tradeoffs between costs to implement advanced controls and risk mitigation achieved so that an economic optimum may be attained. Certifying supply chain designs based on cost and risk in annual reports of the State of Technology is an important step in transitioning promising technologies to commercial viability, thereby providing context and justification for decisions.

LAND USE CHANGE DATA AND ANALYSIS

(WBS#: 4.1.2.40)

Recipient:	ORNL
Presenter:	Nagendra Singh
DOE Funding FY14:	$247,712
DOE Funding FY13:	$269,920
DOE Funding FY10-12:	$273,857
Planned Funding:	$608,512
Project Dates:	10/1/2009 - 9/30/2017

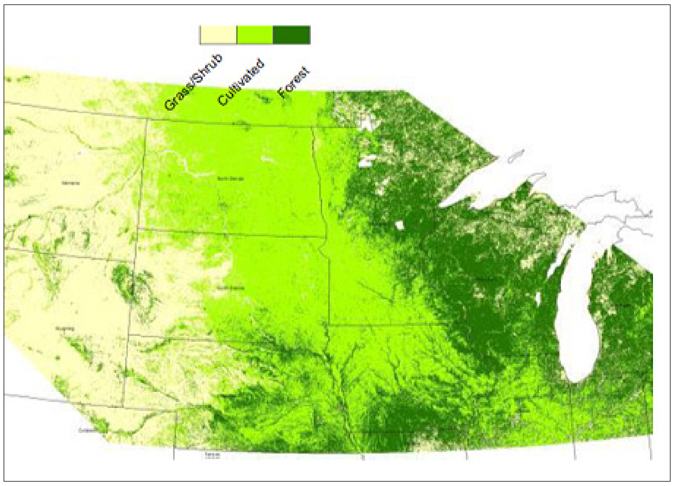
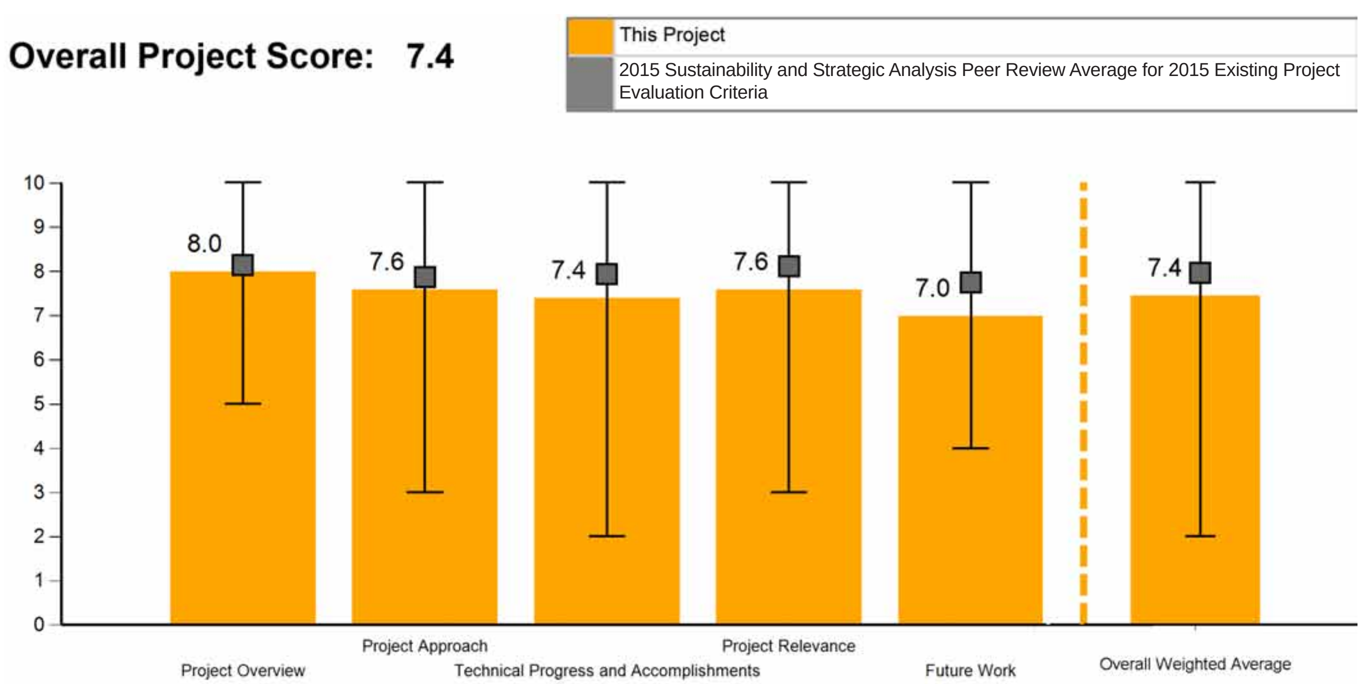


Image Courtesy of ORNL

Project Description

The objective of this project is to develop a novel land cover change detection method using biweekly Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. Though there have been a few studies in the past that used MODIS data for crop changes, most of these methods cannot be scaled over large areas due to computing constraints or cannot be applied (without being supervised or without requiring large amounts of ground-truth data) over any selected region. This project proposes to develop a semi-supervised method, which targets to attain the same accuracy as the supervised methods but works with very limited ground-truth data. A user with limited ground samples can calculate changes between two time periods using the MODIS data. This capability will remove several barriers present in analysis and sustainability studies of bioenergy due to lack of consistent land use data and models. Ultimately, the goal of the project is to convert the model into a monitoring and visualization framework where changes in land cover between two time periods for any part of globe can be analyzed and visualized. This will provide a unique capability for stakeholders to identify



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

areas undergoing rapid change and its impact on the environment. Once areas with significant changes have been identified, detailed assessments of water quality, resource availability, and sustainability, as well as an analysis of the impact of climate change and population, can be performed on these areas.

Overall Impressions

- Designing and developing scalable tools and methodology to understand the impacts of bioenergy policy on land use management has global applicability. In this project, data mining and machine learning were used to look at land use change. This is an interesting approach which tries to measure what has actually happened over time. This is particularly important when trying to determine cause and effect. While having a simpler, data-driven way to measure land use change (LUC) would be informative, the model is not there yet. Further refinement of the model and validation of the results are needed. It would be great if the model could be expanded in the future to look at what impact climatic events, major disruptions, and population growth, etc., have on land use change. I would urge the team to work on getting this tool into the public domain for use and further development. At this point, the model does not have the ability to make definitive quantitation but certainly provides enough resolution to inform the discussion. I think that the model will develop with time and could provide a clear method for quantifying LUC. It would be good to see how this model interacts with other BETO-sponsored models and other BETO work.
- I agree entirely with the 2013 Peer Review report, in that the project has the "potential to supply valuable data and analysis to assess land-use changes as a result of biofuel production." The PI has been successful in addressing the concern about gaps and filling them. The next review will be key in terms of generating some results, which in turn help validate the usefulness of the exercise. It will be key to tackle uncertainty as much as possible; that is always the criticism of models that try to predict land use change. I'm pleased that this will occur through using frameworks to generate, and the generation of real data. I would like to see the PI engage in responding to other efforts to find causality (e.g., the recent publication by Holly Gibbs).
- This project has shifted its approach from a focus on an epidemiological understanding of causal relations in land use change to one in which data or evidence usable to test such causal relations is being collected. This is a welcome shift, given the difficulty (and possibly futility) of trying to assign clear linear pathways of cause and effect in such complex systems. Nevertheless, there is still some concern that the ultimate aim of this research is to chase down an ephemeral truth about the direct causal relation between bioenergy expansion and land use change. On the plus side, if the focus here is to develop a system that can offer real time or near real time information on land use change, then this is ultimately valuable. Without a doubt, when it comes to land use, we need to shift from driving a car by looking in the rear view mirror to one in which we are looking where we are in real time. As to future work for this project, there seems to be a huge leap from the technical progress and status of this work to the goals established for future work. Technical progress seems to be at the level of early demonstration of a methodology, while goals encompass very ambitious and broad goals of "understanding" land use change globally. More specificity in achievable milestones is needed.
- This project is taking a novel and commendable approach to understanding drivers of land use change. The use of satellite imaging along with the assessment of empirical relationships is a commonsense method for determining causality. This project has the potential for great relevance in academic

and policy making settings, but transparency of the causal framework being developed will be essential for establishing credibility. More information is needed on the assumptions being made behind the scenes to accurately assess the merits of the results being developed.

PI Response to Reviewer Comments

- We certainly agree that all input data and assumptions need to be transparent and more effort should be dedicated to analyzing actual data and testing hypotheses using scientific methods. We received significant contributions from various national and international experts and incorporated it in the causal framework design. If this work were to resume, we would look forward to engaging stakeholders
- We have not claimed or scoped in the future work plan that we will understand and model global land use. However, our aim is to develop scalable tools and solutions, i.e., those which can be scaled computationally for large areas or time periods, as well those which can be scaled spatially in terms of parameter variability (vegetation types, etc.).
- The algorithms and models are being developed in such a way that they can be used in any part of the globe. Once the algorithm has been rigorously tested and validated for a test area, scaling up it to global scale can be achieved fairly easily.

We would be happy to prepare a documented response to Lark, Gibbs, et al, if this is a priority for BETO. The work by Lark, Gibbs, et al., suffers from the same drawbacks as the paper by Wright & Wimberley to which our response was published by PNAS in 2013 (see bibliography in the Peer Review presentation). Some of these results were due to data aggregation, merging land cover classes and high misclassification errors in the derived land cover data. We had a conversation with Lark and Gibbs in April, 2015, and made them aware of potentially misleading assertions published in their study.

Over the next two years, our focus will be to rigorously test, refine, and validate the land cover change algorithm. Our future goal would be to take this to the next level, i.e., enabling prediction of future changes based on climate scenarios, population growth, etc. We have already done some work in this area and started testing algorithms where the model "learns" from massive amounts of past data, predicts the future, and detects any anomaly that occurs due to natural or manmade disturbances. All tools and data will be publically available through the KDF or other platforms as recommended by DOE.

BIOFUELS NATIONAL STRATEGIC BENEFITS ANALYSIS

(WBS#: 4.1.2.41)

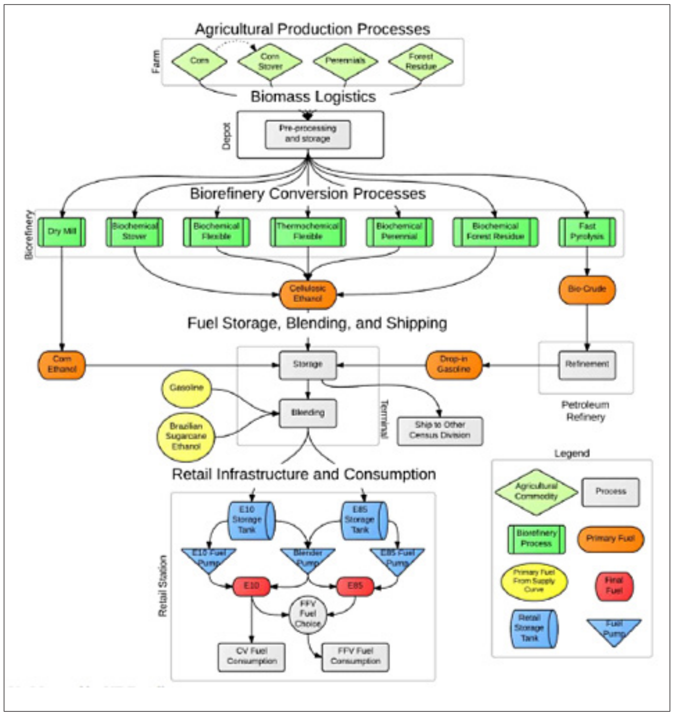


Image Courtesy of ORNL

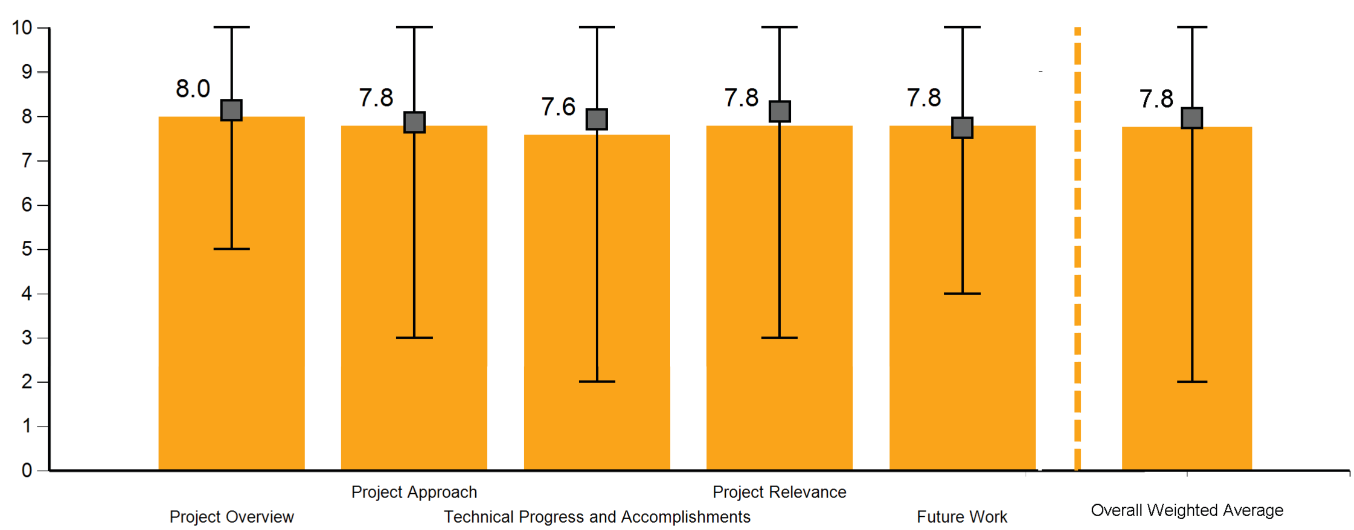
Recipient:	ORNL
Presenter:	Paul Leiby
DOE Funding FY14:	$154,080
DOE Funding FY13:	$326,595
DOE Funding FY10-12:	$125,545
Planned Funding:	$1,243,781
Project Dates:	12/15/2011 - 9/30/2018

Project Description

The fraction of fuels that advanced biofuels will represent in the light-duty vehicle fuel market in the next two decades depends on the complex interplay of vastly different economic actors: farmers, biorefinery investors, vehicle OEMs, fuel producers and retailers, and consumers. This project creates stylized representations of those interactions to examine the market outcomes (biofuel consumption, biofuel and fuel prices), the regional distribution of costs and benefits and the incidence of costs to government, firms and consumers. One of the major thrusts has been the development of a mathematical programming model (BioTrans) that depicts the whole supply chain, at the national level,

Overall Project Score: 7.8

(orange)	This Project
(gray)	2015 Sustainability and Strategic Analysis Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

for the potential choice set of biofuels pathways being pursued by BETO. In building this "big picture," BioTrans draws on other models (e.g., Billion Ton Update, BLM, design reports of NREL and PNNL, EIA's AEO) for parameters, cost functions, reference conditions and technology specifications. This project belongs in the class of initiatives meant to reveal supply chain-wide linkages and dependencies, with a special emphasis on measuring market-wide economic and energy security benefits.

Overall Impressions

- This project attempts to look at the potential fuel market impacts and economic and security benefits of biofuels. The value in this project is having the ability to explore various scenarios such as oil price volatility and shocks to the biofuel supply and to understand the economic and social benefits of these scenarios. Having a model that can assess how market changes can impact consumer behavior and choice is also valuable. The project showed good progress in developing the model and applying it to several scenarios. I am less certain as to how the various models interact and how one validates that the information being supplied to the model is robust. I would, however, encourage the researchers to continue to use the model to address relevant questions and current concerns. Understanding the potential impacts of various disruptions can help make the national bioenergy system more resilient to possible future disruptions.
- I do not disagree with the comments made in the 2013 Peer Review. The work is relevant and it has the potential to inform policy. However, I was not able to critique the outputs because I cannot find them online. After two years of work, I would absolutely expect some of this work to be online. Echoing the comment from the 2013 Report, I would not only like to see BETO coordinate better all the modeling work, but even more, I would like to see the policy modeling groups be combined into one overall effort that could better frame strategic research choices made in the space. It would be fabulous, in terms of outreach to the public and disseminating this work in the policy space, for the policy/economic modelers to have their own webpage. You could create a graphic that explains all the work in this area. This work otherwise is so inaccessible and that makes me question its impact in the policy space, unless BETO is somehow doing the translation elsewhere.
- This project combines traditional partial equilibrium economic modeling and empirical/econometric analysis of historical data. The two approaches together provide valuable insights on energy security. Among its strengths is the reliance on well-accepted economic theory and analysis. It can thus speak with credibility to the vast audience of conventional economists that dominate much of the dialogue in energy policy. It also provides a complementary perspective to that of the system dynamics modeling approach used in other projects within the analysis platform. This project has made tremendous progress over the past three years. The analysis of the effect of price and supply shocks on biofuels is insightful. Its analysis of risk and uncertainty impacts on biofuels industry growth show, in very quantitative ways, just how important these factors are in the context of different policy environments. This work, when combined with insights gained from BETO's BSM dynamic supply chain model for biofuels, offers valuable input for making strategic decisions about the bioenergy program. Plans for future work are sound. This project is now positioning itself to be used as an analytical resource for bioenergy program managers. This reviewer would encourage deep collaboration with the system dynamics modeling work (Biomass Scenario Model). Together, these two projects could help set strategic direction for bioenergy as an industry as well as DOE's bioenergy program.

- Bioenergy cannot be analyzed without concurrent consideration of petroleum markets. This project tackles important issues in oil price volatility, energy security, and bioenergy versus petroleum supply stability. These factors are difficult to estimate given the complex dynamics between international oil markets and bioenergy. However, this project considers key uncertainties and makes important contributions to understanding the risks to our current energy system and by quantifying economic, social, and energy security benefits from various channels of biofuel growth.

PI Response to Reviewer Comments

- Thank you for the encouraging words and the specific suggestions on how to do better, through greater coordination with other BETO modelers, and strong focus on producing visible, policy-relevant results.
- We welcome, and will pursue, closer collaboration with the system dynamics community. Our ties to the BSM group have strengthened in the past year, and we plan continued cooperation through both the exchange of modeling approaches and insights and the complementary application of BioTrans and Biomass Scenario Model to selected planning studies (Renewable Super Premium fuel and the RIN markets are two specific examples). We find continued interactions with all the policy modeling groups to be essential. This can be both through periodic BETO conference calls and less formal discussions, and through formalized venues like the Bioenergy Modeling Workshop. Follow-up activites for that workshop are planned. We also like the idea of a webpage for policy/economic modelers, for both public and collegial information exchange. Some of this need can been met through the growing use of the BioEnergy KDF as an information clearing house, but we will meet with BETO and our colleagues over the coming year to explore other options.
- We plan to pursue applications of our BioTrans model to salient questions that arise from the volatile energy markets and now sharply lower oil prices. We are proposing to extend the representation of the petroleum market, including a compact representation of crude supply, transport and refining, in order to better consider oil-biofuel interactions, and to address BETO's identified goal of quantifying the impact of advanced biofuels use on gasoline and diesel prices. We will also work with BETO, other DOE offices (FE and EPSA), and EPA to identify and study energy-security related issues that link biofuels to petroleum markets and the broader energy landscape.

GCAM BIOENERGY AND LAND USE MODELING AND DIRECTED R&D

(WBS#: 4.1.2.50)

Recipient:	PNNL
Presenter:	Marshall Wise
DOE Funding FY14:	$157,650
DOE Funding FY13:	$200,092
DOE Funding FY10-12:	$272,682
Planned Funding:	$469,576
Project Dates:	3/1/2010 - 9/30/2017

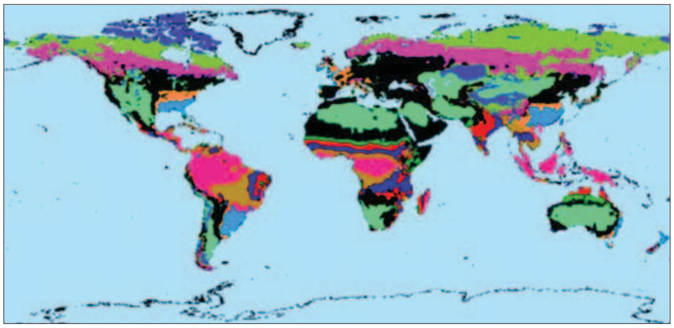
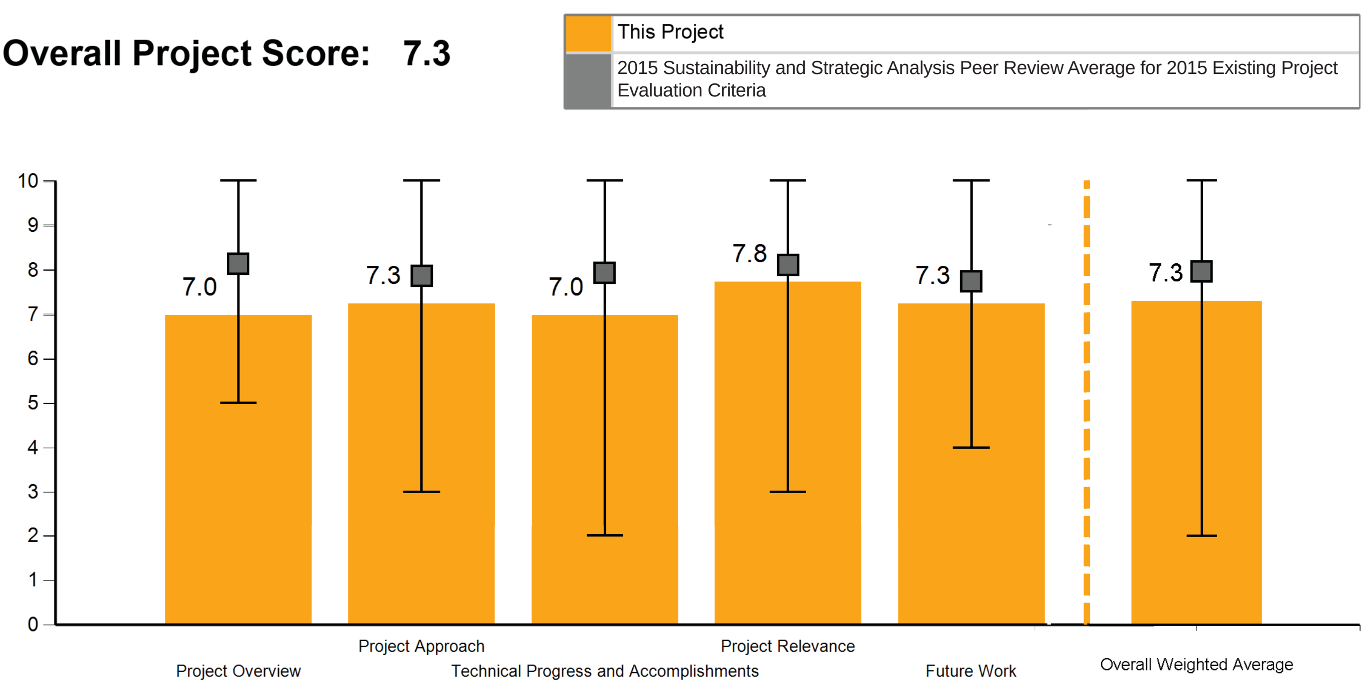


Image Courtesy of PNNL

Project Description

This project provides global modeling and analysis of bioenergy questions using the PNNL Global Change Assessment Model (GCAM). This project is relevant to BETO analysis and sustainability platforms as it analyzes bioenergy in the integrated context of global energy and agriculture. The GCAM modeling project is an established, multi-client effort ongoing for over two decades. GCAM is widely used by DOE and EPA, participates in international analysis efforts such as the IPCC and the Stanford Energy Modeling Forum, and is a community model available to all. This BETO project leverages the GCAM program to focus on improving modeling capabilities, data, and analysis in key areas related to bioenergy production and use. Beginning in 2010, technical accomplishments include published analyses about lignocellulosic bioenergy crops, bioenergy technologies for liquid fuels and power, and bioenergy with CO_2 capture and storage. FY13 and FY14 focused on modeling water demand parameters for bioenergy production. For FY15, the project is to analyze the potential and the impacts of large-scale production and use of bio-based jet fuels for aviation. Using the transportation demand sector of GCAM, the potential demand for aviation biofuels will be modeled in the context of the growing U.S. and global

Overall Project Score: 7.3



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

demand for air transportation, integrated with the competing uses of bioenergy in other sectors.

Overall Impressions

- PNNL's Global Change Assessment Model was designed to provide insight into long-term, global issues involving land use change, agriculture, energy, and emissions. Major progress has been made in looking at water requirements as well as in exploring the impact of regional crop production on land use change, prices, and energy use in the last few years. The model provides a nice framework to explore the impacts of bioenergy production on land use change and other policy issues. It also complements the analysis of other tools and has the potential to inform policy makers. The model is now open sourced and available for use, which is a real plus. Future work centers on the analysis of the impact of global and U.S. jet transportation, including biojet fuel production and use. This will be a great addition to the model. The strength of the model is its ability to look at large, global impacts. The challenge is that the model is very complex. Because of the size and complexity of the model, all model future development needs to be thoroughly vetted and documented.

- As stated in the 2013 Peer Review Report, the utility of the project was not well articulated. It appears that its purpose jumps around a bit, and the reason for that was not articulated. In fact, it was stated that the water work, which constituted a good part of the presentation, was not supported by BETO. BETO should be very careful to get value for the investment from pursuing jet fuel analysis. There is no indication in the presentation that there is a basis for the need of such analysis independent of the FAA investment in Aviation Sustainability Center of Excellence (ASCENT). If there is, then it should have been articulated.

- The value of this project is, overall, positive. Working with the GCAM modeling community offers an opportunity to engage with experts using a modeling framework that has a high level of visibility and credibility. The model is unusually comprehensive in the range of issues that it considers with regard to global climate, environmental and economic impacts of our energy system. That said, like most general and partial equilibrium models, GCAM is a black box. It offers little transparency, and little access beyond the experts who have climbed the huge learning curve needed to use the model. The modelers, nonetheless, approach the questions about biofuels with a degree of humility not seen by many of the other economic modelers. Their emphasis on the importance of assumptions is a case in point. This is a project that continues to offer genuine value to the program.

PI Response to Reviewer Comments

- To clarify just a couple of points, the biofuels water consumption analysis presented was supported by BETO funds. The BETO project was scoped specifically to bioenergy, but was able to do so because of the leveraging of a larger, multi-year program of water supply and demand modeling development that is funded mainly by DOE's Office of Science.

- Also, the point that the focus of the specific tasks on this project has jumped around from year to year. This is due to at least two factors in the program design. One factor is that this is a relatively small project in a larger GCAM program with other funders, and we have opportunistically identified bioenergy-specific analysis areas each year that could most effectively leverage concurrent development in the larger program. The second factor is that we define each year's tasks in a manner that makes it clear the BETO efforts are additional to the larger GCAM program, and that there are clear deliverables representing key bioenergy analysis and sustainability questions to justify the model development and research. Over time, this has resulted in tasks focusing in different areas of bioenergy production and demand, with the longer focus being on the integrated analysis of bioenergy questions.

- A grateful thanks for the attention and expert guidance from the review panel. This and previous peer review efforts have improved our ability to focus our research on areas that complement other BETO analyses in the BETO program, and, perhaps just as importantly, effectively explain the analysis to the technical and policy community in government and industry.

IMPACT OF PROJECTED BIOFUEL PRODUCTION ON WATER USE AND WATER QUALITY

(WBS#: 4.2.1.10)

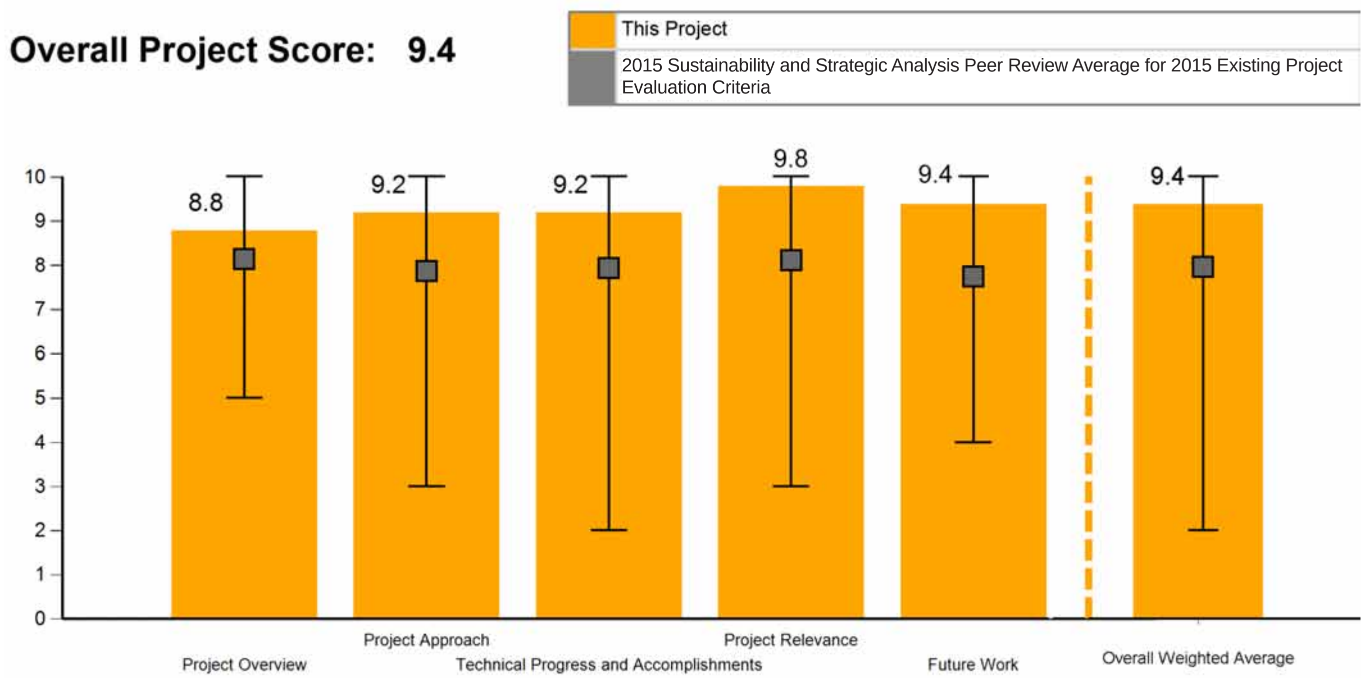
Recipient:	ANL
Presenter:	May Wu
DOE Funding FY14:	$59,039
DOE Funding FY13:	$563,277
DOE Funding FY10-12:	$1,214,235
Planned Funding:	$1,883,449
Project Dates:	10/1/2006 - 9/30/2017

Project Description

This project develops an analytical framework and tool to quantify the relationships between bioenergy production and water use, water quality, and water resource availability with spatial resolution; evaluates management practices in bioenergy landscapes that protect water resources and increase water-use efficiency; and identifies scenarios to improve water sustainability of advanced bioenergy. Water use and wastewater release are two key issues associated with water sustainability in biofuel production. Outcomes from the project are: geospatial analysis of national-scale, county-level water footprint (WF) of biofuels for the U.S.; WATER—a spatially-explicit model for biofuel; an energy-water data inventory; and a suite of multi-scale SWAT models. Since the 2013 Peer Review, this project has assessed WF for forest wood-based biofuels; developed perennial and forest wood pathways in WATER (two major releases); developed methodology for the representation of grey WF for biorefineries; estimated grey WF for pyrolysis/hydrotreating processes; developed a SWAT model for the South Fork Iowa River watershed and examined impacts of riparian buffer, integrated landscape design, and climate change on water quality; completed two SWAT models for the Missouri River Basin; implemented a BT2 scenario; and conducted major tributary watershed analyses. Output from this project feeds directly into strategic analysis in support of TEA, sustainability indicators development, and GREET.

Overall Impressions

- Due to the significant water issues we face here in the U.S. as well as other parts of the world, understanding the role of water in bioenergy production



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

is critical. This project sets up the framework to understand not only water use but water quality and availability across the entire bioenergy supply chain by developing an analytical tool to quantify the water use, quality, and availability throughout the various stages of bioenergy production. The team has made great progress since 2013. They have been able to further develop the WATER model for county-level spatial analysis. They have developed two major biofuel production pathways—one for perennial grasses and one for forest residues. There is much yet to be done. I applaud plans to update the water use of electricity generation as well as natural gas. Biogas could be another resource to add in the future. Continued development of better spatial analysis is also important. Algae, due to its high water use but also its ability to utilize gray and salty water, would be a great addition to the model. Also, taking a renewed look at water use in the production of baseline gasoline from petroleum would help make consistent comparisons possible. This project continues to be key in understanding water issues, and it will play an even greater role in the future as water scarcity and water conservation become more prevalent.

- I have no additional comment with regard to the relevancy and value to BETO, which was memorialized in the 2013 Peer Review report and remains true today. BETO is getting a lot for its investment here. This work is highly relevant not only to the bioenergy space but also the broader water quality and quantity space. BETO should think about how this work could be strategically leveraged to insert bioenergy into broader policy conversation about improved water quality in the agricultural landscape. The project is engaged in Iowa, a "hot-spot" for policy development, but I would like to see how the work could translate more broadly through collaboration with EPA and USDA.
- This is a truly exciting project. For years, stakeholders in the environmental community have lamented the lack of data and attention to the possible water impacts of bioenergy. The WATER tool (available to stakeholders outside the immediate BETO research community) addresses their concerns very well. This project is an important center of gravity for all of the work being done in the program on water impacts.
- This project has contributed and should continue to contribute great value to the assessment of bioenergy impacts on water systems. The focus on water footprints in the project is a nice compliment to other work focusing more on water quality impacts. Further, the WATER tool developed to assess these footprints has achieved great success. Ongoing efforts to include TEA and integration with GREET will further enhance this project's relevance.

PI Response to Reviewer Comments

- We would like to express our deep appreciation for the comments and constructive inputs from the reviewers. We are so excited about what has been accomplished in the last two years. Moving forward, we hope to continue the data, modeling and analysis in the water area and contribute to BETO's overall mission of developing a sustainable bioindustry.

INTEGRATED LANDSCAPE MANAGEMENT

(WBS#: 4.2.1.20)

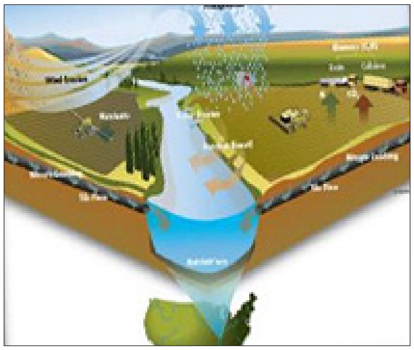


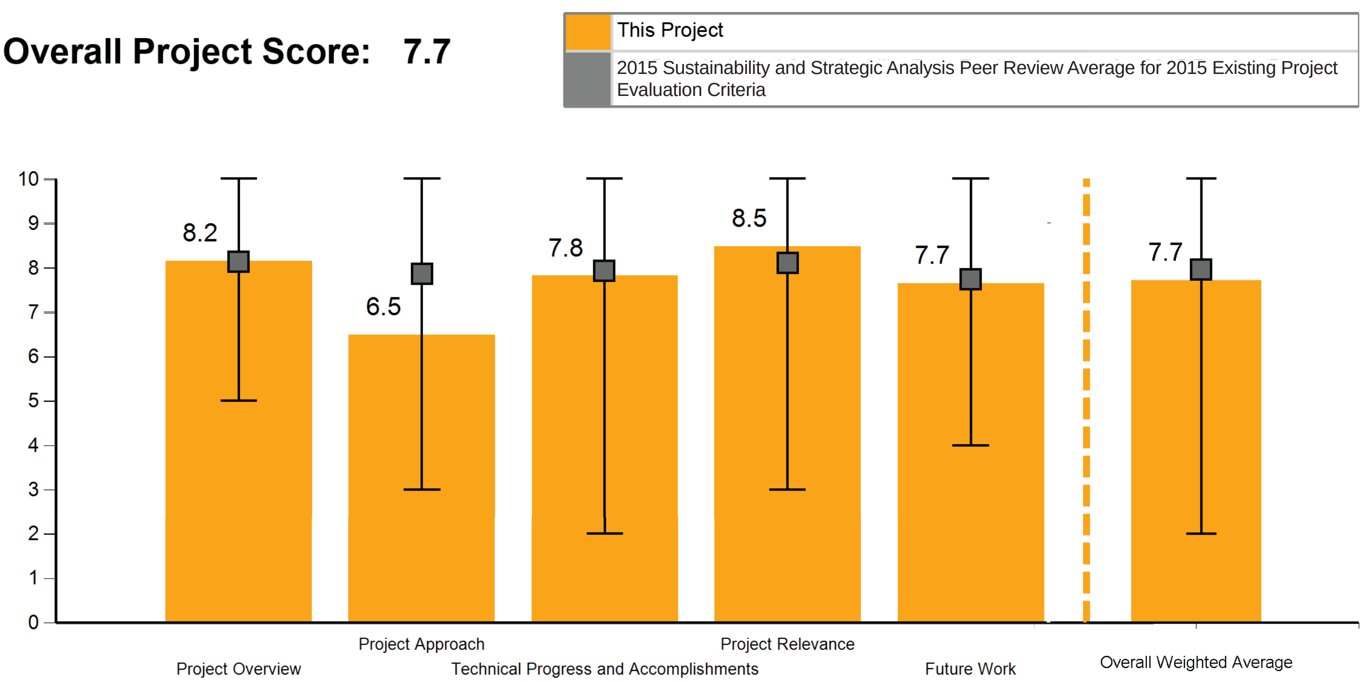
Image Courtesy of INL

Recipient:	INL
Presenter:	Jacob Jacobson / Ian Bonner
DOE Funding FY14:	$395,783
DOE Funding FY13:	$208,825
DOE Funding FY10-12:	$766,902
Planned Funding:	$638,148
Project Dates:	10/1/2013 - 9/30/2017

Project Description

Biomass supply systems solely dependent on agricultural residues are subject to strict limitations and risks in feedstock availability when soil health, offsite environmental impacts, uncertain growing conditions, and producer economics are considered. This project was a new startup in FY14 and is designed to increase overall biomass production, reduce grower losses on agricultural lands, and improve soil and water quality. By utilizing subfield decision making tools to integrate energy crops into the landscape, field-level profitability can be improved while annual biomass availability may be nearly doubled. The objective of this project is to develop foundational data layers and deployable products that advance the understanding and design of integrated landscapes that increase sustainable biomass availability. This project directly informs the BETO 2017 analysis goal of evaluating and comparing the sustainability of biofuels produced from agricultural residues and energy crops through barrier St-G: Representation of Land Use and Innovative Landscape Design. This project evaluates how innovative landscape designs made at the subfield scale can be used to optimize the balance of productivity, sustainability, risk, and economic return. Additionally, by increasing overall biomass availability the cost of procuring the necessary biomass to supply a biorefinery will decrease and thereby support the 2017 cost target of delivering biomass to a refinery at $80/dry ton.

Overall Project Score: 7.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- The project seems to overlook the operational cost implications of subfield work. What are the operating costs of bioenergy production as subfield area changes? Small, fragmented areas are likely not estimated well by simple cost per acre values. Similarly, the effect of removing subfield areas on row-crop operating costs must be assessed. Marginal acres may lose money but save on overall cost by increasing efficiency of operations (fewer turns, headrows, etc).
- The project seems to assume that bioenergy is justified on any area that is losing money. However, you have to consider that leaving the marginal areas fallow has zero operating cost and zero loss (generally). It seems like bioenergy has to return value per acre or it is not worth doing.
- This is a strong project overall and will be of great value to other BETO projects once completed. I applaud the researchers for their innovative look at overall landscape design. They have shown that the co-production of energy crops and current agricultural crops can be optimized from the current system. They have successfully obtained data at the subfield scale and have quantified the impact on profit by sub-yielding areas. This supports their overall concept of good land management. I am glad to see that the researchers will continue to further their concept of landscape design to get higher biomass availability and improved sustainability into other crops and soil types across the U.S. I also applaud their future goal of deploying this tool for public use. Getting this tool in the hands of large farmers who make landscape-relevant decisions that not only improve sustainability, but also dd to the profit margin of the farmer is critical. I would encourage the researchers to reach out to farmers about their strategy to get their perspective on planting and harvesting methods and how these could be integrated into the system. The goal to supply a tool for public use brings direct benefit from this government-funded research directly to the growers and helps them drive profits of their own enterprise.
- I really like this tool because it approaches deployment of a sustainability tool from a farmer-economic perspective. It is a great tool for identifying marginality. I would really like to see this tool deployed by and/or advertised to policymakers seeking to address water quality and biodiversity problems.
- The performers have done a good job demonstrating the power of using a subfield-level landscape design tool to optimize sustainable production of corn in central Iowa. The biggest concern with the results presented thus far is with the interpretation that the researchers have made in terms of understanding the economics of substituting energy crop production in poor performing regions of a farmer's fields. The idea of setting a bar for energy crops based on the ability to lose less money than corn in a corn field seems unrealistic. The proposed future work is sensible, and of great value to BETO's program, especially the effort to link the LEAF tool with other watershed-scale sustainability projects. Deployment of the tool to farmers and other interested users will be important, but little information was provided on how this would be done.
- The concept of sub-field bioenergy crop integration being explored in this project holds great importance for the widespread development of bioenergy crops given the potential economic and environmental benefits. The next steps of deploying a functional tool while maintaining the resolution necessarily for it to be effective will be challenging but of great potential benefit if completed. The PI did not communicate the considerable amount of research and stakeholder outreach on economic viability that has to be performed simultaneously with the technological developments in order for the prescribed integration techniques to be successful on a widespread basis. The adoption of such systems will hinge on the perceived economic viability by farmers of such a system, along with their ability

to have perfect (or near-perfect) information on where subprime areas are in their fields. The justification of improved profitability that was relayed seemed to rely almost entirely on the crop returns without focusing on the increased costs of coordinating and implementing these more complex systems. These cost factors could have considerable implications on the economic viability of these integrated systems, so the issue has to be explored further.

PI Response to Reviewer Comments

- Thank you all for your constructive feedback. We appreciate your positive remarks and respect your concerns. Of primary concern is the likelihood that growers can or will manage their lands in innovative ways to minimize loss. The use of subfield performance and profit to inform farmer decision making is not a concept, but a present reality. As one of the reviewers noted, farmers are actively managing their lands to maximize performance. In many cases, however, the amount of control is limited by technical capability. Many farmers are investing large sums of capital into new technologies to enable subfield planning and improve profits. With this in mind, it is important to remember that every grower's opportunity and interest will be unique. We do not intend to suggest that energy crop integration is a one-size-fits-all solution for profitability or sustainability. Nevertheless, for growers with a local biomass market and willingness, such a technique may have considerable financial and environmental benefits.
- When working with a system as complex as biomass production and logistics, it is important to consider all of the potential costs and benefits rather than fixating on any one component. For instance, choosing to fallow a portion of a field does not come at no-loss as the land's value will be idled, rental rates still apply, and plant growth potential goes unutilized. This project is actively working to improve internal collaborations at INL and external collaborations with industry, agencies, and academia and to help ensure all critical components are adequately considered and incorporated. We agree with and appreciate the reviewer's concern on the costs of managing multiple crops, both at the field level and within the supply chain. Going forward, the project's goals will be more clearly directed to quantify the economic tradeoffs of increased field complexity through case study analyses and interdisciplinary publications. Quantifying this potential will be incredibly important for communicating the broader range of costs and benefits to stakeholders. This work and the tools being developed will play a critical role in defining where and when such technical challenges exist. We are working closely with our project partners to ensure the project's products are useful, but will make an additional effort to understand the practicality and economics of integrated landscapes.
- While our case study analyses are useful as demonstrations of analytical capability and depictions of general opportunity, they are not a roadmap to success or an end-all prescriptive solution. One of the project's core objectives is to provide control to individual users by deploying this capability in a public-facing analysis toolset. By doing so, the assumptions used for productivity, management, or enterprise budgets can all be customized to suit individual needs. Such a toolset will give producers and researchers the power to understand how and if opportunity exists within their own specific constraints, and provide forward-looking analytical capability and insight to industry. As the biomass and bioenergy markets develop and the demand for biomass increases, the tools developed by this project will become increasingly relevant as stakeholders seek alternative pathways to increasing biomass availability, sustainability, and efficiency of biomass utilization.
- As noted by one reviewer, communicating this project's results to stakeholders is key, not only for dissemination, but for fielding ideas and improving our products though active feedback incorporation. This will be accomplished in collaboration with oth-

er national labs, ARS, NRCS, industry (AgSolver, FCDE), and universities (Iowa State, Purdue). Being a national lab, we recognize this research should not and cannot be successfully executed in a vacuum, and we believe our progress to date demonstrates significant efforts are being made to ensure this project is a collective, interdisciplinary effort.

SUSTAINABILITY ANALYSIS

(WBS#: 4.2.1.30)

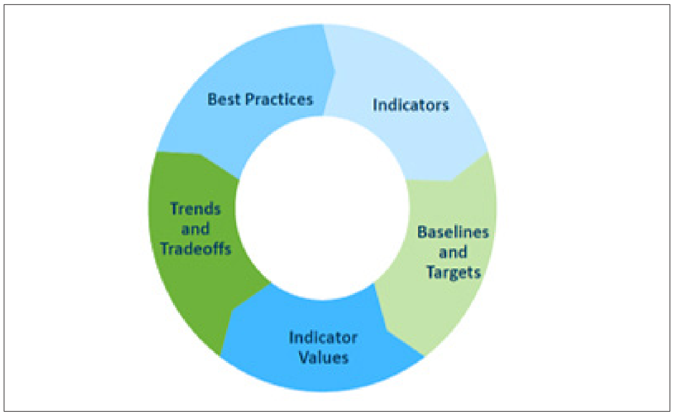


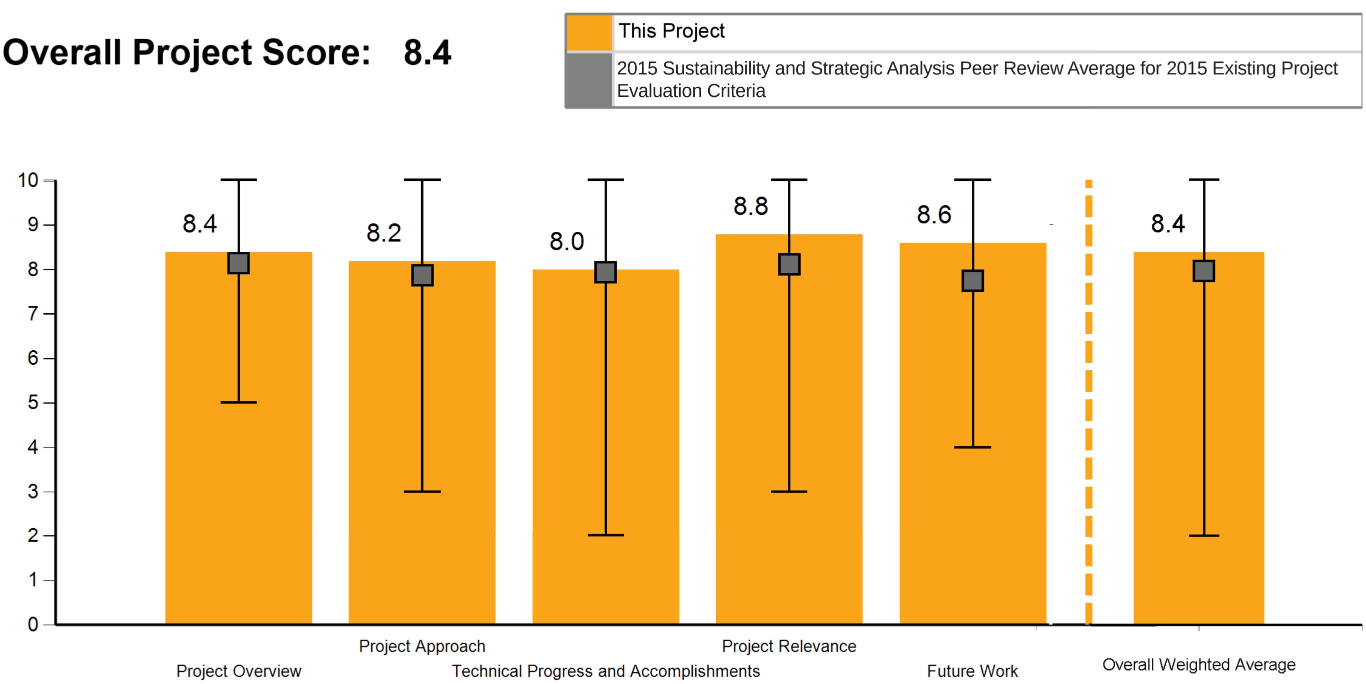
Image Courtesy of NREL

Recipient:	NREL
Presenter:	Daniel Inman
DOE Funding FY14:	$1,114,290
DOE Funding FY13:	$1,130,608
DOE Funding FY10-12:	$2,017,886
Planned Funding:	$1,501,218
Project Dates:	10/1/2011 - 9/30/2017

Project Description

This project addresses the air quality impacts of large scale development of advanced biofuels and focus on the two major challenges in assessing the environmental impacts of the biofuel industry in order to meet regulatory requirements. The project will incorporate spatial and temporal heterogeneity in air emissions inventory and develop rigorous estimates of air pollutant emissions for advanced biorefineries and feedstock preprocessing facilities. This project provides BETO and other stakeholders (e.g., EPA, regional and state air quality managers and planners) with information necessary to understand the potential air quality and human health impacts of large-scale production of advanced biofuels, and enables the consideration of multiple aspects of sustainability throughout the biofuel supply chain. In addition, the results will provide insights into identification of important emission-contributing activities and facilitate development of strategies (e.g., best practices, emissions control measures) to minimize negative impacts. Future work includes continued formulation, characterization, and reactivity study of carbides to obtain fundamental insights and data necessary for the optimization of catalytic performance, pilot-reactor

Overall Project Score: 8.4



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

testing with real bio-oils, in-depth analysis of upgraded products and reaction pathways, long-term stability assessment, and deactivation mitigation.

Overall Impressions

- This research expands on the conventional analysis of estimating air emissions from a potential process to looking at how well the process design meets current air regulations. This work is important in understanding the emissions generated at a specific local refinery. It also informs where needed design changes could be made to further reduce the environmental impact. This is critical as we move toward large-scale deployment and biofuel commercialization. The project has made great progress. So far, they have been able to complete life cycle inventories for five feedstocks and two key conversion pathways—sugars to hydrocarbons and fast pyrolysis. The current analysis doesn't look at mitigation strategies, but does point out areas of concern such as potential problems that may arise from the co-location depots at conversion sites. There is still a need to get good temporal and spatial data to understand the source-level impacts. They are working with Abengoa and other commercial plants and hope to have access to real emission data as soon as it is made public. During the 2016-2017 time frame, the project aims to look at the distribution and end use portions of the value chain. There are many studies that may be of help in developing this portion of the study. The National Petroleum Council Future Transportation Fuels Study is one such study. It contains a vehicle choice model to estimate vehicle penetration and fuel use under a variety of conditions.

- I echo the comments of the 2013 Peer Review report regarding the value of the project. The PIs appear to have been responsive to the previous comments of how to improve integration of TEA and LCA.

- This project offers a powerful approach that brings spatially explicit context to air emissions associated with biorefinery supply chains. Air quality impacts, like water impacts, are highly influenced by temporal and geospatial factors. The spatially explicit LCA analysis in this project will greatly improve the ability to assess real impacts of supply chain air emissions on local air quality and public health. The current focus on assessing maximum potential emissions associated with the biorefineries themselves is critical, and the team has appropriately identified the boiler system as central to understanding air emissions.

- Air quality is a central component of environmental and socio-economic assessments of bioenergy systems, and this project is positioned to offer comprehensive insights to the supply chain impacts of various bioenergy operations. The project has done a thorough job of collaborating with research partners and stakeholders to inform modeling assumptions. The future success of the model will largely center on its versatility in considering different feedstocks, growing practices, and supply logistics (such as biomass depot systems), as well as the cost effectiveness of different supply chain options—a component of this project that was not given much weight in the presentation (though the PI indicated that work was being performed in this area).

PI Response to Reviewer Comments

- We appreciated the reviewer's constructive comments and are taking them all into consideration as we develop our future work plans. Specifically, we are beginning to examine ways to mitigate and/or reduce emissions at the biorefinery for a number of conversion pathways. Additionally, we are working to gather stack testing data to validate our modeling efforts.

INTERNATIONAL SUSTAINABILITY AND SUPPORT TO IEA BIOENERGY TASK 38

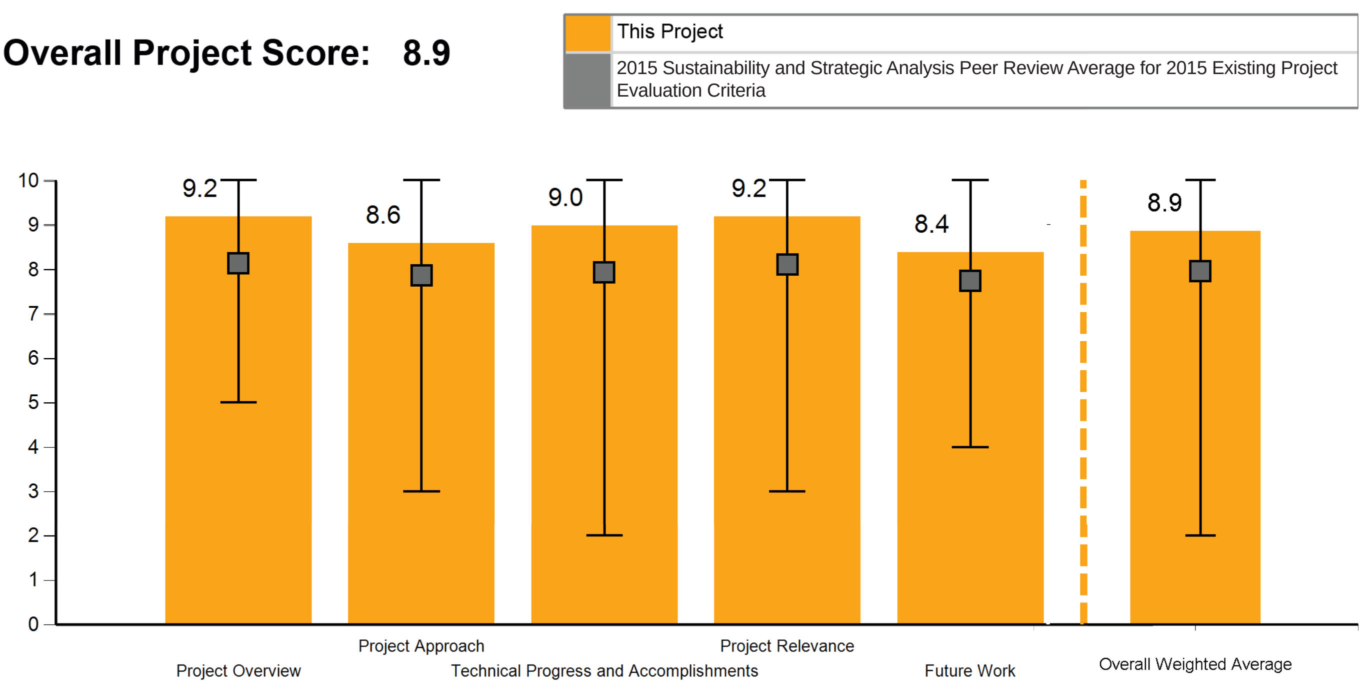
(WBS#: 4.2.1.31, 6.4.0.6)

Recipient:	NREL
Presenter:	Helena Chum
DOE Funding FY14:	$52,826
DOE Funding FY13:	$215,725
DOE Funding FY10-12:	$470,115
Planned Funding:	$508,314
Project Dates:	10/1/2009 - 9/30/2016

Project Description

Technical expertise of the PI, team, and BETO researchers was provided through this activity to various high-level assessments of bioenergy and sustainability. Insights from climate change and resource efficiency studies suggest that the use of systemic approaches to production, conversion, and product(s) use of biomass is needed. Partnering and stakeholder engagement in bioenergy and sustainability assessment is conducted for U.S. government/BETO United Nations (UN)- or International Energy Agency (IEA)-related multilateral initiatives, which are updated periodically. The task: (1) provided a systemic view, including from multiple feedstocks, conversion pathways, product(s), and uses; (2) disseminated findings; (3) identified areas for high-level BETO publications as these studies continue; (4) identified opportunities for the U.S. bioenergy industry with global expansion efforts; (5) produced highly cited, high-impact publications; (6) confirmed the validity of BETO's approaches for sustainability assessments; (7) increased knowledge of global partners of the current commercial and developing technologies; and (8) worked to decrease barriers to international trade from U.S. industry. Plans include: (1) synthesize, analyze, and make recommendations to BETO on complex inter-related global multilateral activities in biomass and sustainability; (2) SCOPE Bioenergy and Sustainability launch, policy brief, and findings dissemination; and (3) IEA Bioenergy and related activities.

Overall Project Score: 8.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- Dr. Chum's frequent presentations and papers help to frame the bioenergy discussion globally but also serve to highlight the work going on in BETO and facilitate its use by all stakeholders. Her participation on boards and in scientific forums helps to reduce the barrier for U.S. trade and economic participation as well as increases the opportunities for the biofuels industry here in the U.S. Biofuel use here in the U.S. has slowed due to blend wall issues, but biofuels are still seen as a way for many regions of the world to create jobs, improve national security, drive GDP and wealth creation, and improve the standard of living especially among rural populations, while also having a positive impact on the environment. I like the increased focus on system effects and would encourage efforts to move from life-cycle-inventory-only work to looking at the impacts on toxicity, human health, etc. With a project like this, communication is not only critical but essential. Maintaining an ongoing dialog with all stakeholders is important. The goal is not only to influence the world stage but to bring that learning back to BETO.
- There is nothing more I can add to the 2013 Peer Review report and I echo that report's sentiments. The PI has kept up the same pace as the last report. BETO gets a lot from the investment in this project. It would be a huge strategic oversight for BETO to alter or discontinue this international engagement. Often times, DOE is the only U.S. agency present in some of these international discussions. BETO should be highly commended for its strategic leadership in this area.
- The international activities included in this project have borne much fruit in the past two years. Major milestones include participation in newly released reports from IPCC (International Panel on Climate Change—under the auspices of the United Nations) and from SCOPE (the Scientific Committee on Problems of the Environment). These reports may pave the way for a much better understanding of the benefits and trade-offs of bioenergy and a much better understanding of how to implement bioenergy sustainably.
- This project provides significant contributions to BETO's portfolio. The goal of collaborating with international stakeholders to promote the sustainable development of bioenergy is of great importance. Building common understandings of sustainability will reduce barriers to trade and foster commerce across sectors, which are crucial goals for future bioenergy expansion. The Pl has built critical relationships, disseminated important material to the international community, and is well positioned to advance this work.

PI Response to Reviewer Comments:

- We thank the reviewers for very insightful comments and suggestions, and recognition of the leadership of BETO in these activities. This active engagement enables NREL, ORNL, and other program participants to be active in the exchange of information and insights, essential for the global bioeconomy development. We will work on strengthening communications of these activities.

FORECASTING WATER QUALITY AND BIODIVERSITY

(WBS#: 4.2.1.40)

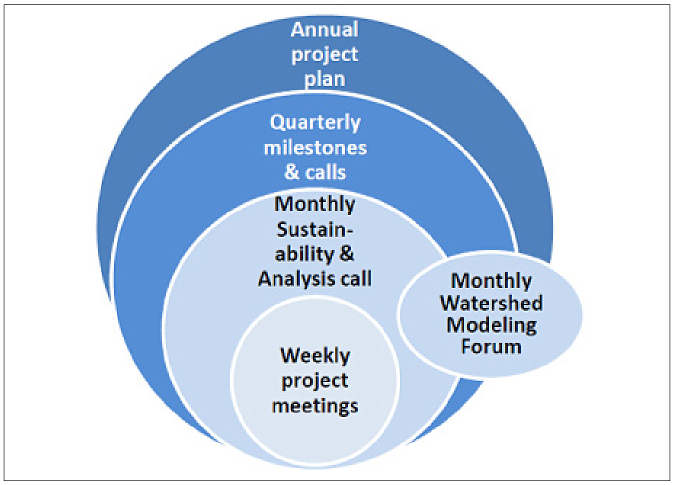


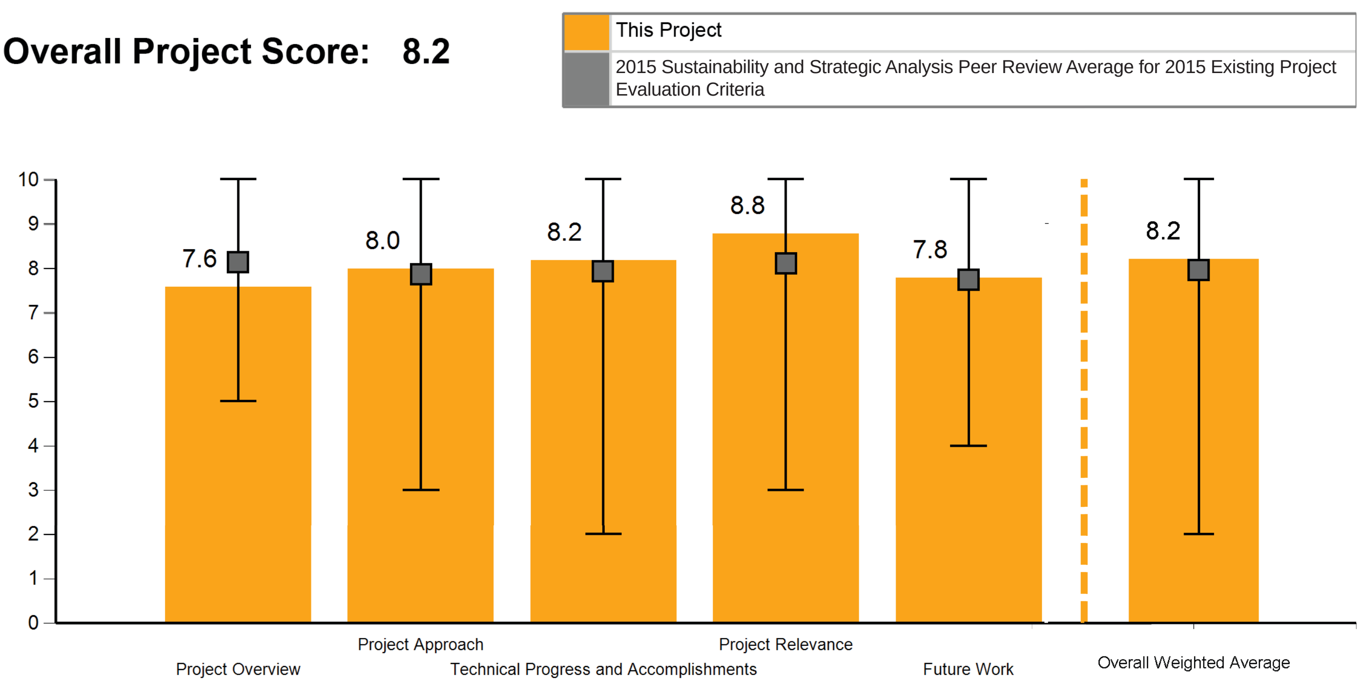
Photo Courtesy of ORNL

Recipient:	ORNL
Presenter:	Yetta Jager
DOE Funding FY14:	$241,637
DOE Funding FY13:	$201,985
DOE Funding FY10-12:	$394,921
Planned Funding:	$536,457
Project Dates:	10/1/2008 - 9/30/2017

Project Description

The emerging bioeconomy has raised public concerns that land conversion might reverse progress toward reducing adverse effects of agriculture on biodiversity and water quality. Our modeling research has addressed these concerns by quantifying changes in water quantity and quality indicators under a 2030 future scenario and a business-as-usual scenario. Median projected nutrient and sediment loadings showed decreases in both the Arkansas-White-Red (AWR) and Tennessee River (TRB) basins. For a large part of the AWR, areas converted to grow perennial feedstocks produced water quality benefits. Similarly, preliminary forecasts suggest that the TRB holds promise for producing cellulosic feedstocks that enhance water quality. In a second task, we are using science-based approaches to understand how bioenergy landscapes can be proactively designed and managed to enhance benefits to wildlife and water quality. For water quality, the project team is collaborating in an effort to extract concrete design principles

Overall Project Score: 8.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

to enhance water quality in bioenergy landscapes, and has conducted a similar synthesis of design principles to promote wildlife. Finally, the sustainability portion of the next Billion Ton report will be greatly expanded. The project is supporting this effort by quantifying sustainable feedstock production achieved via smart allocation of conservation practices and crops for water quantity, quality, and biodiversity.

Overall Impressions

- Developing tools to assist in agricultural land management optimized for sustainability is important to better understand the relationship between large-scale bioenergy crops, biodiversity, and water quality. Key accomplishments included documenting how bioenergy crops influence wildlife, identifying positive wildlife management practices, and identifying landscape patterns that promote wildlife and biodiversity. The project looked for win-win scenarios that supported bioenergy while maintaining water quality and biodiversity. I liked the idea of being able to use the data generated to forecast future biodiversity under various design scenarios. This would have a great impact on understanding the impact of producing large-scale bioenergy crops. It could also inform how best to optimize the land to achieve both bioenergy and biodiversity. The key issue that remains to be addressed is the issue of tile drainage. This could have a significant impact on water quality and is something that will need to be looked at in the future.
- This is one of the most exciting projects in BETO's portfolio; it is way far out in front of research in the area and has the potential to build the foundation for bioenergy to receive ecosystem services credit in the policy space. The approach and work ethic of the project should be mirrored in other BETO-funded ecosystem service projects. There is great potential for synergy with ANL's water work and ORNL's work in forestry.
- This project has set ambitious goals for understanding the full national impacts of bioenergy on water. It is delivering on those ambitious targets. It is exciting to see this and several of the other water-related projects gradually putting together all of the puzzle pieces that represent the diverse regional elements of water supply. This project highlights the need for the BETO management team to think through how all of the modeling and experimental work it is conducting on landscape, watershed, and river basin scale can be connected.
- This project has produced important insights for watershed water quality impacts and has developed an interesting and much needed approach for assessing terrestrial biodiversity. This project has achieved a great deal in assessing water quality impacts of bioenergy integration at the scale considered. Given the uniqueness of each different regional landscape and water system, scaling these results nationally is challenging, but the methods performed in this project should serve as a framework for assessing other systems.
- Continued project coordination with USDA and USGS experts, resources, and constituencies should be highly encouraged.

PI Response to Reviewer Comments

- Thank you for your positive feedback. We greatly appreciate your support and suggestions for improvement.

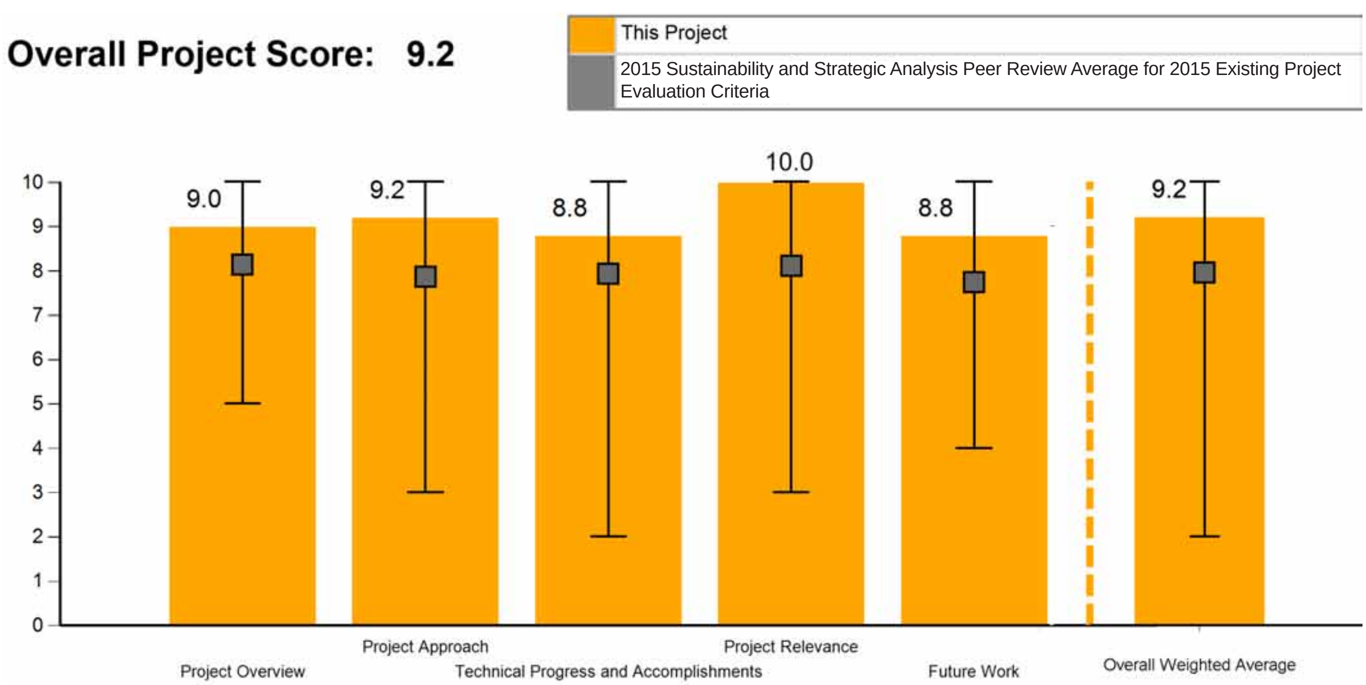
ADDRESSING GLOBAL BARRIERS TO GROWTH OF THE U.S. BIOECONOMY

(WBS#: 4.2.1.41)

Recipient:	ORNL
Presenter:	Keith Kline
DOE Funding FY14:	$154,080
DOE Funding FY13:	$326,595
DOE Funding FY10-12:	$125,545
Planned Funding:	$1,243,781
Project Dates:	10/1/2013 - 9/30/2017

Project Description

Industry, society and government share interest in developing consistent standards that support clean energy options and reduce investment risks. Uncertainties surrounding sustainability requirements for market access and modeling of indirect effects create barriers to growth of a U.S. bioeconomy. This project responds to stakeholder requests for support with global sustainability issues that require broad-based consensus on definitions, criteria, and methods for measurement. It builds on, shares, and amplifies the impacts of other DOE projects through participation in processes involving the International Energy Agency, the United Nations Committee on Food Security, the International Organization for Standardization (ISO), and others. The project leverages resources through strategic collaborations that help test indicators, accelerate discovery, and promote broad ownership of the science and practice of sustainability. The focus is on completing ISO 13065 "Sustainability Criteria for Bioenergy," facilitating an improved understanding of interactions between biofuels and food security, and addressing issues related to land-use change and appropriate reference case development. The project helps develop and disseminate science-based tools for consistent and cost-effective methods to assess performance and guide continual future improvement. Relevant outcomes include more transparent and comparable assessments needed to reduce market barriers for bio-based products.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project strives to take all of the hard work conducted by BETO and ensures it impacts decision making. International engagement is essential since biofuels are a global commodity. Dr. Kline has developed good connections and is having an impact. Some might claim this work is not innovative. However, the definition of innovation is the application of invention. All of the work being done at BETO are great inventions, but they are not innovations until they are applied. This project is making sure those inventions are being used to impact decision making. It is critical to make sure that the standards and regulations are in line with the interests of the U.S. It is difficult to understand the value this type of work has, but it is making a difference. I would encourage broadening the scope to include other venues beyond the scientific community (ISO, ASTM, etc.) to include regulators and government officials.

- This project plays a critical role in international policy discussions. I would be aghast if DOE discontinued this translational work. A significant number of the modeling projects suffer greatly from a translation perspective; this project very well may be the savior of that shortfall. It would have been great to have more time to talk about that translation. I very much hope that BETO focuses on that ability and its importance. It cannot be overstated.

- This project brings a highly collaborative approach to engaging in the international discussions and negotiations that are and will continue to impact the development of a sustainable bioenergy industry in the U.S. and abroad. The team has collaborated with partners across the DOE program and outside of it to bring important data and insights generated by the BETO program to light in the effort to establish international standards for sustainable bioenergy. The only weakness apparent in this effort is whether or not the resources available to engage in these discussions matches the growing demand for such engagement. As their work moves forward, the project performers should carefully define and prioritize its efforts to build international consensus. The specific focus on ISO standards for bioenergy are appropriately their top priority. Plans for other activities may require more thought and detail to ensure that this team is not spread too thin.

- This project's efforts to guide consensus building around the understanding of sustainability are of paramount importance for the development of future international agreements on energy and climate, and streamlining opportunities for commerce. This project has succeeded in engaging international stakeholders and developing milestones to advance the issue. The challenges of this global effort to build common understandings around sustainability criteria are naturally complex and many, but considerable progress has been made. BETO is well served to fund this project and contribute to this tremendous effort.

- It would be nice to see more of BETO's sustainability portfolio shared among these international forums through this project.

PI Response to Reviewer Comments

- The energetic and unanimous endorsement for continuation of this project from the external reviewers is appreciated. We will do our best to fulfill their expectations and continue the work to support effective global frameworks for more sustainable bioeconomies. The reviewers underscored the project's relevance, noting that U.S. business interests and EERE/BETO goals for clean energy development call for proactive international engagements to address the challenges and perceptions about bioenergy sustainability. As one reviewer noted, "more important debates and decisions are being made internationally than domestically." We appreciate this observation and will redouble our efforts to implement reviewer suggestions to clarify modeling results that are otherwise open to misinterpretation and could contribute to global barriers to growth of a sustainable U.S. bioeconomy. As noted by a reviewer, "the critical role in international policy discussions... [of] translation issues are of importance that cannot be overstated." We also appreciate reviewer comments about the potential for some aspects of existing and proposed standards to make things worse rather than reduce the barriers to a more sustainable U.S. bioeconomy; we therefore plan to assess the results of collaborations to date with the ISO Standard and extract lessons that can be applied in future work.

- Finally, we acknowledge reviewer comments about the needs to address many challenges facing the bioenergy sector that are related to variable definitions of sustainability, negative perceptions about land use change and food security, and a lack of awareness and understanding of BETO research results relevant to these barriers. Therefore, we plan to continue work while focusing on those areas and related communications. We will do our best to implement reviewer recommendations for "proactive engagement" in selected international processes that address barriers prioritized by BETO and industry.
- We thank the reviewers for their time, thoughtful comments and suggestions.

BIOFUEL PRODUCTION IN THE WESTERN U.S.

(WBS#: 4.2.1.50)

Project Description

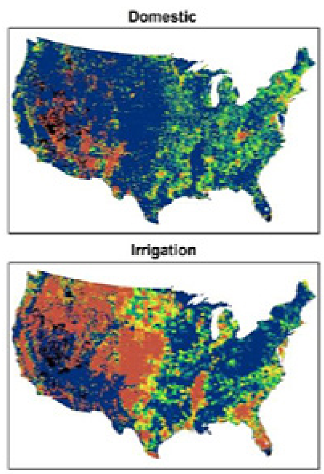
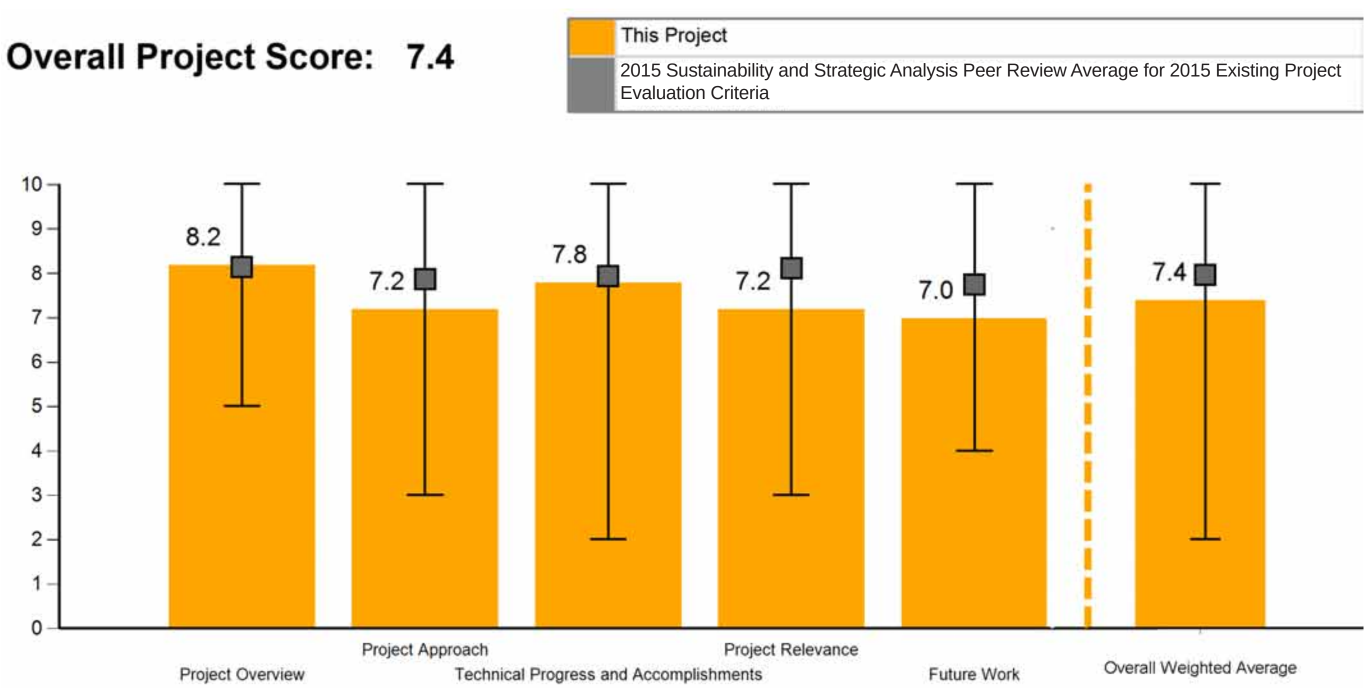


Image Courtesy of PNNL

Recipient:	PNNL
Presenter:	Mark Wigmosta
DOE Funding FY14:	$440,041
DOE Funding FY13:	$242,015
DOE Funding FY10-12:	$306,456
Planned Funding:	$27,250
Project Dates:	6/1/2010 - 9/30/2014

The goal of this project was to identify opportunities and sustainability constraints at the sub-county level to produce specific biofuel feedstocks. Efforts were focused on three specific areas: 1 – Identify spatial and temporal patterns in consumptive water use and water scarcity. The spatiotemporal scale of the analysis is critical in defining water scarcity. During the winter at the local scale (~12x12 km), 92% of the land in the contiguous U.S. is unstressed, 29% is stressed and 5.6% is water scarce. In the summer, these percentages are 80%, 5.1%, and 17%, respectively. 2 – Assess potential integration of switchgrass into the existing western U.S. crop mix to increase national biofuel production without increasing net water use. The project evaluated the introduction of Alamo, Blackwell, and Kanlow switchgrass on currently irrigated pasture, hay, and small grains. Approximately 31-37% of the highest yielding lands would be required to meet the Billion Ton 2022, $50/dry total production target of 78.2 Tg/year. 3 – Evaluate the potential for blending feedstocks that exhibit significant seasonal variability (i.e., algae) with alternative feedstocks having superior storage and transportation properties (e.g., municipal soil waste) to stabilize feedstock throughput. Depending on the algae strain, feedstock blending reduced the amount of land required for a given production target by 34-50% and the amount of water by up to 60%. There was also a significant reduction in required nutrients.



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project directly addresses a key question that has always existed in the Billion Ton Study, and that is: can any energy crops be grown sustainably in the western United States? Up until now, this area has largely been ignored. This project focused on understanding the water resource availability in this region as well as crop yields of switchgrass. Great progress was made on this project since the last review. The team provided water use with both spatial and temporal resolution and also by sector. Now that the water resource data is available, it would be interesting to use the model to look at forage sorghum or other crops that are low water users and are drought tolerant. An annual crop might also have better acceptance by the ranchers/farmers in the region. The project should focus on understanding the current biomass needs and looking for a solution that would continue to meet the current requirements, but could also provide extra income for the farmers; it could be a win-win for all. Is there a way to optimize to both livestock feed and biomass for fuels? Also, conducting a TEA on the switchgrass production scenario would be of value. The algae and MSW feedstock blending study was interesting but lacks convincing commercial viability.
- This project has a lot of potential for use in even more general water quality decision making by policymakers. I'll be interested in the publications when they come out. I hope that BETO can continue to translate the work into the policy space to advance perennials as displacement for annual crops in regions with over-stressed aquifers.
- The approach outlined by the project performers is (ironically) both highly detailed and highly preliminary in nature. It combines detailed geospatial data on water availability with an assessment of broad potential for switchgrass production based on western field studies. In effect, it sets constraints on the possibilities for energy crop production in the western states. Finally, this project opens the program to the idea that there may be sensible and sustainable applications for energy crop production in currently irrigated western agricultural lands. I applaud the team's willingness to challenge the conventional wisdom that any and all irrigated scenarios are a priori unsustainable. This kind of thinking has caused the bioenergy program to put on blinders in the past with regard to the Great Plains. The key, as pointed out by the team, is to find ways in which energy crop production will not place additional burdens on water-stressed areas (and perhaps, in this reviewer's opinion, even reduce water stress in regions) by replacing inappropriate water-thirsty crops with economically viable energy crops. The algae-MSW analysis added to this project felt a bit out of place relative to the scope of the project. The technical findings from this project point to a potential of the western states to benefit from and contribute to a sustainable bioenergy industry.
- This project offers quality insights by taking a high-resolution look at key variability in western U.S. systems including temperature and water scarcity. However, the absence of concurrent assessment of economic considerations for establishing switchgrass systems hinders this project from greater relevance. A more comprehensive analysis of the economic viability of bioenergy with the physical opportunities and/or limitations would have enhanced this project's relevance by offering key insights toward bioenergy supply potential from western U.S. systems.

PI Response to Reviewer Comments

- We thank the reviewers for their thoughtful comments and suggestions. As noted in our previous responses, we agree the switchgrass results are preliminary and would benefit from more focused outreach and economic analysis. However, we hope the work and subsequent publications achieved under this project will help open more dialog to bring about more location-specific approaches for determining the most beneficial and sustainable means of feedstock production. This may include inclusion of more candidate bioenergy crops (perennial and annual), crop rotation scenarios (alternative bioenergy and traditional crops), evaluation of local environmental conditions (i.e., climate, extreme events, water availability and quality, soils), incorporation of TEA, and potential improvements over current practices.

BIOMASS PRODUCTION AND NITROGEN RECOVERY

(WBS#: 4.2.2.10)

Recipient:	ANL
Presenter:	Cristina Negri
DOE Funding FY14:	$549,622
DOE Funding FY13:	$429,644
DOE Funding FY10-12:	$1,037,323
Planned Funding:	$1,113,411
Project Dates:	4/1/2010 - 9/30/2015

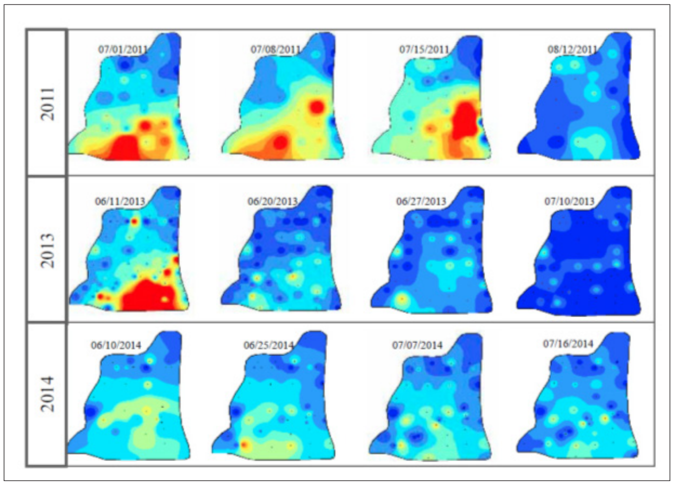


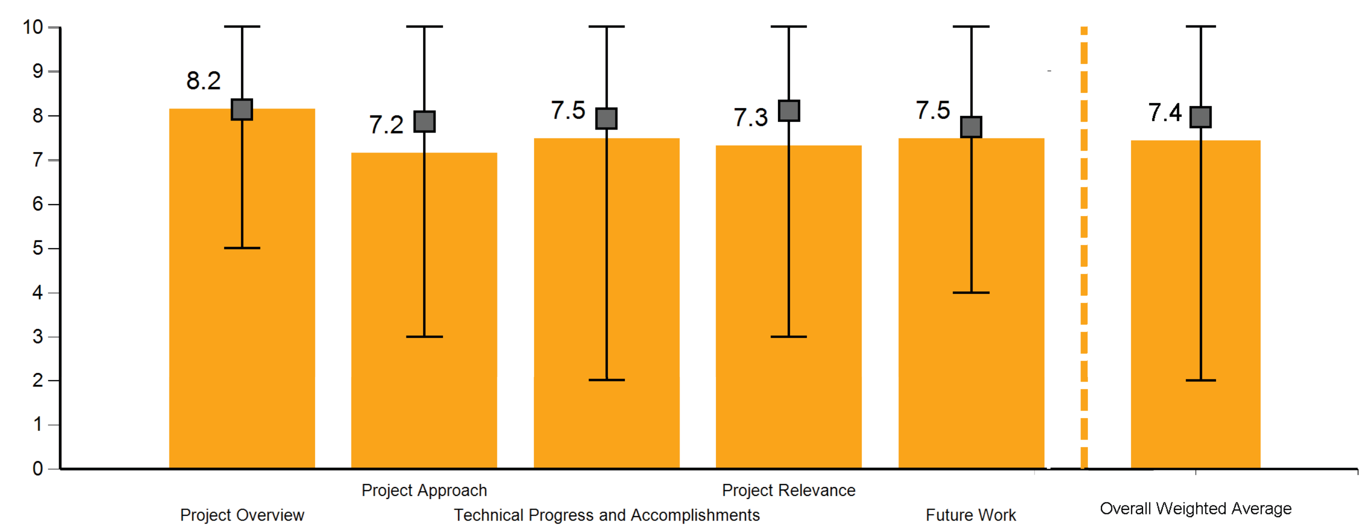
Image Courtesy of ANL

Project Description

This project applies concepts of landscape design to bioenergy crop production in the agricultural Midwest from the field/farm scale, at which farmer decisions are made, to the small watershed scale, in support of BETO's sustainability platform goals. This project evaluates the sustainability of a biomass production system based on the recovery of landscape elements like marginal land, nutrients, and impaired water. At the field scale, this project monitors sustainability indicators (water quality and quantity, soil quality, greenhouse gas emissions, yields) of a willow buffer planted in sub-productive portions of the field to mine and recover nitrogen lost by corn. The willow buffer was replanted in 2013, and environmental monitoring data were collected throughout the 2013 and 2014 growing seasons. The field was also used to test monitoring approaches suitable for cost-effective scale up. At the watershed scale, this project develops landscape designs that utilize underproductive/environmentally vulnerable land to grow bioenergy crops, and models the impacts of such designs on nutrient and sediment exports, water yields, and crop

Overall Project Score: 7.4

(orange)	This Project
(gray)	2015 Sustainability and Strategic Analysis Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

production. The challenge of determining the value to farmers is addressed by seeking stakeholder involvement to inform designs through targeted workshops using visualizations and guided discussions. This project is relevant to finding sustainable land use changes and innovative landscape designs, and preparing a watershed for bioenergy investments.

Overall Impressions

- This project involved two scales: the field site and the watershed site. Significant progress was made on both the watershed design and field testing. Extensive monitoring and data collection were key and provide a solid foundation as the researcher moves to use this data to scale up to larger areas. Stakeholder engagement and farmer acceptance was well done. This is particularly important as the landscape design complicates logistics for farmers with small patches. Understanding the cost of the whole crop systems and the return to farmers is critical moving forward. There is an opportunity to maximize for farmer value as well as for added biomass and ecosystem services. The close correlation of satellite data with in-field data should improve tool development for remote sensing, etc. Results showed that converting low-productivity land to energy crops reduces run off. Willow may not have been an optimal choice. Expanding the research to look at other crops would be beneficial.
- This project is a logical complement to INL's LEAF work and ORNL's work. In addition to giving us answers as to how we can get farmers to grow bioenergy crops from an economic incentives perspective, I can see this work and modeling being very useful to states in developing their nutrient management strategies. The PI understands that dynamic and is able to work it into her interactions with farmers.
- The project performers have made significant progress over the past two years. After an initially failed attempt to establish willow as a bioenergy buffer crop, they have successfully completed replanting. Likewise, they have collected a substantial amount of empirical and modeled data on greenhouse gas emissions and nitrate leaching impacts of the willow buffer system. They have been reaching out to farmers to get feedback on their interest in applying willow buffer strips as part of a management scheme for improving the sustainability of corn production. However, despite recommendations from the last peer review two years ago, the project still has not conducted a preliminary economic analysis needed to understand the viability of such a system.
- This project is now 70% complete. Given the delays in establishing the willow buffer strips, it probably makes sense that the project be extended for an additional year to allow for as complete a set of data as possible. Plans for conducting an economic analysis are, however, way overdue. There is no excuse for not conducting this analysis in the first stages of the project. This analysis could have served as a means of establishing required performance targets and/or even supporting an early go/no-go decision. Instead, the project finds itself in the situation of having spent over $2 million without any assurance of economic viability and relevance, which should not be permitted in future (costly) multi-year field trials. This reviewer hopes that both high-level (crude) economics, alongside the project's planned detailed economic analysis, will be done. If it turns out that the economics of the proposed willow buffer system show it to be unsustainable, an effort should be made to understand how a preliminary economic assessment might have avoided a large investment in a scheme that ultimately proved uneconomic.
- This is a project that could add value to BETO's goals of identifying environmentally beneficial bioenergy systems. The work performed in the watershed analysis provides great insights on the environmental impacts of willow buffer in the zones considered. However, this project is relatively narrow in approach and could have benefited from sen-

sitivities such as the systematic variance of nitrate application and testing alternative bioenergy crops in addition to willow. Beyond the environmental implications, questions remain of the economic viability of willow buffer strips, and questions such as the costliness of collecting the bioenergy material and ability to sell this material need to be explored further. These questions are site-specific so the ability to apply the insights gained from this specific watershed analysis are limited with current progress.

PI Response to Reviewer Comments:

- **Lack of Economic Analysis**: The Presenter respectfully disagrees with the statement that a crude economic analysis would have been useful to prevent the risk of investing in a non-viable approach. As mentioned during the 2013 review, an economic analysis was started but was postponed because the uncertainties in the data would have made it useless and not able to stand a peer review. Over the course of this project, we have examined the economic model for this approach and determined that under the relatively benign conditions in the area under study, production costs of any crop grown in buffers with corn or soybean could be approximated by those in conventional planting, barring yield variations and organizational issues. Many studies are available that have calculated these costs. Logistics costs, however, have the potential for being quite different, particularly (using the INL model) in the phase of transport from the field to collection point. They are highly dependent on spatial configurations, and therefore transport costs could not be assessed before we had identified target planting areas and developed a rough design for the bioenergy planting in the watershed. Additionally, we have identified from farmer feedback, in addition to potential organizational obstacles, several elements bringing positive organizational efficiencies and farmer preferences, including ways to overcome the burden of managing small patches. These need to be quantified. Finally, a third, still unquantified element is critical in the assessment of the economic cost and value of the end product(s). As we are growing bioenergy crops for two purposes (production of feedstock and of ecosystem services), any economic analysis that does not incorporate both would be incorrect and incomplete. Our work has shown that there could be a definite benefit from the use of landscape design to guide biomass deployment. Our empirical data will allow us to quantify and assign a value to some of these services. We plan to conduct a complete economic analysis (production, logistics and ecosystem services) in FY16 when the uncertainties will be reduced. We believe that this project will provide a valid assessment of production costs, logistics and transport, and value of the ecosystem services provided. There is a tremendous interest, across the U.S., in nutrient trading programs as well as large uncertainties in the quantification and valuation of the services to be traded. A premature economic analysis may have incorrectly labelled (positively or negatively) a potentially useful practice without any scientifically grounded data. Additionally, even if this approach should prove economically unsustainable, there is value in the empirical data generated by this project on environmental performance of a bioenergy crop (greenhouse gas emissions, water quality impacts, water use, and productivity) and an added return on the investment in terms of availability of data to the broader research community.
- **Narrow Scope**: This project is focused on biomass and expanding the focus to nitrogen management practices would have been outside of the area of relevance to bioenergy development objectives. Demonstrations of these practices are, however, ongoing in the watershed as part of an independent effort and synergisms could be explored if appropriate resources were available.
- **Specificity to Site Conditions**: Many of the ques-

tions posed in this comment sectionare the object of current work. Our work in testing methodologies to scale up are specifically working toward the objective of expanding from site-specific relevance to ultimately providing data and input to broader models. More field/watershed trials are needed to provide the statistically viable basis for this scale transition. This work is greatly beyond the current scope and financial capacity of this project, and has already been proposed as a separate project.

BIOENERGY SUSTAINABILITY: HOW TO DEFINE AND MEASURE IT

(WBS#: 4.2.2.40)

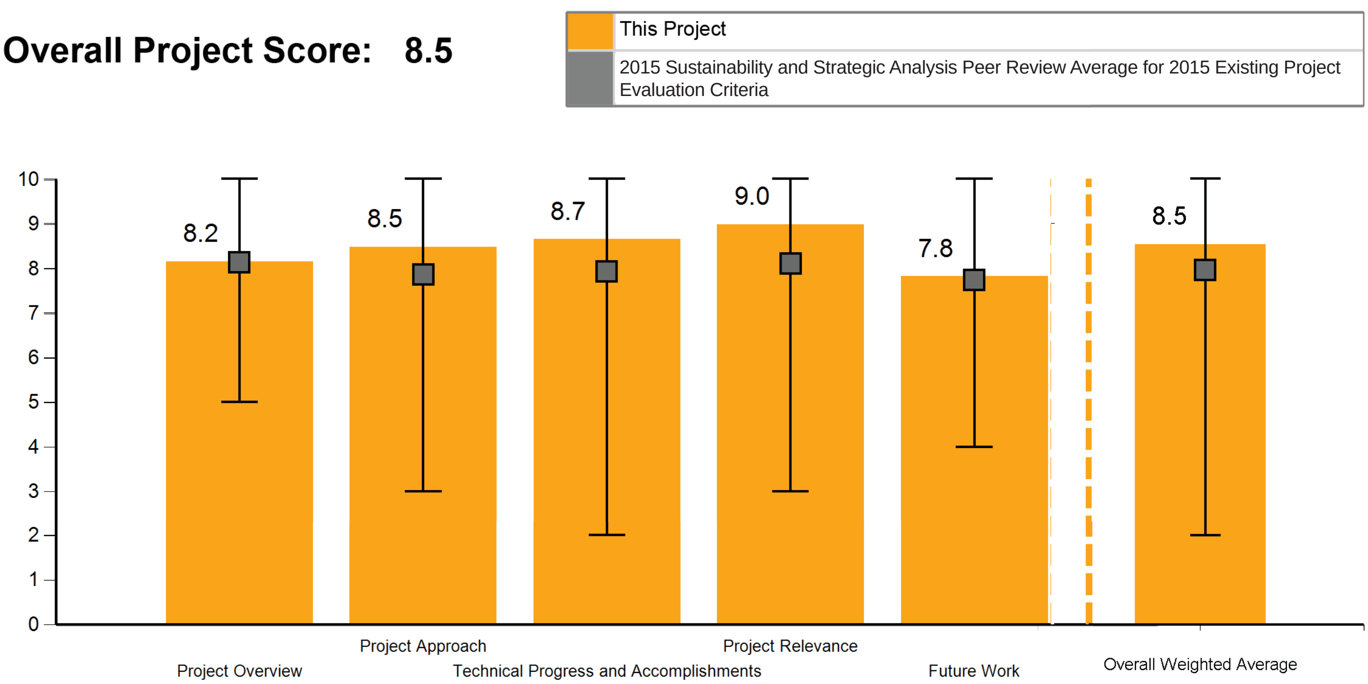
Photo Courtesy of ORNL

Recipient:	ORNL
Presenter:	Virginia Dale
DOE Funding FY14:	$897,870
DOE Funding FY13:	$575,396
DOE Funding FY10-12:	$1,045,862
Planned Funding:	$964,873
Project Dates:	10/1/2008 - 9/30/2017

Project Description

The project will establish methodology for measuring and assessing progress toward a sustainable bioeconomy. Building from our previously proposed indicators and analysis, the project focuses on: (1) particular indicators that are difficult to measure (e.g., biodiversity and water quality); (2) case studies to both validate and further develop our approach (e.g., using switchgrass and woody residues from the southeastern U.S.); (3) development of the underlying approach of applying aggregation theory to bioenergy sustainability; and (4) visualization tools. These efforts have moved from establishment of indicators to determination of baselines and targets for particular contexts, evaluation of indicator values, consideration of trends and potential tradeoffs/synergies, and ways to develop and test good management practices. This project entails all parts of BETO's "circle diagram" (Figure 2.40 in BETO's Multi-Year Program Plan (March 2015) and addresses

Overall Project Score: 8.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

the following BETO Technical Challenges and Barriers: St-B: Consistent and Science-Based Message; St-D: Indicators and Methodology; and St-C: Sustainability Data Across the Supply Chain. The project outcomes will move the bioenergy industry toward more doable, consistent, comprehensive, cost-effective, and legitimate ways to measure and assess progress toward a sustainable bioeconomy, as defined by context-specific targets and as documented through use of ORNL's interactive visualization tool.

Overall Impressions

- This is an important line of research and the work is commendable. The implications of this, however, are necessarily broader than bioenergy. Some discussion of how sustainability assessment of bioenergy can co-exist with sustainability of conventional land-use (forestry and agriculture) would be helpful. A project of this scope is difficult to assess within the time allotted. Much of the technical work was left out in the interest of time, making it very hard to assess approach, relevance, and progress. This particular project is central to BETO work on sustainability. It is also a project that has significant policy implications for other sectors. It should really be more thoroughly reviewed by a broader team with more time. At a minimum, this would help develop credibility for the approach and work.
- This project covers a broad scope as it seeks to evaluate and standardize the use and understanding of sustainability. This is fundamental to all of the other projects in BETO. It is innovative in seeking to provide a balanced, yet scientifically based approach to the issue. The results will provide a reference point for future work across the bioenergy field. It allows for consistency and transparency in doing sustainability work. Aggregating or down-selecting the vast array of metrics will be difficult and could lead to weighting issues and other tradeoffs. However, it is a goal worth pursuing. Overall, this project covers a broad scope but is critical to identifying a universal framework that can be consistently applied across the entire value chain of the complex biofuels industry. It is imperative that this work is widely distributed because it will be most successful when the learnings generated impact decision-makers and the entire bioenergy industry.
- The project is important for national and international efforts to build an indicator architecture for sustainability quantification of bioenergy. The PI has aptly recognized that the next steps are to be able to quantify the indicators and balance between outcomes. This work is highly relevant to the other technology areas within BETO, as none could be commercialized without meeting quantified sustainability metrics. I hope that future work encourages BETO's socio-economic sustainability model (i.e., JEDI modeling) to incorporate more holistically the socio-economic effects of bioenergy in communities, for example, the economic value of an improved environment. There is no doubt that this project is highly productive and valuable to the BETO program.
- Over the course of this project's history, the team at ORNL, along with its partners, have advanced the fundamental thinking about sustainability in general, and laid out a framework that is applicable not only to bioenergy, but to many other sectors of society. Their work continues to break new ground. The effectiveness with which the team has communicated with and engaged groups outside of DOE is also impressive. Internationally and domestically, they are at the table with organizations that are grappling with the questions and controversies that surround bioenergy. Their record of publication in peer-reviewed journal articles and book chapters also speaks to their success in communicating their progress to the rest of the scientific community and in building a solid and credible basis for a sustainable bioenergy industry.
- Two areas of concern have surfaced in this year's overview of the work. First, it is not clear exactly what has been accomplished in the evaluation of sustainability metrics for wood pellet production and trading. This reviewer found it difficult in gen-

eral to draw a clear line between progress reported in 2013 and work done since then. Second, the project has introduced a new approach to simplifying the presentation of metrics that seems to involve a rigorous mathematical technique for aggregating the complex set of metrics of sustainability in a set of high-level indicators. This approach was not explained in any detail and it raises concerns. While the mathematical rigor implies objectivity and sound science, it also raises the specter of technical complexity that may result in reduced transparency of the aggregate measures. There may be an unwelcomed trade-off here between ease of use and transparency of meaning for the end users. No details of how these indicators are generated was presented. This reviewer would like to see a thorough review and discussion of the justification for this approach before a large investment is made in time, money, and resources.

- The objectives of this project are ambitious and critically important to universally promoting bioenergy, and innovative strategies are needed to tackle the massive undertaking of defining sustainability across different systems, technologies, and regions. The effort has been ambitious in understanding the factors contributing to sustainability and diagnosing the contextual differences that must necessarily be considered. There is reasonable uncertainty around the formation and application of an aggregation methodology to assess the many factors of sustainability collectively, but it is a worthy undertaking, as is the future development of a universal function tool for performing comparisons.

PI Response to Reviewer Comments

- We are pleased that the reviewers recognize that this effort has advanced fundamental thinking about sustainability in general and sets forth a framework that is applicable not only to bioenergy but also to other sectors of society. Several comments relate to two parts of the project that were not reported in detail because they are under development: (1) applying the sustainability metrics to wood pellet production and use, and (2) developing a rigorous and transparent mathematical technique for aggregating metrics when appropriate. Ensuring ease of use and transparency is an essential part of our work. We agree with the reviewers about the importance and sensitivities surrounding the aggregation methodology. As we proceed, we will help document where risks arise due to inappropriate aggregation, and the visualization tool will illustrate where trade-offs can occur and the implications of those tradeoffs.
- We have compared bioenergy to conventional energy and land uses (see Dale, et al., 2015, Parish, et al., 2012 and 2013) and plan to do so in the future. For example, as we initiate the case study of wood-based pellets in the southeastern U.S. this year, we are working with industry and other stakeholders to identify the appropriate scenario (counterfactual) for comparison to the pellet industry.
- We are pleased with the reviewer's comment that, "it is imperative that this work is widely distributed since it will be most successful when the learnings generated impact decision makers and the entire bioenergy industry." Regarding communication, we widely distribute our results and discuss our ideas not only in the scientific arena but also to stakeholders across bioenergy production systems. Our publications, fact sheets, workshops, forum, monthly reports, and webinars are frequently accessed on the Center for Bioenergy Sustainability website: *http://web.ornl.gov/sci/ees/cbes/*. In addition, the project regularly provides information to the Bioenergy Knowledge Discovery Framework: *https://www.bioenergykdf.net/*.
- We have presented at public field days, webinars, and scientific meetings as well as peer-reviewed journals. Via each of these venues, we seek input and advice on how best to proceed. Interfacing with diverse decision makers involved in bioenergy has shaped our research program.

- Our 2015 framework paper (Dale, et al., in press) describes how to select indicators depending on the context, goals, and stakeholders involved. Our goal for the visualization tool is to enhance the ability to communicate results of the sustainability assessment across diverse contexts.
- It is heartening that the reviewers recognize that while the project covers a broad scope, its efforts to evaluate and standardize the use and understanding of sustainability is fundamental to all of the other projects in BETO. Our future work will continue to identify a strategy for assessing progress toward sustainability and conditions in case studies that enhance progress across different systems, technologies, and regions.

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Parish, E.S., K.L. Kline, V.H. Dale, R.A. Efroymson, A.C. McBride, T.L. Johnson, M.R. Hilliard, and J.M. Bielicki. A multi-scale comparison of environmental effects from gasoline and ethanol production. Environmental Management, Volume 51, Issue 2, pages 307-338, February 2013.

SHORT ROTATION WOODY BIOMASS SUSTAINABILITY

(WBS#: 4.2.2.41)

Recipient:	ORNL
Presenter:	Natalie Griffiths
DOE Funding FY14:	$325,547
DOE Funding FY13:	$205,682
DOE Funding FY10-12:	$31,483
Planned Funding:	$475,288
Project Dates:	10/1/2009 - 9/30/2018

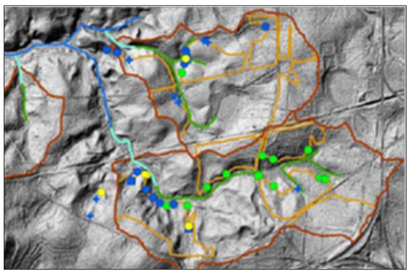
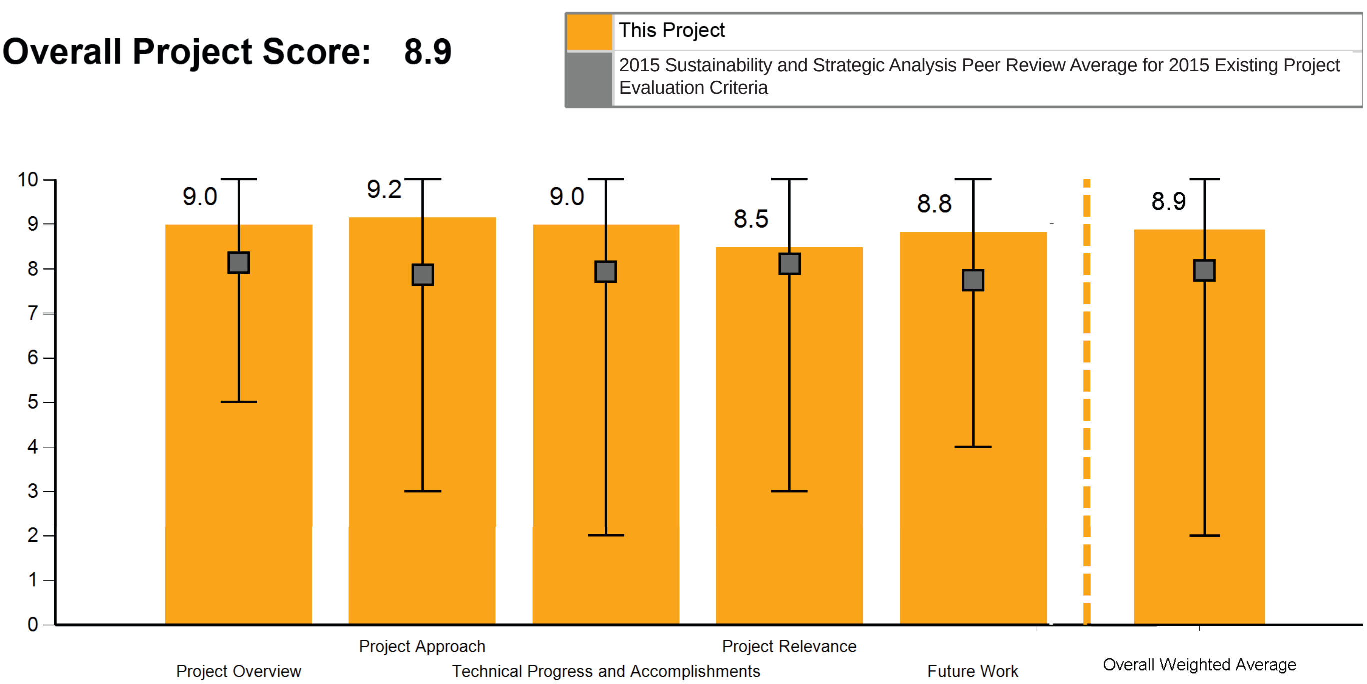


Photo Courtesy of ORNL

Project Description

Woody biomass is expected to be a dominant bioenergy feedstock in the Southeast; however, environmental effects have not been evaluated. This project uses a watershed-scale experiment and a distributed watershed modeling approach to evaluate the environmental sustainability (water quality, water quantity, soil quality, and productivity) of intensive silviculture practices in the southeastern U.S. Three adjacent watersheds (2 treatment, 1 control) in South Carolina were instrumented and baseline data were collected for two years (2010-2012). Over 40% of the treatment watersheds were then harvested (2012) and planted with loblolly pine seedlings (2013). Pine management practices (herbicide, fertilization) have occurred annually and best management practices were followed. Baseline hydrology and biogeochemical measurements showed that groundwater is the dominant flow path linking silvicultural activities and streams. Nitrate concentrations increased in groundwater (<2 mgN/L) post-treatment, but nitrate has not increased in stream water. Herbicides in stream and groundwater were below detection. Hydrological models are being parameterized with field data and will be used to scale results spatially and temporally. Modeling of management scenarios with a standard model (MIKE-SHE) found little net change in stream flow under intensive pine production. Water and soil measurements will continue through 2018 (canopy closure) and model devel-

Overall Project Score: 8.9



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

opment and application will occur in parallel.

Overall Impressions

- This is an excellent project that is a stellar example of solid research work on bioenergy sustainability/ impacts. DOE should be proud of this one.
- Woody biomass has the potential to be the dominate bioenergy feedstock in the southeastern United States. Therefore, understanding the environmental impacts of woody biomass grown for bioenergy is critical. This project looked at various levels of fertilization, herbicide application, and site preparation on complex water systems. The researchers looked at nitrogen not just at the stream level, but in the soil as nitrogen mineralization, etc., as well as uptake. This represented a comprehensive approach. The significant quantity and quality of data collected allowed the researchers to adapt their model to better match the data and develop scenarios to validate the model. It will be important to apply this work to develop sustainable best practices around using this resource, as well as to test the ability of this work to be used in other watersheds. Future work includes conducting a TEA to look at costs (target of $60) of using woody biomass crops as a potential bioenergy feedstock. The work was highly leveraged and well executed.
- The project is ambitious and complex in its approach in reaching measurements for soil and water quality. It is surprising that industry has not studied similarly the application of best management practices (BMPs) in relation to increasing interest in quantification within watersheds. To the extent that industry has not generated information similar to this project, this effort is certainly necessary to fill those gaps in order to prove that these systems do not impair the environment. The relationships with the National Council for Air and Stream Improvement (NCASI) and the U.S. Forest Service are critical to ensure that the work translates into more quantification of BMPs in relation to state and federal goals for increased water quality. I would have liked to have seen how these systems could incorporate more innovative, less monocultured systems and how this project relates to the new project that ORNL is embarking on with Europeans. How these types of systems relate to landscape level biodiversity is a hot-button question in policy that is not being addressed by this project.
- This is an extremely well-managed project. The objectives are clear. A detailed management plan is in place, and all milestones have been met to date. The project performers are clearly on their way to addressing all critical success factors, most importantly that of being able to validate environmental sustainability of high-yield woody crop systems relative to current best practices in silviculture. Adoption of efficient, high-yielding short rotation woody crop systems in the southeast U.S. is a critical element for a sustainable supply of bioenergy. This project will generate important and highly relevant information about the environmental sustainability of such systems. Project plans for the future basically focus on continued monitoring and modeling of soil and watershed impacts of intensive, short rotation woody crop systems. This will be invaluable information. At the same time, this information is being brought to relevant stakeholders, which is vital to sustainable implementation. The project performers might consider performing a broader economic and environmental life cycle assessment to highlight the full range of sustainability implications. This may require additional funds, but would be well worth the investment.
- This project is a quality component of BETO's portfolio. With the ever increasing role of the Southeast to supply domestic and international bioenergy demands, an evaluation of the soil and water quality impacts of variable silvilculture treatments and a critical assessment of existing BMPs are essential.

The approach is well suited to capture the variety of options that may be implemented for short rotation systems. The modeling techniques are thorough and the data collection process is well organized. Future work of applying methods to an alternative region and developing methods to upscale results will enhance the utility of this project's efforts in broader arenas.

PI Response to Reviewer Comments

- Regarding the comment on the silvicultural system, we chose a loblolly pine monoculture because pine is what southeastern foresters grow. The wood production infrastructure is focused on pine - there is plentiful nursery stock, silvicultural knowledge, contractors who know how to harvest, plant, and apply chemicals, and markets for products. The tree is hardy and quite reliable. It has been the dominant commercial tree of the southeast for over half a century, and there is no sign of that changing. However, pine has not been grown on a 10-12 year rotation, because there has not been a market for wood that small. Traditional forestry does not disturb the ground as much, remove as much product, or apply as many chemicals (fertilizer and herbicides) as would be done if the bioenergy market created demand for short rotation pine biomass. Thus, studies of BMP effectiveness for traditional forestry do not encompass the site conditions associated with short rotation biomass production. One of our goals is to determine if current BMPs are adequate for short rotation woody biomass production given these differences in management.
- We felt that making the design any more complex than it is currently would make interpretation of the results more difficult. In addition, extensive experience in operational settings by several of the PIs suggests that the logistics of establishing and managing complex species and structure arrays is prone to failure. It is one thing to prepare, plant, and manage a single crop in a limited area, but adding additional species/structure is very difficult on a large scale.
- Regarding connections between our project and other ORNL research projects, we are actively working (and will continue to work) together to use consistent methods (i.e., we are measuring many of the sustainability indicators developed by Virginia Dale's team) and share results relevant for evaluating the environmental sustainability of woody biomass feedstocks in the southeastern U.S.
- We appreciate the comment on expanding the project to include biodiversity and economic factors and life-cycle assessments and will explore potential pathways to leverage funding to include these measures. Currently, the project has no funding to support biodiversity and socio-economic indicators or to do life-cycle assessments. The Savannah River Site has a great deal of scientific information and databases on species and community-level impacts to vertebrates and invertebrates as they relate to normal forestry practices (harvesting, herbicides, stocking, etc.). Important questions relate to the effect of simplification of these systems directly and their influence on the adjacent reserve lands used as buffers, which are typically riparian forests and wetlands. A study could be designed if funding were available. Similarly, it would be important to determine the social-economic impacts of an alternative bioenergy crop as a market alternative to pulp and paper, pelletized wood for Europe, other wood composites and non-food crops.

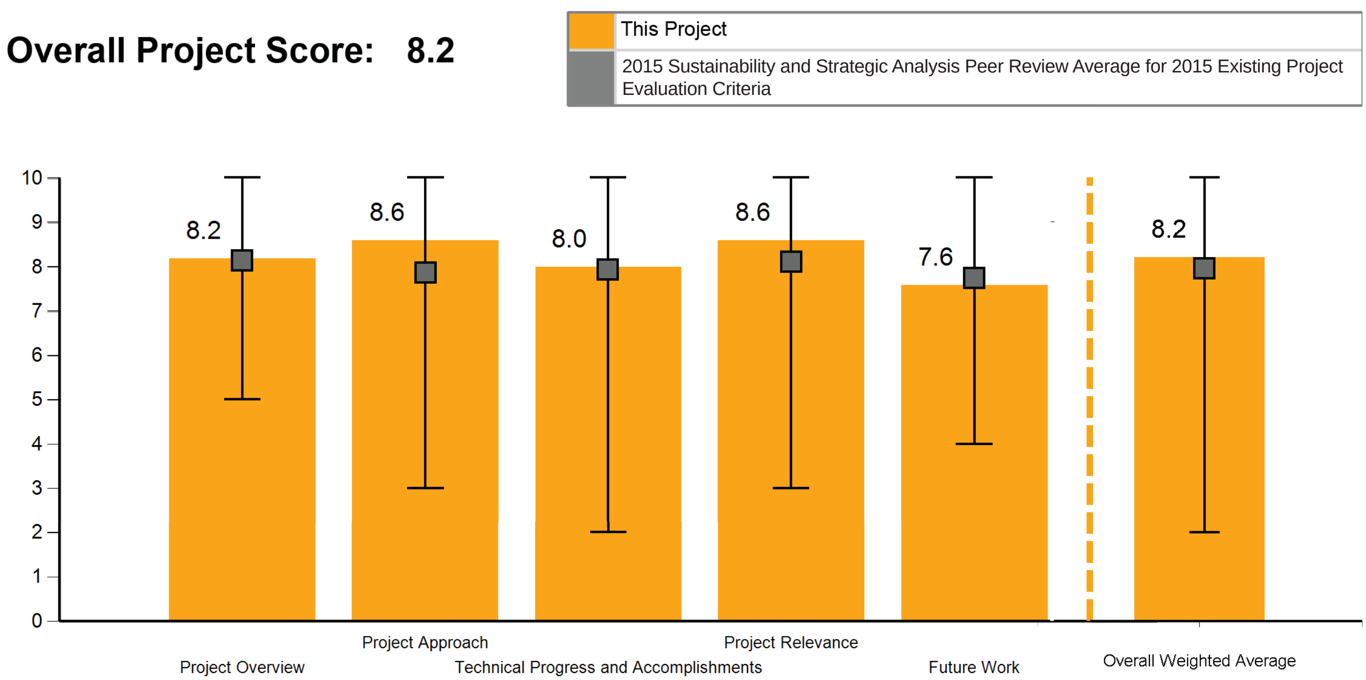
BIOFUELS INFORMATION CENTER (BIC)

(WBS#: 6.3.0.1)

Recipient:	NREL
Presenter:	Kristi Moriarty
DOE Funding FY14:	$253,191
DOE Funding FY13:	$69,636
DOE Funding FY10-12:	$429,038
Planned Funding:	$481,823
Project Dates:	10/1/2008 - 9/30/2017

Project Description

The Biofuels Information Center (BIC) was created by NREL in FY08 for the Bioenergy Technologies Office as an extension of the widely used Alternative Fuels and Advanced Vehicles Data Center (AFDC) at *www.afdc.energy.gov*. The changing fuels market, as well as the large federal investment in biofuels, creates an imperative for maintaining current and relevant information to inform decisions among biofuels investors, businesses, and government partners. The goal is to provide easy to use data, information, and tools that will grow the domestic bioenergy market. FY14 work focused on updating AFDC biofuels pages (biodiesel, ethanol, emerging fuels), updating all data layers for BioEnergy Atlas tools, and migrating to a new, more user friendly platform. Combined, the AFDC biofuels pages and BioFuels Atlas tools had nearly 570,000 website visits in FY14. All 42 AFDC biofuels pages were reviewed, edited, and updated by expert staff. BioEnergy Atlas tools (BioFuels Atlas and BioPower Atlas) provide



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

users with biomass datasets which can be viewed on a map, queried, downloaded, and analyzed to determine biofuels or biopower production potential for selected feedstocks in a geographic location. Keeping these tools up to date and adding more advanced capabilities provides users with data and information to inform their strategic decisions, identify new market opportunities, and assess major barriers to deployment.

Overall Impressions

- This project is not as glamorous as some of the other projects, but instead requires the monumental task of reviewing and updating all the data and tools used in the Biofuels Information Center. The relevance of this project comes from its ability to help BETO meet its goals and provide a resource for disseminating relevant bioenergy data and assessment tools to the wider stakeholder audience. One example is the Alternative Fuels Data Center whose web pages and content was recently updated. The Alternative Fuels Data Center is the most visited EERE website. With a project of this size and scope, being able to down-select and prioritize projects are essential. The project has progressed smoothly. The website has a nice look and feel as well as a lot of useful data and tools. Future work includes looking at the reasons behind the lack of E-15 infrastructure and making upgrades to the Bioenergy Atlas.
- In the next review, I would love to see how these pages compare to other pages that provide information. I think the work could be advertised more, but then again, I think that it needs some examples of how the information can be used, and/or have DOE employees use it and publish on the site the ways in which they used it and how it was valuable. Otherwise, it seems like a site for researchers who want to do analysis runs, but if you are not a researcher doing that, then you would not exactly know the ways in which it can be used to get useful results.
- The BIC efficiently delivers important and useful data to a wide-ranging audience in a way that is user friendly. Its intended audience is not the community of experts and researchers deeply engaged in bioenergy development activities, but rather the audience of stakeholders such as consumers, regulators, policymakers, and marketers who need to assess the value of bioenergy. In that capacity, the BIC is critically important. In general, the job of disseminating useful data and data tools is very well done, building effectively off of other EERE-sponsored web resources. It is surprising that the BioEnergy Atlas, which delivers a rich set of data and analysis capabilities, is among the least popular elements of the BIC. The project team may need to consider whether this Atlas/GIS approach to data presentation is sufficiently useful to its intended audience.
- The AFDC has grown to be a superb source for information on biofuels and bioenergy feedstocks. The quality of the highly visual interfaces, enhancements, and numerous interactive features are validated by the impressive popularity of the site among the public.
- Overall, the BIC is a worthy project and I recommend that it continue.

PI Response to Reviewer Comments

- The AFDC is the most-visited EERE website, accounting for 23% of EERE website traffic. AFDC biofuels pages are updated annually and are a resource for a very wide stakeholder group, which includes bioenergy companies; other government departments/agencies (DOD, DOI, DOT, EPA, USDA); industry groups (Advanced Biofuels Association, American Petroleum Institute, ASTM, Growth Energy, National Association of Convenience Store Owners, National Association of Truck Stop Owners, National Biodiesel Board, Petroleum Equipment Institute, Renewable Fuels Association, Steel Tank Institute, Western Governors Association); state offices (economic development, energy, environment); institutions; investment firms; and universities. Stakeholders provide suggestions and edits and we incorporate those where possible. As an example, EPA had suggested edits to the AFDC RFS page and the Renewable Fuels Association had a suggested edit to the AFDC RIN page. These changes were reviewed, updated, and released on the website in April 2015.

- Outreach plans for BioEnergy Atlas tools include an NREL press release, a BETO webinar on how to use the tools, and distributing and demonstrating it for state energy/environmental offices through an existing partnership. These activities will increase the users and relevance of these tools.

BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK

(WBS#: 6.3.0.2)

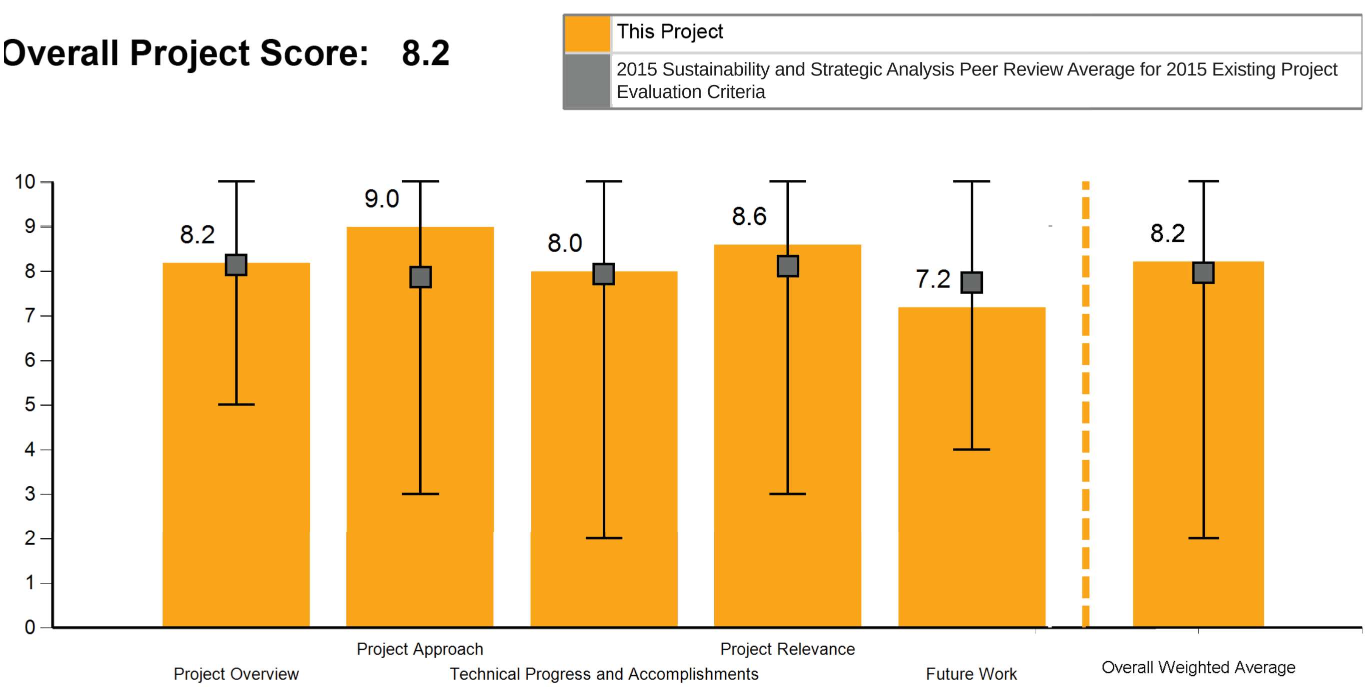
Photo Courtesy of ORNL

Recipient:	ORNL
Presenter:	Aaron Myers
DOE Funding FY14:	$509,119
DOE Funding FY13:	$483,059
DOE Funding FY10-12:	$2,117,229
Planned Funding:	$661,355
Project Dates:	10/1/2008 - 9/30/2017

Project Description

There are many issues in the biofuel supply chain from production to delivery that have to be addressed in order to foster a viable biofuel industry. Infrastructure issues related to generation, distribution, and delivery of biofuels include finding the optimal locations to site biorefinery to minimize cost with adequate availability of feedstock resources nearby. The Bioenergy Knowledge Discovery Framework (KDF) is a collaborative platform for knowledge creation, collection, curation, and discovery to support DOE's effort to develop a sustainable biofuel industry. The Bioenergy KDF facilitates informed decision making by providing a means to synthesize, analyze, and visualize vast amounts of information in a spatially integrated manner. The Bioenergy KDF enables data harmonization from different sources, serves as a source of authoritative and benchmark datasets and provides integrated decision-making capabilities to its different stakeholders. It serves as an open platform, leveraging collaborative aspects of the social web to catalog and share datasets and other relevant information. The Bioenergy KDF will also host "apps" addressing different bioenergy-related problems. These apps will include techno-economic models, routing models for

Overall Project Score: 8.2



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

transportation, and apps for visualizing different feedstock production scenarios.

Overall Impressions

- The Bioenergy Knowledge Discovery Platform provides a key role in serving as the repository of information and connecting those who desire access to that information. It serves as a single point of access to a board range of bioenergy information, tools, and data. Much has happened since the last review. Adding the Legislative Library was a nice touch. This has obviously filled an important knowledge gap as it has become the 10th most viewed page on the site. Overall, the site appears to have been well received with a steady stream of users. This is encouraging as it is critical that the work being done gets into the hands of those who need it. The team has made it easy for others to upload information to the site. Going forward, BETO may want to consider requiring all data generated from BETO-funded projects be uploaded. I applaud the efforts to try to quantify the value the site has had and concur that the tool cannot be everything for everyone. The team has chosen to focus at the researcher level and not the general public level. I would encourage adding algae to the site. This is a current gap in the knowledge base. I would also recommend developing a marketing plan to increase visibility and use of the site.
- BETO should particularly emphasize the ROI analysis. It is not clear how "return" will be measured, but one method could be another "mini" review of the KDF site. I don't think a generic online survey of its benefits would attract much valuable input because I am not sure if people would take the time necessary to be contemplative. "Return" should span use by academe, government agencies, and policy makers. As to the latter, much discussion was had within the peer review group as to how all of BETO's portfolio could be better translated to the policy community. KDF is one step, but an additional critical step would be to reach out and learn how it is used, and then translate that to policy makers. KDF facilitates knowledge and analysis, but BETO really does not have a grip on exactly how this translates into furthering the bioeconomy, both technically and in policy.
- The Bioenergy KDF has come a long way since its inception. It was originally seen as the ultimate forum for delivering "knowledge" writ large on bioenergy to a wide range of audiences. Since the last peer review (and in response to the comments made by the peer review panel), the KDF team has narrowed its focus to address the needs of the bioenergy research community. They have been able to transform this web-based knowledge tool into a timely and comprehensive source of data and analysis.
- The universe of bioenergy is vast and complex. With such diverse feedstocks, technologies, systems, and regional variability, a centralized, credible, and accessible database to collect information and inform stakeholders is paramount. The KDF has become an excellent framework to suit these purposes. Continued improvements in the site's organization allow for better navigation while added capabilities such as the Biomass Scenario Model tool and the Legislative Library have increased the site's functionality. The success of a site such as this hinges on the active participation of its users. The impressive range of features that have been and continue to be developed should only promote KDF's position as the go-to bioenergy data resource for academics and policymakers.
- There needs to be an increased effort to ensure that outputs/results of BETO-funded projects consistently get posted onto the KDF. Making this a mandatory milestone for all projects may help.

PI Response to Reviewer Comments:

- Thank you for your feedback and comments on how to improve the Bioenergy KDF and acknowledgment on the efforts that have been made since the last peer review. The KDF Team feels we are moving in the correct direction and continue to work to engage new users and identify new capabilities to bring to the user community. Though having mandatory milestones for adding content to the KDF is good, there is a fine line between requiring usage and building an engaged user community. This is an area in which the development and management teams will need to continue to define best practices. The ROI discussion is one where much research is needed and the KDF fits into a unique area where common metrics do not necessarily provide the same justification as they would for a business or standard data access site.

CARBON CYCLING, ENVIRONMENTAL AND RURAL ECONOMIC IMPACTS OF COLLECTING AND PROCESSING SPECIFIC WOODY FEEDSTOCKS IN BIOFUELS

(WBS#: 4.2.1.60)

Recipient:	CORRIM
Presenter:	Steve Kelley
DOE Funding FY14:	$0
DOE Funding FY13:	$161,938
DOE Funding FY10-12:	$399,802
Planned Funding:	$678,694
Project Dates:	5/1/2015 - 5/1/2018

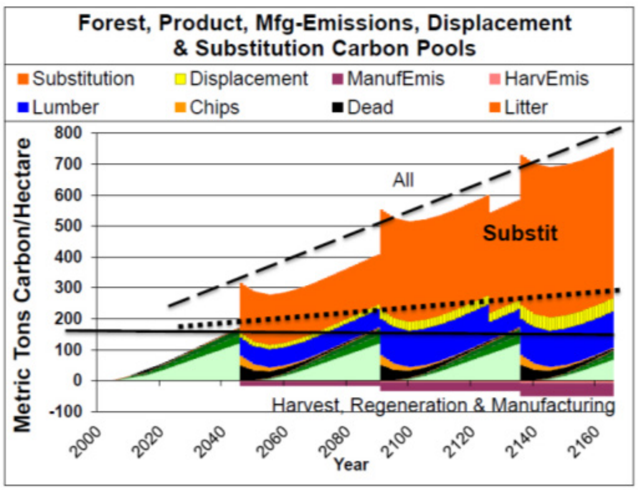


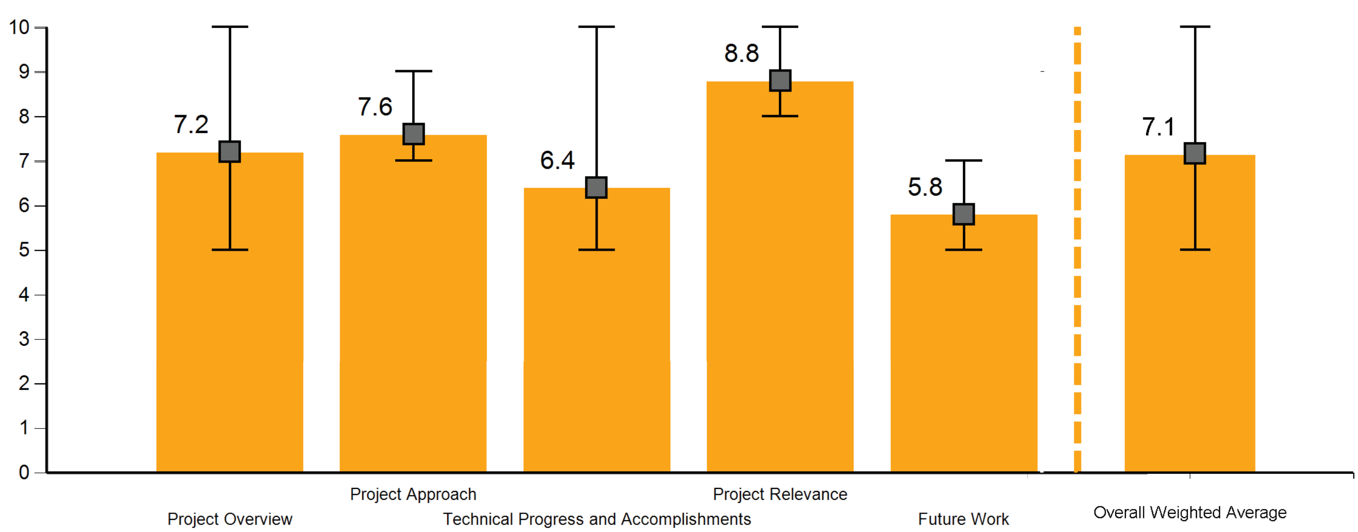
Image Courtesy of ICORRIM

Project Description

The project will quantify sustainability criteria for regionally specific woody feedstocks from both commercial softwood systems and short rotation woody crops (SRWC) and provide the life cycle assessment (LCA) inputs for the Argonne National Laboratory (ANL) GREET model. Analysis will cover feedstocks from three U.S. regions (PNW, SE, and NE). The feedstocks will be used as inputs for the DOE Biochemical (BC) and Thermochemical (TC) process models to evaluate the LCA impacts of variations in woody biomass properties, and the tradeoffs between the use of wood biomass for durable wood products and biofuels. Allocation of environmental burdens for the use of forest residues from current commercial operations (cost, quality, and

Overall Project Score: 7.1

	This Project
	2015 Sustainability and Strategic Analysis Peer Review Average for 2015 New Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

transportation issues) and understanding the implications of durable wood products as a co-product will be quantified. The impact of the extended temporal aspects of durable wood products (20-70 years) and commercial forests (30-50 years), and the variations in commercial practices between regions will be addressed. The current demand for commercial, durable wood products and the unique role of forests in the minds of the American public means that the sustainability of woody biomass systems attracts even more attention than other biomass sources. Using LCA to quantify elements of sustainability is designed to reduce barriers to the use of woody feedstock for energy products. The LCA outputs will be matched to the ANL GREET protocols.

Overall Impressions

- This limited project basically seeks to leverage existing databases to estimate the life-cycle burdens associated with the production and collection of woody biomass. The end goal is to be able to supply a full well-to-wheels data set to GREET. Communication and a close working relationship with the GREET team are essential to success. Because this project just started, there were limited results. However, the researchers did discuss how they planned to proceed and gave some examples of the type of results they hoped to achieve. Biomass varies by composition and ash content, etc., all of which need to be taken into account in the study. One limitation of the project is that the project only looks at lumber not plywood, compressed wood, and other wood products. Looking at these other wood streams could increase the applicability considerably. This project is in direct response to a request by BETO and is well connected with other BETO projects. GREET is the direct customer of the work and is an active partner in the discussions. It is difficult to understand how, if solid wood is a co-product that lasts many years, you decide how long the durable wood lasts. Modeling a range of options seems like the only option unless you know the specific use.
- Investigating carbon accounting approaches and applications is an important task. I would strongly emphasize collaboration with an assessment of policy forums in which methodologies are being investigated (e.g., EPA Biogenic Science Advisory Board, UK RFO) to ensure that work is as relevant as it can be. There is a vacuum for this type of work and I would really like to see the group incorporate inustry's ideas.
- This project is difficult to assess given its relatively turbulent history. It has been started, shut down, and restarted over the course of the past two years. Overall, the new goals and approach outlined for conducting regionally specific woody crop life-cycle assessments for use by the GREET modelers makes sense. As does the idea of accounting for the effects of lost carbon sequestration potential for alternative use of the wood in durable wood products. Given its unsteady start, it would be good to see the project team develop more detailed plans for milestones and deliverables.
- The matter of developing LCA estimates for woody biomass are especially relevant to BETO and the entire bioenergy community, both domestic and international. The ambitious effort to address these issues is commendable. Complexities such as temporal dynamics, product substitutability, and expectations of economic conditions/forest owner decision making could have substantial implications on the results, so assumptions should be investigated thoroughly. This project is in early stages, so it will be interesting to see how it unfolds. This will be highly impactful for both policy makers and industrial stakeholders.

PI Response to Reviewer Comments

- As noted in the presentation, the goals of this work are relatively focused; provide DOE and the GREET Team with Life Cycle Inventory (LCI) information needed to include these six woody feedstocks in the GREET modeling work. But, in the real world, there are many competing uses for woody biomass, and these need to be included in the LCIs.

For the three short rotation wood crops (SRWC), e.g., Northwest Poplar, Northeast Willow and Southeast Eucalyptus, this LCI is relatively straight-forward because 100% of the biomass is used for the biofuel product. In the case of SRWC, the growth rates, chemical usage, harvesting/storage methods, and the detailed chemical composition of the three different SRWC will all impact the LCI.

For the three commercial softwoods, e.g., Northwest Douglas Fir, Northeast Fir, and Southeast Loblolly Pine, the LCI is much more complex due to significant differences in the growth rates, silvicultural practices, the use of thinning, and the allocation methods used for biomass burdens assigned to the biofuels or the durable wood products. This later work will build on CORRIM background data, and publically released data provided by the USDA AFRI projects, as well as selected new data. The regional differences in the manufacturing of dimension lumber will also be included. Finally, working with DOE and the GREET team, the LCI will consider the issues with allocation of biomass burdens with two very different time scales, shorter term for biofuels, and much longer term (potentially 50-80 years for a single rotation) for durable wood products.

- The focus on dimension lumber is a simplifying assumption, although a realistic one given the budget limitations. This “single product” focus will allow for a detailed comparison of the regional forestry systems. As time and budget allow, we also hope to evaluate the implications of a simple composite panel product in place of dimension lumber.

GLOBAL FEEDSTOCK SUPPLY MODELING AND LAND USE

(WBS#: 4.1.1.40)

Recipient:	ORNL
Presenter:	Debo Oladosu
DOE Funding FY14:	$28,327
DOE Funding FY13:	$307,545
DOE Funding FY10-12:	$463,200
Planned Funding:	$180,928
Project Dates:	10/1/2008 - 9/30/2015

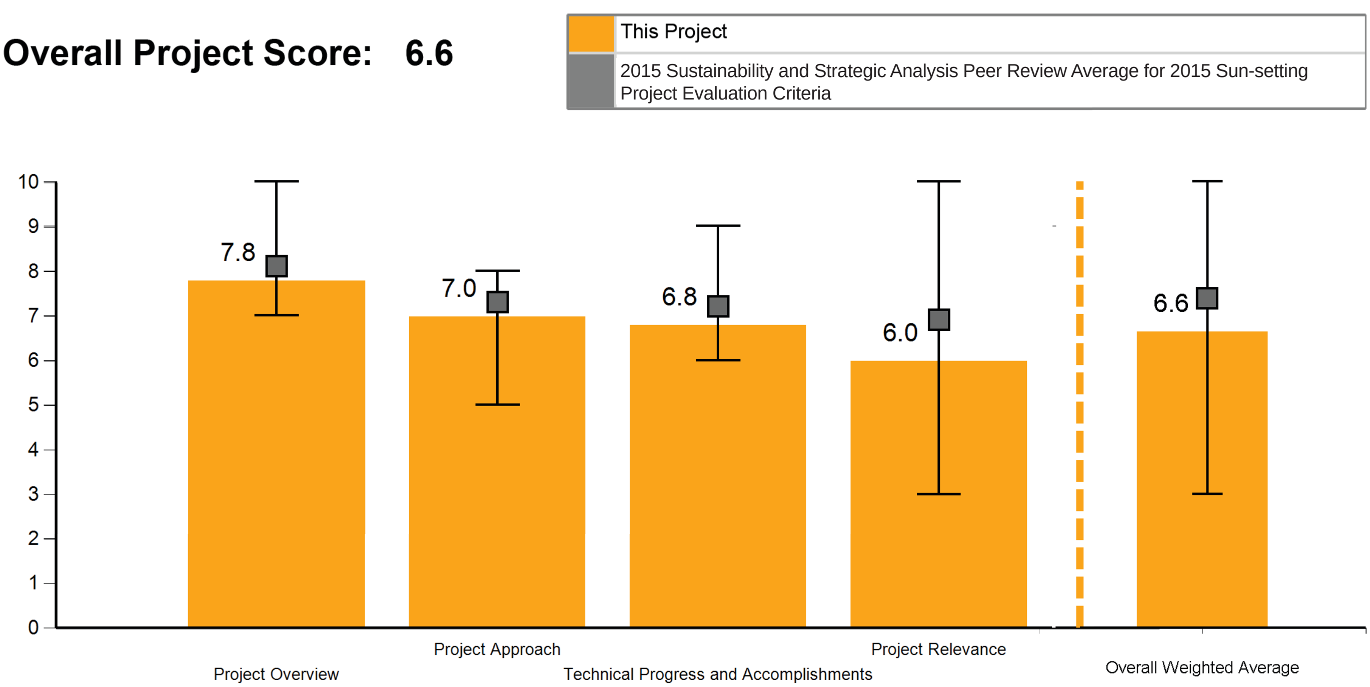
Project Description

The mission of the Bioenergy Technologies Office to "develop commercially viable bioenergy and bioproduct technologies" (BETO MYPP, 2014) depends on demonstrating "the positive economic, social, and environmental effects and reducing the potential negative impacts of bioenergy production activities." Many of the crucial drivers of the economic, environmental, and social benefits/costs of biofuels are outside the biofuel supply chain. Thus, analytical methods are required to capture the interrelationship engendered by biofuel policies among the agricultural, energy, and other sectors of the economy, as well as to evaluate alternative scenarios for a sustainable national biofuel industry and its interactions with the global economy. The main objective of this project is to provide DOE with integrated analyses of the costs, benefits, and indirect impacts of domestic biofuel policies that account for these drivers at the national and global levels. The primary approach is the use of a global general equilibrium model for the comprehensive assessment of the benefits and indirect effects of biofuel policy. General equilibrium models are multi-market economic models that incorporate all sectors of a given economy. The outcomes of the project effort provide metrics such as impacts on energy markets (supply, demand, and prices), economic growth (gross domestic product, employment, etc.), land use change, food market changes, and greenhouse gas emissions, among others.

Overall Impressions

- This project used the Energy Policy in General Equilibrium Model to look at the impacts of biofuels in both a global and national context. It is clear that there are many critical drivers that lie outside

Overall Project Score: 6.6



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

the biofuels supply chain that could have an impact. Understanding these is important. The improvements made in the model to more finely divide agricultural land should greatly improve the estimates of land use impacts. The work on the impact of the RFS on biofuels in the market place was interesting and timely. Without access to the assumptions used, it is hard to judge the results. However, I am not convinced that the model is taking all of the factors into consideration. Price plays a role. If ethanol is priced competitively enough, customers will buy it, and this will in turn lead to infrastructure build out. Currently, there is a push for higher-octane fuels. Is the use of a Renewable Super Premium (E-30) fuel considered in the model? Also, the model predicts all of the mandated growth will come from advanced hydrocarbon fuels. However, the large number of commercial plants needed to meet the demand will not be available by 2022. Most advanced hydrocarbon technologies are still at the pilot or demonstration scale and the fuels are not yet cost competitive. There are other models that might be able to more easily look at these questions. We should exercise caution in the assumptions being made and apply the best tools to get the answers we need. It would be nice to see how all of BETO's models fit together and which ones cover what space. I would like to see biogas added to the model. Since biogas (bio-CNG, bio-LPG) and liquid fuels made from biogas qualify for advanced and cellulosic RINs, some of the advanced hydrocarbon fuels needed to meet the RFS mandates could come from biogas.

- The PI and BETO should reconsider the 2013 Peer Review report's charge to make "clear who might best assume [the responsibility of sorting out the meaning of different models]." That is, the models must be sorted out, through publication and interface with regulators, with regard to the implications of data used and assumptions made. I have found no evidence in the policy space of this effort influencing the use of the Global Trade Analysis Project (GTAP) in the policy space.
- This project approaches land use change through the well-worn approach of using general equilibrium models of the global economy to estimate current and future changes in land use due to bioenergy expansion. The team appears to have taken the existing GTAP model from Purdue and added further granularity in the land use categories available to the model. Land use change is determined using elasticities among land use choices, which were already questionable at best in terms of the assumptions and data that underlie them in the original GTAP model. This project team has further refined the land use categories, requiring additional estimates of elasticities among this more refined group of land use classes. How these new elasticities were determined and how reliable they are remains a serious question. From a broader perspective, there remains serious doubt that such general equilibrium models can provide any kind of reasonable prediction of shifts in global land use given the challenging task facing any general equilibrium to predict future, economically driven shifts in a complex and highly interconnected global economy. There is some limited value in joining the debate on land use change using a tool such as GTAP, but only if that modeling effort is done in a collaborative fashion within the GTAP community. There is no indication here that the kinds of unilateral model changes implemented by the project team have been developed in a way that allows buy-in or at least understanding of the revised model among the experts in the GTAP modeling community. The issue of land use change is highly relevant to the bioenergy program. But the relevance of this project is diluted by the uncertain and questionable value of modifying the GTAP model to generate results for comparison with other dubious estimates of land use change offered by other modelers using the same basic modeling framework. This project brings no new understanding beyond the work done by Purdue several years ago in collaboration with Argonne National Laboratory. Those studies worked with the GTAP community to understand the impact of key assumptions, particularly regarding background effects of yield improvement.

- Like others before it, this project uses a computational general equilibrium (CGE) framework to tackle the worthy goal of assessing the domestic and international economic, social, and environmental impacts of increased biofuel production. The model does an admirable job of comprehensively capturing these large and diverse impacts, but as is inherent to all CGE approaches, it comes at the cost of a lack of sectoral resolution. As such, it is difficult to focus too narrowly on any one finding. That being said, the continued enhancement of CGE frameworks is an important effort to ensure that high-level economic and social insights can be gained, while also capturing more system-level dynamics.

PI Response to Reviewer Comments

- Many thanks for highlighting the project's effort to help address the important domestic and international economic, social, and environmental impacts of increased biofuel production. The comment on reduced sectoral resolution within this framework is well-received, and results from an inherent need for balance between detail and scope. We have made an effort to incorporate the results of more detailed modeling efforts by other BETO supported projects over the years.
- The CGE framework can be considered to be unique in its scope and capabilities for modeling important drivers of the biofuel market that are outside the biofuel supply chain. As such, it is complementary to other BETO-supported modeling efforts that generally address issues on the biofuel supply chain in greater detail. The PI is willing to support any effort by BETO and has the required expertise to help establish a comprehensive picture of how individual models fit into the analytical requirements in support of BETO's mission.
- The main reason the EPGE* model does not account for the details of infrastructure (such as gas pumps) is because it covers the entire economy. As such, details in each sector of the economy are incorporated as necessary to address the issues at hand and keep the model size reasonable. The scenarios that we discussed during the peer review are only a few of those that have been examined with the EPGE model, but we have not examined additional incentives to promote biofuels beyond the RFS. Thus, these results suggest that the RFS, while necessary for advanced biofuel deployments, would likely require additional incentives, programs and policies to overcome remaining barriers. Future simulations with the EPGE model can easily evaluate scenarios of these potential incentives and programs, and their efficacy in supporting the deployment of advanced biofuels. Indeed, previous publications show that, if barriers can be overcome, advanced biofuels would provide positive economic impacts to the U.S. economy [*see Oladosu, G., Kline, K., Leiby, P., Uria-Martinez, R., Davis, M., Downing, M., & Eaton, L. (2012)*. *Global economic effects of U.S. biofuel policy and the potential contribution from advanced biofuels. Biofuels, 3(6), 703-723)*]. The focus of the analysis so far has been on biofuels, but we have included biopower in the model by allowing cellulosic residues and energy crops to be potential fuels for electricity generation, and can incorporate additional technologies. [**The Escola de Pós-Graduação em Economia (EPGE), Graduate School of Economics, a Brazilian higher education institute.*]
- The job of reviewing a variety of studies using vastly different methodologies is a daunting one that we appreciate greatly. However, we strongly disagree with a couple of the statements made in these comments. We note here that the history of this project includes collaborations with the Purdue biofuels team and Argonne National Laboratory. We are proud to say that the efforts under this project,

at Purdue, and elsewhere, have benefited greatly from interactions with the biofuel community and our insights into the land-use change issues. The complex nature of the issues means that it is crucial for multiple, independent, but interacting modelers to engage in biofuel-related analyses. This not only provides a fertile ground for the comparison of efforts, but prevents unintended “herding-behavior.” The results of efforts under this project have been made widely available to the biofuel community toward supporting a well-examined consensus on the overall direction of the land-use change impacts of biofuels. We note that despite differences among the land-use change results of different models and remaining uncertainties, an emerging consensus is that biofuels production in the U.S. has not led to large conversions of forests and other lands around the world. This emerging consensus contrasts with earlier results produced by many models, including earlier simulations by the Purdue biofuel team.

HIGH LEVEL TECHNO-ECONOMIC ANALYSIS OF INNOVATIVE TECHNOLOGY CONCEPTS

(WBS#: 4.1.1.50)

Recipient:	PNNL
Presenter:	Sue Jones
DOE Funding FY14:	$92,838
DOE Funding FY13:	$197,514
DOE Funding FY10-12:	$149,765
Planned Funding:	$84,883
Project Dates:	10/1/2012 - 12/31/2014

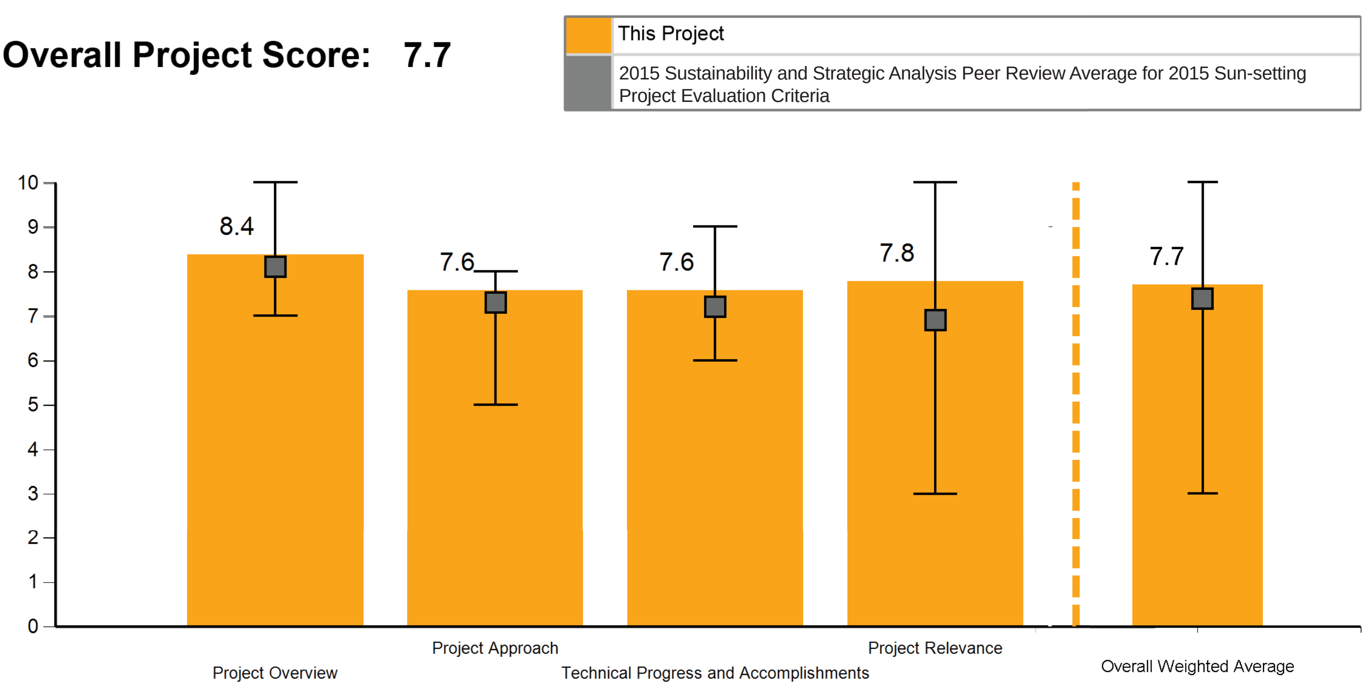
Project Description

In this completed project, the Pacific Northwest National Laboratory and Iowa State University (ISU) leveraged their joint capabilities to assist the Bioenergy Technologies Office in the evaluation of emerging biofuels and bio-products technologies. The objective of this collaborative effort was to perform high-level techno-economic analyses of innovative technology concepts using experimental data from both institutes and the open literature. The FY12/13 work produced techno-economic analyses for eight direct and indirect liquefaction processes and developed Monte Carlo uncertainty analyses for four of those processes. The outcome was for BETO and other Sustainability and Strategic Analysis projects to benefit from the findings of the uncertainty analyses performed and the methodology developed to complete the uncertainty analyses. Indirect liquefaction (gasification) has narrower error bars around the production costs than the direct liquefaction cases (catalytic pyrolysis) resulting from the greater maturity of the former process relative to the latter. The results are either published or being prepared for press.

Overall Impressions

- The key objective of this project was to develop and perform rapid screening of eight different biofuel pathways by leveraging the literature and data collected at the partnering institutions. Uncertainty analysis was then applied to the TEA results generat-

Overall Project Score: 7.7



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ed. Good progress was made and the results allowed for a quick determination of major impacts as well as areas of greatest sensitivity. Uncertainty analysis is not simple, and one important learning was that analyses done with a lack of data are risky. The project provides a quick way to assess the techno-economic viability of various conversion pathways and should be easily adopted for use by others in the future. This was a good conclusion to the project. It would be useful to integrate the lessons learned (gaps and opportunities) going forward.

- Now that the project has concluded, in addition to publications (note: the PIs should put all the outputs on their website pages), it would be nifty to translate the work into easy-to-understand summaries/graphics of the pathways and the considerations/assumptions/boundaries, etc., that were made in the project. I think this could help, for example, graduate students working on these types of projects to understand the method, as well as the substantive outcomes.

- The analysis work described in this project seems to be related to the strategic support task described by NREL project performers. The same critiques listed there apply here. The methodology and approach used by ISU to conduct rapid screening analyses of technologies is not consistent with the well-established approaches already used by NREL. The new work described here relates to use of Monte Carlo analysis to develop measures of uncertainty. It is not clear that the Monte Carlo analysis has added any real insights on uncertainty and risk.

- The development of a thorough sensitivity analysis on top of the techno-economic analyses that were previously performed for four biofuel processes resulted in a more robust analysis for identifying the relative favorability of these processes. Given BETO's MYPP goal of identifying pathways at $3/gge, this analysis is well-positioned to inform future decision making.

PI Response to Reviewer Comments

- We agree that publication of the methods and results is of value to the wider biofuels community. ISU has undertaken this task through publication in peer reviewed journals. We also agree that the insights related to uncertainty analysis should be translated into general use. While it is outside the scope of this modest project, which has ended, we are considering ways to incorporate it into other existing projects.

COOKSTOVES

TECHNOLOGY AREA

Photo Courtesy of University of Washington

CONTENTS

INTRODUCTION

The Cookstoves Technology Area is one of seven key technology areas that were reviewed during the 2015 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on May 23-27, 2015, at the Hilton Mark Center in Alexandria, Virginia. A total of seven cookstove projects were reviewed by six external experts from industry, non-governmental organizations, and government agencies. These projects represent a total U.S. Department of Energy (DOE) investment of approximately $4 million (FY2013-FY2014), which equates to around 1% of the BETO portfolio covered at the review. The Principal Investigator (PI) for each project was given approximately 45 minutes to deliver a presentation and respond to questions from the Review Panel. Projects were evaluated and scored for their project approach, technical accomplishments, relevance to the field of clean cookstove technology development, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the Cookstoves Technology Area and full scoring results and analysis are also included in this section. BETO designated Elliott Levine as the Cookstoves Technology Area Review Lead. In this capacity, Mr. Levine was responsible for all aspects of review planning and implementation.

COOKSTOVES

OVERVIEW

On September 21, 2010, the Secretary of State announced the establishment of the Global Alliance for Clean Cookstoves, a public-private partnership led by the United Nations Foundation that focuses on creating a thriving global market for clean and efficient household solutions.

The founding partners of the Alliance were DOE, the U.S. Department of State, U.S. Environmental Protection Agency, U.S. Department of Health and Human Services, Centers for Disease Control, National Institutes of Health, and U.S. Agency for International Development. These organizations forged an unprecedented federal partnership to mobilize financial resources, top-level U.S. experts, and research and development tools to help the Alliance achieve its target of "100 by 20," which calls for 100 million homes to adopt clean and efficient stoves and fuels by 2020.

DOE pledged to contribute $10 million to the effort over five years. The agency also agreed to conduct research in the areas of combustion, heat transfer, and materials development to address technical barriers to the development of low emission, high efficiency cookstoves.

Five of the Cookstove projects reviewed at the 2015 Peer Review were competitively awarded through this initiative. Additionally, two national laboratory projects that focused on materials durability testing and cookstove development were also reviewed.

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

COOKSTOVES SUPPORT OF OFFICE STRATEGIC GOALS

BETO Cookstove projects aim to increase the viability and deployment of renewable energy technologies through research, development, and tools that lead to clean and efficient biomass cookstoves. These innovative cookstove designs allow users to burn wood or crop residues more efficiently and with less smoke than open fires and traditional stoves, thereby helping to save lives and improve livelihoods. Cookstoves developed through BETO support must:

- Meet or surpass the highest levels of stove performance (90% emissions reductions and 50% reduction in fuel use);
- Be low-cost and affordable;
- Use biomass fuels found in indigenous areas; and
- Be durable and safe.

COOKSTOVES TECHNOLOGY AREA REVIEW PANEL

The following external experts served as reviewers for the Cookstoves Technology Area during the 2015 Project Peer Review.

COOKSTOVES	
REVIEWERS	
Ranyee Chiang (Lead Reviewer)	Global Alliance for Clean Cookstoves
Jim Jetter	EPA
Michael Johnson	Berkeley Air Monitoring Group
John Mitchell	EPA
Jacob Moss	U.S. Department of State
Sheila Moynihan	EERE International

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

Introductory Information: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data, as provided by the PI for each project.

Project Scoring Information: The final score charts depict the overall weighted score for each project in each technology area. Titles for each project and the performers are also provided in the scoring charts.

Project Reports:

- **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space allotted.

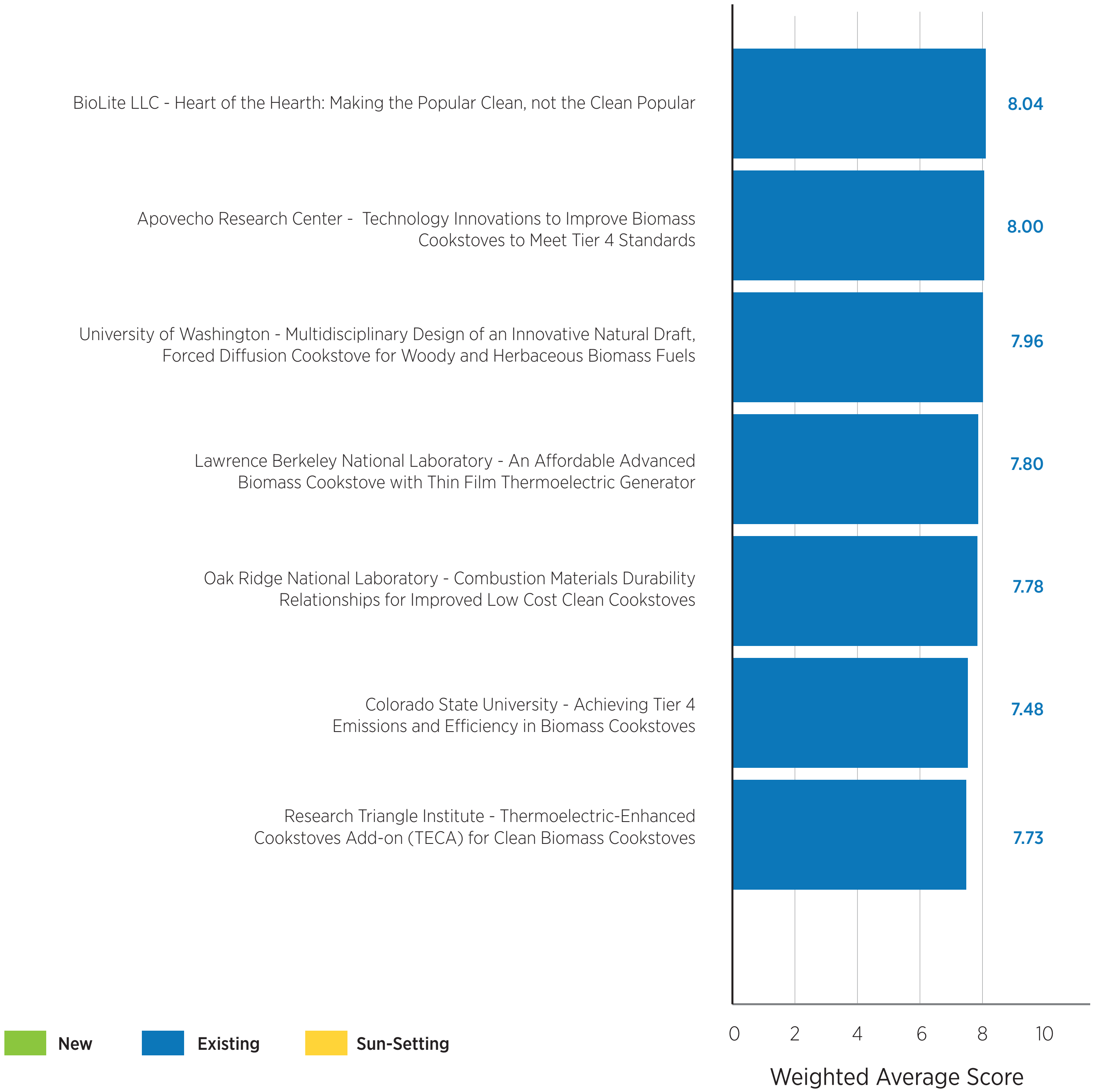
- **Project budget and timeline information** is based on self-reported data, as provided by the PI for each project.
- **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and whiskers charts depict the range of scores for each evaluation criteria across all projects reviewed within each technology area.
- **Reviewer comments** are presented as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.
- **PI responses** represent the response provided by the PI to reviewer comments, as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by reviewers, and in other cases, provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the Review Panel. This unique formatting was maintained to uphold the integrity of the comments.

TECHNOLOGY AREA SCORE RESULTS

The following chart depicts the overall weighted score for each project in the Cookstoves Technology Area.

COOKSTOVES TECHNOLOGY AREA SCORING



AN AFFORDABLE ADVANCED BIOMASS COOKSTOVE WITH THIN FILM THERMOELECTRIC GENERATOR

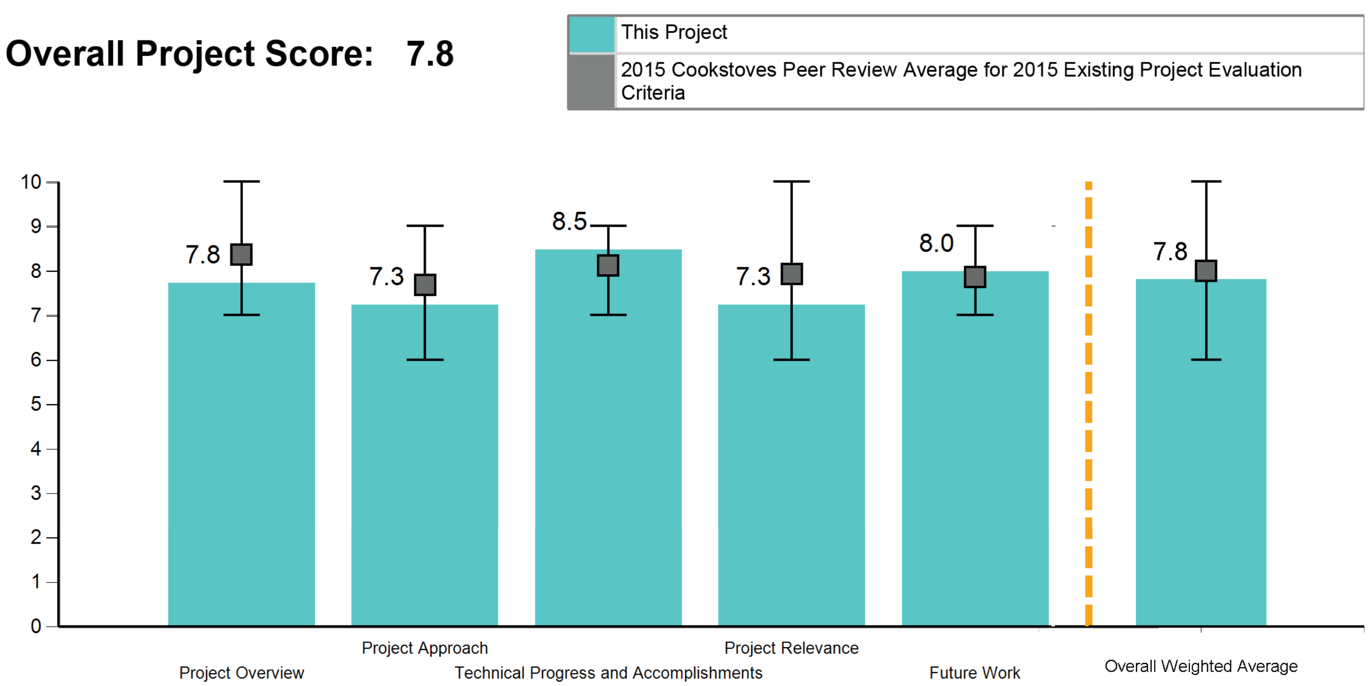
(WBS#: 5.2.0.1)

Recipient:	Lawrence Berkeley National Laboratory
Presenter:	Ashok Gadgil
DOE Funding FY14:	$1,150,000
DOE Funding FY13:	$1,100,000
DOE Funding FY10-12:	$0
Planned Funding:	$1,150,000
Project Dates:	10/1/2013 - 9/30/2015

Photo Courtesy of LBNL

Project Description

Ultra-clean cookstoves must be affordable and attractive, while dramatically reducing per-meal emissions. This project, started with a DOE grant in Fall 2013, aims for technological breakthroughs in emission reductions and performance improvements to front-loaded wood-fired cookstoves. The project seeks to achieve this via flame manipulation through forced air addition. These breakthroughs have relevance because our generalizable innovations support an international commitment by the U.S. Government, while facilitating the Global Alliance for Clean Cookstoves (GACC) goal of 100 million clean and efficient domestic biomass stoves adopted by 2020. This program has the potential to help reduce the 4 million annual deaths caused by cooking smoke. The primary scientific challenge of this work is quantifying the appropriate flow rate, location and tem-



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

perature of forced air added to a cookstove. Additionally, there is a hardware challenge in building a thermoelectric generator and blower system that can replicate optimal flow conditions. To date, the project team has created and tested seven architectures for dramatically reducing emissions. In preliminary laboratory testing of unoptimized stoves, over 60% PM2.5 reductions have been demonstrated relative to baseline technology. Additionally, the project team has developed a circuit for thermoelectric generator power management to run a blower, charge a battery, and provide the USB electricity to customers living off grid, a common condition for the poorest 2 billion people using biomass fires.

Overall Impressions

- This project has made enormous strides toward the goals DOE has laid out. I very much look forward to the final phases of work and seeing how powerful (and more generally applicable) their final results are. I hope that LBNL is able to leverage its new stove testing laboratory to support cookstove design innovations for many years ahead.
- Based on the review criteria, my overall assessment is that this is a good project with more strengths than weaknesses.
- The overview of the project did not present a distinct niche for this work within the portfolio. However, the approach has led to some interesting initial designs that are worth further investigation. There are still open questions about the user acceptance and manufacturability of some of the air injection configurations, and this will be critical to demonstrate in the remaining time of the project. The performance of the final prototypes should be tested through a third party to verify results. The open-minded design approach was strengthened by considering some prototypes as being more useful for iterating on the design (since they are easier to manipulate), but other prototype designs are used for manufacturability considerations. It would have been interesting to see the results of the design process if users and manufacturability were integrated earlier in the design process.
- LBNL's interdisciplinary team's multi-prong approach promises to advance the scientific rigor of many aspects of cookstoves. This approach includes building a state-of-the-art cookstove test facility; participating in the international standards development process; and designing, building, and testing an advanced cookstove design. It will be exciting to see the insights gained through this project applied to the LBNL-designed cookstove as well as to cookstoves designed by others who utilize the user facility and/or are informed by the standards and other work.

PI Response to Reviewer Comments:

- Thank you for your insightful comments and recommendations. LBNL's project occupies two distinct and unique niches, with no other public-domain competition in those niches to our knowledge and to the knowledge of those, with whom we have interacted within and outside the U.S. First, LBNL is pioneering research to understand and elucidate the engineering science of low-emission biomass combustion in cookstoves (producing 8 kW or less) using low-power airflow and flame manipulation. To advance this science, our interactions have extended from the top experts in flames laser-diagnostics (e.g., Prof. Paul Medwell at University of Adelaide) to the leading experts on combustion and emissions modeling (e.g., Prof. Jyh-Yuan Chen at UC Berkeley). Although industrial experts have successfully reduced emissions from large (high thermal power) industrial-scale biomass combustion systems, their challenges are vastly different than those of biomass cookstoves (e.g., non-uniformity of combustion process, high surface-to-volume ratio of the flame domain, etc.). Therefore, industrial solutions are not directly applicable.

Second, LBNL is the first (to our knowledge) to build and operate a world-class cookstoves efficiency and emissions testing laboratory that serves the stoves research community. This facility serves as a calibration standard for global stoves labs, via the GACC Round Robin testing, and as a tool for deeper understanding of health impacts of biomass smoke using chemical characterization of cookstove particulate emissions (e.g., aerosol mass-spectrometry research in collaboration with MIT). Additionally, the LBNL group has worked to develop open source data collection software that is available to any interested party developing their stoves laboratory operations. In the future, this facility will advance the standard of stoves science worldwide by serving as a resource for training scientists from the major developing countries and regions.

We would also like to reiterate that the stoves we have designed are for research purposes and not intended for acceptance or manufacturing. Our stoves are designed for better understanding of the scientific underpinnings behind effectively and consistently reducing particulate matter (PM) emissions from wood-burning biomass cookstoves. The designs and techniques we identify for reducing PM are intended to aid cookstove designers with improving their existing stoves as well as guide development of new stoves.

In response to comments about future work beyond this project, we would like to note that BETO funding ends this year, but enthusiastically agree that it would be very desirable to extend this work toward commercialization and training related to the knowledge gained here.

COMBUSTION MATERIALS DURABILITY RELATIONSHIPS FOR IMPROVED LOW COST CLEAN COOKSTOVES

(WBS#: 5.2.0.2)

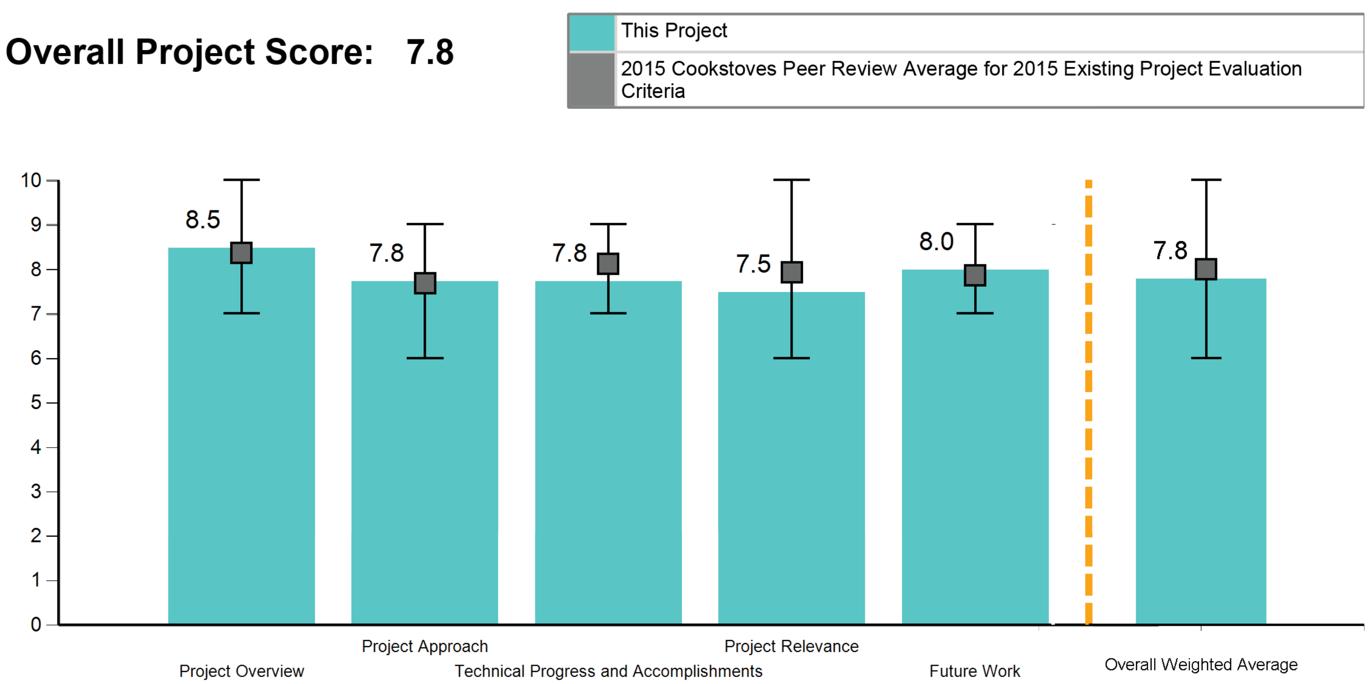
Photo Courtesy of ORNL

Recipient:	Oak Ridge National Laboratory
Presenter:	Tim Theiss
DOE Funding FY14:	$300,000
DOE Funding FY13:	$300,000
DOE Funding FY10-12:	$0
Planned Funding:	$395,000
Project Dates:	10/1/2013 - 9/30/2015

Project Description

The success of clean biomass cookstoves with improved efficiencies and reduced emissions are critically dependent on the materials of construction. The most challenging component is the combustor, which must operate at high temperatures (often >600 °C) in the presence of aggressive oxidizing species derived from the combustion of the biomass fuel. Such conditions pose a significant materials durability challenge considering the need for low-cost materials to permit widespread cookstove adoption. This project seeks to: (1) develop cookstove-relevant corrosion test methods; (2) generate

Overall Project Score: 7.8



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

corrosion data under cookstove conditions for a wide range of alloys; and (3) identify alloy/coating paths to achieve >40% improved corrosion resistance for metallic cookstove combustors. Supporting tasks include combustion model development for insight into how different biomass fuels impact temperature and corrosive species generated, and supply chain sustainability indicators assessment.

Overall Impressions

- This project is a unique and critical part of the DOE cookstoves R&D portfolio, with important implications for cookstove performance, durability, and cost.
- Based on the review criteria, my overall assessment is that this is a good project with more strengths than weaknesses.
- As the only project in the portfolio focused only on materials and durability, this is a unique project within the portfolio. The approach to selecting materials, using a variety of materials testing strategies, and having systematic exploration of parameters is valuable. The important impacts of this project will be seen in how the results are disseminated. In particular, results should be disseminated in a public and understandable way—especially which material options have the longest durability per cost. The project team should also clearly report (with the necessary experimental evidence) the applicability of these results to materials or conditions that were not tested in this study and broaden the applicability of the results as much as possible. Other useful outcomes would be sharing procedures for testing materials, so that others can replicate the results, and sharing recommendations the project has generated for simplified and shortened testing that could be done in lower-resource environments.
- This project is advancing our understanding of materials corrosion in cookstoves. The performers appear to be taking a scientifically rigorous approach to testing a variety of materials in conditions representative of harsh, real world environments. The results of this work have the potential to lead to tangible improvements in a wide variety of cookstoves. One of the key remaining challenges will be transferring the knowledge gained through this project to cookstove manufacturers.

PI Response to Reviewer Comments:

- We appreciate the reviewers' positive comments regarding the importance of this work and its implications for future cookstoves. We agree that knowledge transfer is a critical aspect to the potential impact of this work. We plan to publish our findings in the open journal literature. We also plan to present at the Clean Cooking Forum 2015 in Accra, Ghana, November 10-13, 2015, and perhaps at other related forums. We are also actively considering several approaches to place the corrosion data generated on readily accessible website data depositories, such as the ORNL website, and journal supplementary data depositories.

ACHIEVING TIER 4 EMISSIONS AND EFFICIENCY IN BIOMASS COOKSTOVES

(WBS#: 5.2.1.1)

Recipient:	Colorado State University
Presenter:	Morgan Defoort
DOE Funding FY14:	$550,503
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$304,497
Project Dates:	2/1/2013 - 1/1/2016

Project Description

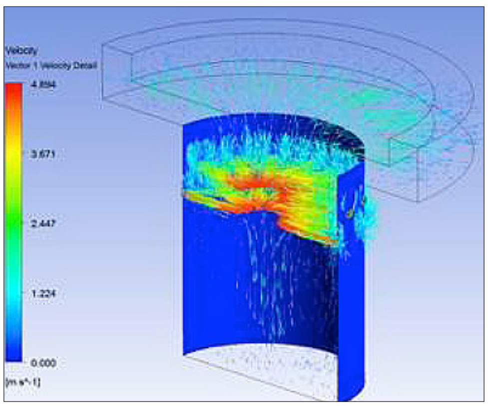
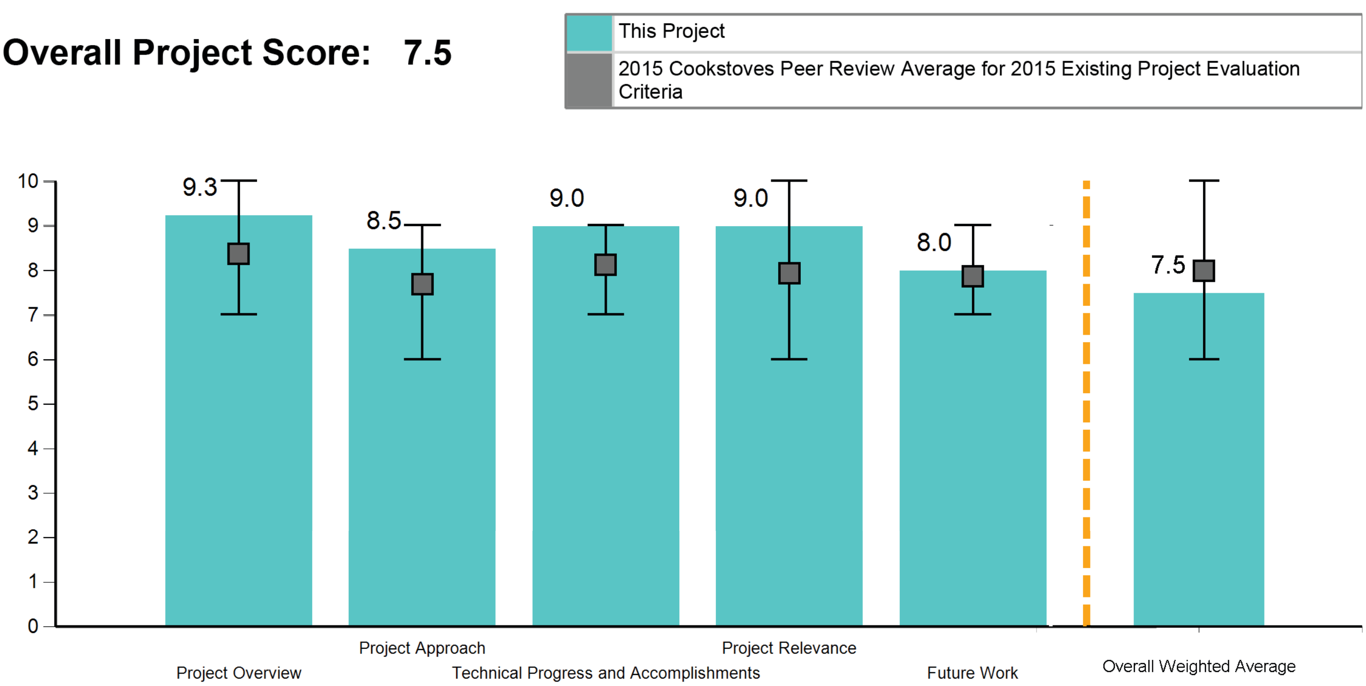


Image Courtesy of Colorado State University

As health data grows, it is increasingly more apparent that emissions reductions of improved stoves using rocket-elbow technology are not adequate to safeguard health, especially when used indoors. Breakthroughs in stove performance (both efficiency and emissions) are critical to reach the aspirational (Tier 4) levels of performance outlined in the International Workshop Agreement for Cookstoves (IWA 11:2012 – Guidelines for Evaluating Cookstove Performance) led by ISO (International Standards Organization). Semi-gasifier stoves have shown promise in their ability to reach ultra-low emissions levels, however they are notoriously susceptible to emissions spikes in transient operation. This project aims to: (1) improve the sector's fundamental understanding of the physics associated with combustion, emissions formation, and heat transfer in the fuel bed and the chemically reacting flow field above the fuel bed in a forced-air semi-gasifier cookstove; and (2) develop validated computational models of these regions to assist in stove design. The project team has tested a variety of design parameters in a systematic way to provide baseline performance data, and is using optical diagnostics and high-resolution, open-source computational fluid dynamics (CFD) tools to work toward a

Overall Project Score: 7.5



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Tier 4 stove that, through a variety of operational conditions, consistently achieves Tier 4 for emissions and efficiency performance.

Overall Impressions

- I see this project as probably the biggest risk/reward project in the cookstove portfolio. It demands a tremendous amount of pioneering research and science, which creates risk and may ultimately pose more questions than it can answer. However, if this project succeeds in developing a proven open source code to aid in future cookstove design, it could represent the greatest leap forward for the sector from any of the projects in DOE's portfolio.
- Based on the review criteria, my overall assessment is that this is an excellent project with many more strengths than weaknesses.
- The two major strengths of this project, which make it a highlight within the portfolio, are the combination of experimental and computational modeling of the semi-gasifier stove and the focus on what leads to high performance as well as consistent performance. In order for the project team to maximally deliver on this goal, there are some areas that could be clarified or strengthened further. When do the experimental and computational models point in the same direction, and when do they lead to different results? How are these potential differences resolved and then used to strengthen both the experimental and computational models, as well as design recommendations? It will be important to thoroughly emphasize and explore parameters that define the possible variability of usage and then evaluate the consistency of performance. The parameters presented during the review did not have a strong emphasis on testing for high performance through variable usage (fuel type, uniformity, lighting, operation, tending), which is a significant difference of this project from the others in the portfolio. The demonstration of impact will be shown through developing distinct new prototypes as well as sharing usable design tools, design lessons, and datasets. The framing and design of the project have a high potential for improving stove performance and robustness, but they will only be realized if the project finishes up with tangible results that are shared in a useful way.
- The team led by Colorado State University is applying state-of-the-art tools for combustion science to inform the design of cleaner cookstoves. This innovative approach has the potential for wide-ranging impacts because it is designed to advance our understanding of fundamental concepts related to cookstoves. One of the main challenges for the remainder of the project will be disseminating the results to the cookstove community in a way that's accessible and can be built upon if new sources of funding become available.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

THERMOELECTRIC-ENHANCED COOKSTOVE ADD-ON (TECA) FOR CLEAN BIOMASS COOKSTOVES

(WBS#: 5.2.1.2)

Recipient:	Research Triangle Institute
Presenter:	David Stokes
DOE Funding FY14:	$186,289
DOE Funding FY13:	$51,548
DOE Funding FY10-12:	$0
Planned Funding:	$547,163
Project Dates:	1/1/2013 - 6/15/2015

Photo Courtesy of RTI

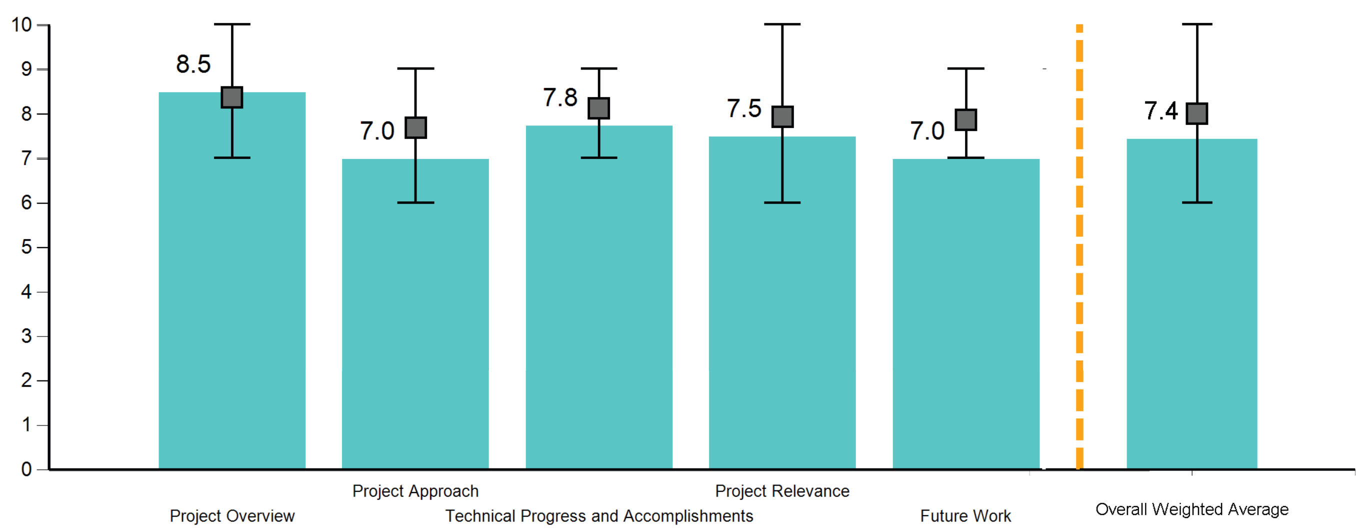
Project Description

This project seeks to demonstrate a solution to enhance existing biomass cookstove performance through the use of Research Triangle Institute's (RTI's) Thermoelectric Enhanced Cookstove Add-on (TECA) device. The self-powered TECA device captures a portion of heat from the stove and converts it to electricity through a thermoelectric (TE) device to power a blower. Colorado State University and Envirofit International are partners that support air injection design and commercialization to enhance combustion in the stove and reduce emissions. By demonstrating a proof-of-concept approach with the Envirofit M-5000 stove and TECA device, the project team hopes to apply this technology to existing stoves that are already in use and reduce emissions for stoves that have already found user acceptance to provide a true health benefit. The technical challenges include achieving Tier 4 emissions from a biomass stove and for such a stove to operate reliably in the harsh field

Overall Project Score: 7.4

This Project

2015 Cookstoves Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

environment. Further, it is difficult to develop a cost-effective solution and ensure adoption and proper use in the field. The project team has demonstrated PM emissions at 82 mg/MJd, a 70% reduction as compared to baseline stove operation, and developed a stove optimization approach that reduces the number of costly experiments. The project team has evaluated component-level reliability and will be testing the stove prototype in the field for performance and reliability.

Overall Impressions

- This project represents an exciting opportunity that could help transform many stove designs into much cleaner stoves that approach ISO Tier 4 levels. However, the project remains weak on the commercialization side of things, and that could be a serious flaw, because the application of the technology may not be a simple, straightforward step (if near optimum performance is key, as it must be).
- Based on the review criteria, my overall assessment is that this is a good project with more strengths than weaknesses.
- Within the broad DOE portfolio, the RTI project represents an approach to improve existing technologies with add-ons, which has the potential to improve the performance of a larger number of stoves. In order to truly evaluate potential of the add-on for multiple existing stoves, the scope of the project should include testing the add-on with multiple technologies. Otherwise, the project is not different from developing a single stove. This is the biggest area to address in order to match the results of the project with the goals that have been laid out. The project success also depends on the baseline stove technology already having a high level of use and that the add-on will not change the usability. RTI and Envirofit should provide more data on the user acceptance and level of use and whether the add-on changes user acceptance and level of use, beyond the surveys that are planned for this project. The strong partnership with Envirofit provides a clear pathway to commercialization, if the technology development is successful.
- Third-party testing should be done at the end of the project to verify the results reported by RTI.
- The project approach was well aligned with the goals for Tier 4 emission and efficiency performance, but could have been strengthened by having clearer and more specific goals to address technical barriers (e.g., go/no-go decision points, starting with research questions that will impact which future pathways to pursue). The progress toward the performance goals are on track, but a more structured R&D plan may have still helped the work progress more efficiently and effectively. I recommend that the lessons on parameters, like hole diameter, nozzle configuration, flow rate, TEG parameters, be shared as widely as possible, so that the research results can be more broadly applied.
- The concept of an add-on device to reduce PM and carbon emission from cookstoves is promising. Findings related to air injection optimization resulting from RTI's research could have broader implications for the cookstove community. It would be interesting to see the potential for reducing costs and designing an add-on device that could work with multiple cookstoves.

PI Response to Reviewer Comments

- We appreciate the opportunity to conduct this work under DOE funding. Additionally, we are excited about the lessons learned from this program and how they might help the broader cookstove development effort. We have shared these lessons learned with the other DOE teams that were funded under the cookstove program and at the 2015 Ethos Conference in Seattle, WA. We also have two journal papers written that will soon be submitted for publication.

HEART OF THE HEARTH: MAKING THE POPULAR CLEAN, NOT THE CLEAN POPULAR

(WBS#: 5.2.1.3)

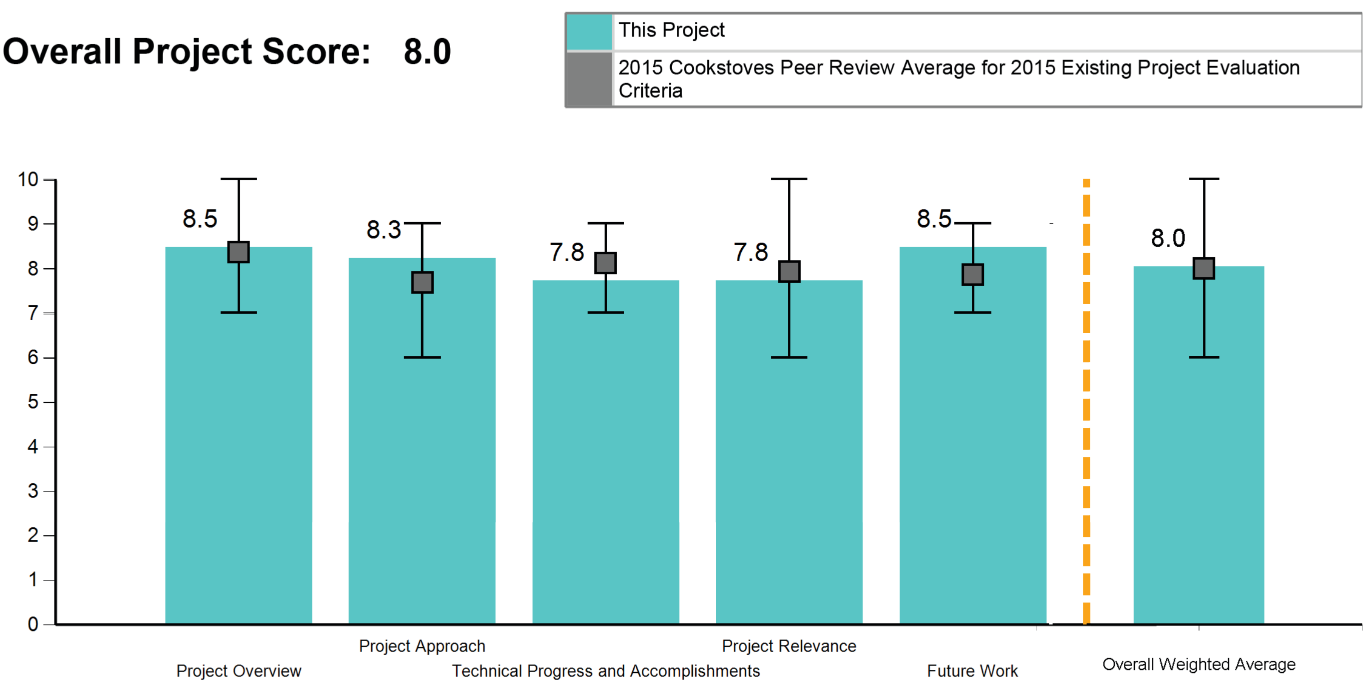
Recipient:	BioLite, LLC
Presenter:	Ryan Gist
DOE Funding FY14:	$417,103
DOE Funding FY13:	$55,130
DOE Funding FY10-12:	$0
Planned Funding:	$410,814
Project Dates:	2/1/2013 - 12/1/2015

Photo Courtesy of BioLite, LLC

Project Description

This project aims to apply BioLite's fan-assisted combustion technology to a clean burning and reliable "combustion core" that can be generally incorporated into the most popular stove types. The project also supports BETO's goals toward reducing pollutant emissions from biomass cooking by 90% and fuel usage by 50%. In pursuit of these goals, the project is working toward: (1) the identification of critical fluid-dynamic and heat transfer mechanisms that lead to high combustion and thermal efficiencies; (2) the design of non-invasive hardware to replicate these conditions inside any general stove architecture; and (3) demonstrating user acceptance and improved stove performance under real-world usage conditions. The project is working to overcome barriers to user acceptance, such as the fact that the highest performing, cleanest biomass cookstove configurations are often not consistent with traditional cooking and fuel preparation practices.

Overall Project Score: 8.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Overall Impressions

- This project offers a very clear opportunity to explore bringing advanced combustion to a plancha stove, perhaps for the first time. The potential is very strong here, but it will be constrained by the final testing that determines whether or not to move forward commercially to bring the innovation to market.
- Based on the review criteria, my overall assessment is that this is a good project with more strengths than weaknesses.
- The project represents an approach to develop and design non-invasive hardware to replicate high-performance conditions inside any general stove architecture, especially traditional stoves. In order to truly evaluate potential to be applicable for multiple existing stoves, the scope of the project should include testing the core with multiple stove types and multiple stoves. Otherwise, the project is not different from developing a single stove. This is the biggest area to address in order to match the results of the project with the goals that have been laid out. This is planned as future work, possibly outside the scope of what is funded by BETO. However, it should be considered, as soon as possible, to test the basic goal of the project. Especially because a large griddle stove is quite different from other basic stove types. The modeling and design process should investigate the suitability of the core to multiple stove architectures. As an alternate output, the project can also consider the output of this project to a design process to design different cores more easily in the future. The separation between the researchers and stove designers from independent monitoring group will lead to results with more credibility, due to the partnership with UC Berkeley and National Autonomous University of Mexico (UNAM).
- Intermediate technical challenges and critical success factors were identified at the beginning of the project (e.g., using the model to narrow down the space for empirical work, clear intermediate targets for cost, emissions, and fuel use, and technical tradeoffs to target), which means that the progress of the research was less ad hoc and more strategic and targeted. If the goal is to have a core that is suitable for multiple stoves, BioLite should consider its commercialization plan as broadly and widely as possible, including opportunities to partner with multiple organizations. To have the largest impact, the lessons from the project should be shared widely.
- BioLite and its partners are deriving from their extensive experiences and unique facilities to develop a cookstove specifically designed for the Latin American market. It would have been nice to hear additional details on how the project performer plans to share the insights gained through this process with the overall community, particularly because the project performer is looking to commercialize technology based on these activities. Overall, an exciting and promising project.

PI Response to Reviewer Comments

- No official response was provided at time of report publication.

MULTIDISCIPLINARY DESIGN OF AN INNOVATIVE NATURAL DRAFT, FORCED DIFFUSION COOKSTOVE FOR WOODY AND HERBACEOUS BIOMASS FUELS

(WBS#: 5.2.1.4)

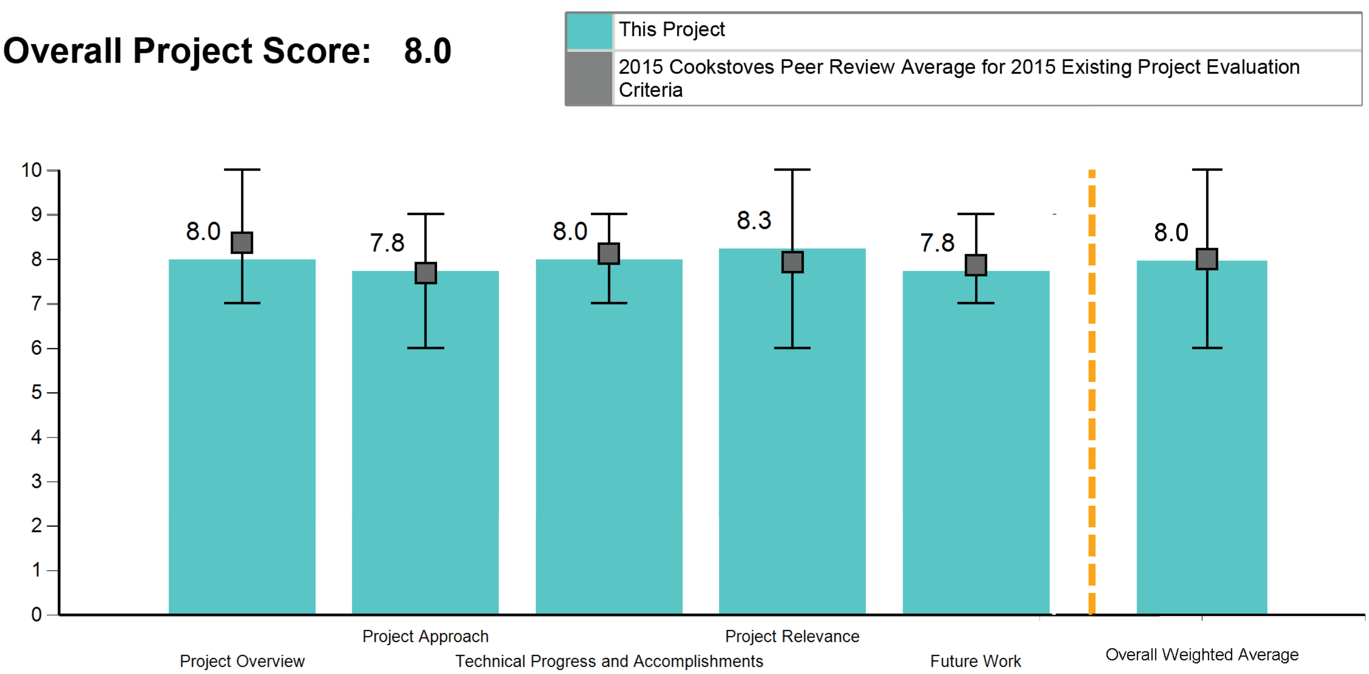
Recipient:	University of Washington
Presenter:	John Kramlich
DOE Funding FY14:	$178,448
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$721,552
Project Dates:	9/1/2013 - 9/1/2016

Photo Courtesy of University of Washington

Project Description

The goal this project is to develop a commercializable cookstove design for rural Kenya that improves health by reducing emissions and deforestation by improving efficiency. The project is built around three team members. The University of Washington focuses on research to improve efficiency and reduce emissions. Burn Design Labs has a stove factory in Kenya, understands the cultural and economic barriers to introducing a new design, and is actively working with user groups to achieve costs and usability goals. Berkeley Air Monitoring will conduct field testing on the models to evaluate emissions and efficiency goals in the home environment. A principal constraint is unit cost, which requires working with natural draft systems. The present work shows that existing natural draft systems tend to be limited by too much excess air (impacting efficiency) and poor mixing between the fuel and the air (impact-

Overall Project Score: 8.0



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

ing emissions). The overall goal is to reduce the excess air, while improving mixing. The general approach to the latter is to increase the area of contact between the fuel gases and the air such that turbulent diffusion leads to greater fuel/air contacting and more rapid burnout. The current results show a substantial improvement in emissions, and the user groups in Kenya indicate that many of the suggested features will be accepted if they result in less wood fuel need and less smoke depositing on the pot.

Overall Impressions

- While not quite there yet, this project offers the extraordinary possibility of integrating user-centered design and very high-tech design tools to achieve an affordable natural draft stove that meets advanced performance goals and is designed for manufacturing. If successful, this project will represent both a real leap forward for the cookstove sector and demonstrate the power of this kind of design integration.
- Based on the review criteria, my overall assessment is that this is a good project with more strengths than weaknesses.
- Within the portfolio, the project represents an approach that starts with user input to guide the parameters of design and performance improvement. The focus on a natural draft stove will help to minimize price and potentially simplify the number of components if the performance targets can be reached.
- The strong partnership with Burn Design Labs provides a clear pathway to optimization for manufacturing and commercialization, if the technology development is successful. The research led to new ideas on how to divide combustion into multiple zones to optimize efficiency and emissions. Additional user testing will provide more feedback on the commercial viability of this design, but it is valuable because its design is distinct from what we currently see in the market.
- The separation between the researchers and stove designers from the field testing group will lead to results with more credibility, due to the partnership with Berkeley Air Monitoring Group. Engaging users, surveying manufacturers, policy influencers, and governments is also potentially valuable, but the goals should be defined more clearly. So, the question is: what do you want to learn from these groups and how did it or will it impact the R&D project?
- The results and technical accomplishments are strong and promising. At the same time, the feedback between prototype development and the computational modeling could have been organized in a more systematic framework and structured feedback cycle.
- I understand why the model is not meant to be shared and was designed for purposes of this project. However, the project team should distill key findings from the modeling exercises to share publicly. Further, the usability results will be valuable for the broader community. There is a strong commitment to share results and collaborate, and BETO should ensure follow through on these goals.
- The University of Washington's approach of a strong focus on user and field testing increases the likelihood of acceptance of its stoves and could provide useful insights for the broader cookstoves community in terms of user tests methodologies, key variables differentiating laboratory and field tests, and user preferences. Partnering with an organization with manufacturing capabilities is likely to facilitate commercialization, though the relatively high expected cost could be a barrier to wider adoption.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

TECHNOLOGY INNOVATIONS TO IMPROVE BIOMASS COOKSTOVES TO MEET TIER 4 STANDARDS

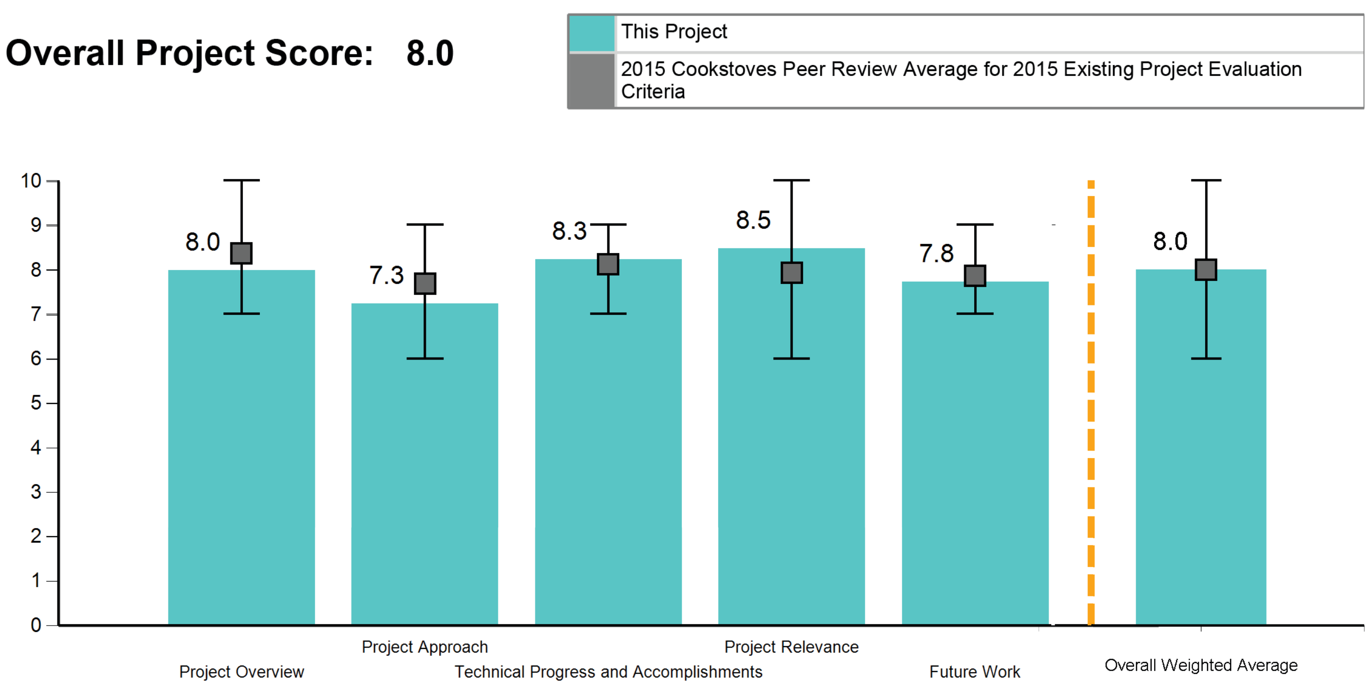
(WBS#: 5.2.1.4)

Photo Courtesy of ARC

Recipient:	Aprovecho Research Center
Presenter:	Dean Still
DOE Funding FY14:	$283,810
DOE Funding FY13:	$0
DOE Funding FY10-12:	$0
Planned Funding:	$415,757
Project Dates:	10/1/2013 - 9/1/2015

Project Description

The project goal is to create biomass cookstoves that meet the IWA/ISO Tier 4 standards designed to use the least fuel, protect human health, and address climate change. The project team conducted three extensive Water Boiling Test surveys of 22 of the cleanest burning cookstoves under an emissions hood and evaluated with the ISO/IWA tiers of performance, establishing a multi-dimensional analysis of existing state-of-the-art cookstoves. Based on the cleaner combustion and superior heat transfer techniques in the best performing stoves, six prototypes that achieve Tier 4 were developed by Aprovecho Research Center (ARC) and the Beijing University of Chemical Technology (BUCT). An iterative development method using both experiments and



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

modeling was employed. The prototypes were evaluated by cooks in six countries, the manufacturer, ARC/BUCT engineers, and the potential U.S.-based distributor/retailer with outlets in 40 developing-world countries. Creating stoves that meet the new World Health Organization (WHO) indoor air quality guidelines for household fuel combustion positively impacts the commercial viability of the biomass industry. The results were detailed in a peer-reviewed journal, two conference presentations, and in a book to be published by EPA in 2016.

Overall Impressions

- If the stoves developed in this project are robustly accepted by users, this effort could be a transformative opportunity to commercialize multiple stove designs (for varying consumer preferences and needs) in urban centers across the developing world.
- Based on the review criteria, my overall assessment is that this is a great project with more strengths than weaknesses.
- The distinguishing feature of the project is the focus on design integrations and tight integration with testing; taking the best of what currently exists and improving from there. Another strength of this project is the tight integration among design for performance, manufacturing, and usability. The focus on so many different geographic areas is a good long-term goal, but my recommendation is to focus on a smaller set of locations in the short term.
- Another area for the Aprovecho team to consider when sharing results is to communicate when design principles have interdependencies. Or strengthen the design of the experiment to understand the interdependencies between the different design principles to clearly show when there are linkages across the design parameters and when there are not.
- Aprovecho Research Center's approach has the potential to make clean, affordable, cookstoves more accessible in a large number of countries across the globe. Strong partnerships with a manufacture and distribution company have the potential to help ARC reach its ambitious goal of manufacturing and selling one million Tier 4 stoves a year. Sharing insights in journal articles and books promises to bring key insights to the broader cookstove community. It would be interesting to learn more about the testing methodology used.

PI Response to Reviewer Comments

- No official response was provided at the time of report publication.

STEERING COMMITTEE FINAL REPORT

Introduction

The Bioenergy Technologies Office (BETO or the Office) technology managers are to be commended for their excellent response to new programmatic expectations while managing ongoing project portfolios. The Office has responded well to programs added for international clean cookstoves, home heating bio-based oil, and including other fuel molecules and bio-based products to the legacy emphasis on ethanol.

Notable successes in this biennium included completion of the initial round of "high tonnage" feedstock supply projects and the commissioning of the first commercial-scale cellulosic biofuel plants. Production of advanced cellulosic biofuels has moved from theoretically possible into reality, in-part due to investment and support from BETO. New research questions and technology needs are being identified that could only become visible through the work of commercial firms trying to be successful at scale. We applaud the responsiveness of BETO to incorporate new and emergent needs into their Multi-Year Program Plan and current efforts.

The review process for 2015 was relatively smooth, yet intense due to the sheer number of high-impact projects that were reviewed. Holding all the platform and program reviews in concurrent sessions during a single week provided increased opportunities for broad discussion, but made it impractical to hold strategic discussions during the event. An improvement in 2015 was that Steering Committee members could move between sessions and topics to gain a broader sense of the BETO portfolio and the review processes followed by different panels. Steering Committee members were afforded opportunities to have internal discussions each day to share observations and focus areas for deeper consideration.

Throughout the review process, the Steering Committee was cognizant of a series of questions posed by BETO to frame its considerations of individual projects, technology areas, programs, and overall program management. These questions were grouped into the following areas: Strengths and Weaknesses; External Threats to Commercialization; Areas to Emphasize, De-emphasize, and Gaps to Fill; Program and Project Coordination; Impacts and Innovation; Strategic Direction; and, Office-level Recommendations.

STEERING COMMITTEE RESPONSE TO QUESTIONS

1 What are the overall strengths and weaknesses of the Bioenergy Technologies Office (BETO) project portfolio? What areas are performing well? Where are improvements needed?

STRENGTHS

Complete Supply Chain from Genetics to Use

The program clearly recognizes that every step of the process from genetics to use of biofuel and bioproducts is interconnected and must be approached as a system-optimization problem. The liquid transportation fuel program addresses the entire supply chain from genetics to engines and emissions as a system. The program managers clearly embrace the system implications of their technology portfolios and the need to coordinate both upstream and downstream with their peers. Cross-program coordination and conversations appear to be much stronger in 2015 than was evident in 2013.

The relatively new algae program is also demonstrating a systems approach, including production of value-added co-products that have the effect of improving biofuel economics and sustainability. Knowledge gained during the past two years is informing office managers as to where to adjust resources for highest impact.

Additional conversion pathways have been identified and studied to better align with the directions that private industry firms are taking. A new incubator program enables support for innovative pathways that are outside those being emphasized by BETO and the national labs.

Demonstration and Pioneer-Scale Projects

The initial round of integrated biorefinery (IBR) and high-tonnage feedstock projects have been completed during this biennium or are nearing completion. Presentations by project managers from the IBR projects were open and frank, with an emphasis on lessons-learned and issues-identified that could not have been known without going through the large-scale engineering, construction, and commissioning effort that was supported by BETO's IBR program.

Similarly, the high-tonnage feedstock projects directly led to the commercial introduction of several new biomass harvest and handling machines, and identified new major technical challenges such as high moisture bales, bale-yard fires, and feedstock variability that would not have been found without operating at-scale.

The Office has already issued a follow-on Funding Opportunity Announcement (FOA) to address new questions raised by the high-tonnage feedstock project. Additional work on the innovative "depot concept" to commoditize feedstocks and address variability issues is ongoing.

Analysis

Major improvements have been made in the rigor and depth of analysis projects since 2013. There is evidence that techno-economic, sustainability, and environmental analyses are becoming increasingly integrated into decisions guiding technical R&D. There also appears to be greater coordination among teams at the various national labs to create more comprehensive and cohesive analyses.

WEAKNESSES

Increased Reliance on Multi-Agency Funding of Large Projects

The Steering Committee observes that the large integrated biorefinery and "Demonstration and Market Transformation" (DMT) projects are maturing, but new demonstrations at similar scale are not forthcoming. As demonstrated by the initial round of IBR and DMT projects, attempting to operate at scale provides critical experience to reduce risks going forward, and to identify potentially game-stopping issues that are not evident at small scale. While we applaud increased cooperation across agencies to support new large projects, particularly with the Defense Production Act (DPA) and USDA, it is not clear how BETO program goals and information needs are to be met.

Need to Advance New Pathways to Pilot and Demonstration Scale

As with the IBR-scale projects, pilot- and demonstration-scale projects are vital to reducing engineering, environmental, and economic risks for emerging supply chain models and conversion pathways. In the past two years, additional biofuel conversion paths have been identified, and a new matrix of hybrid conversion systems has emerged. While exciting and promising, mechanisms are needed to move promising paths from laboratory to pilot and demonstration scales in the U.S.

External Communication

Although communication of technical progress, data, and results is strong, in part due to expanded use of the Knowledge Discovery Framework (KDF), there is a need to better communicate with the public, decision-makers, the financial community and other stakeholders. Recent outreach by the BETO leadership has led to greatly increased numbers of media releases and presentations to industry/scientific/ technical audiences. However, communication through mass media is not effectively reaching local stakeholders who influence siting decisions, permitting, and the views of elected representatives.

The lexicon of bioenergy includes many terms that are prejudicial in the minds of non-technical audiences (e.g., crop residues, synthetic fuels, etc.). There are many supportive and potentially supportive special interest groups across the nation that could be tapped and assisted in their local and regional positive outreach efforts. We encourage the Office to improve its ability to deliver important technical, economic, and sustainability knowledge to non-technical stakeholders and beneficiaries of advanced biofuels and bioproducts.

Lack of Societal License and Soft Sciences in the Analysis Program

Build-out of integrated biorefineries and biofuel supply chains will involve siting of hundreds of large-scale industrial biorefineries and thousands of supply chain business sites (depots, preprocessing sites, biofuel storage facilities, etc.). The first few pioneer facilities are being sited in highly supportive communities and engaging highly supportive stakeholder groups. However, we already see many start-up firms and developers being thwarted in their siting and permitting processes in communities identified as ideal locations via the KDF, Billion Ton Assessment, and other techno-economic analysis (TEA)/logistics models. It is critical that BETO develop methods to incorporate societal license, willingness to support, and soft systems into ongoing and new analyses.

BETO needs to identify the "conditions for successful siting and build-out" across the nation. The Steering Committee believes that such analyses will identify new needs for data, technical information, and demonstrations that are not included in current plans.

Lack of Consideration of Public Health, Emissions, and Effluents in Data and Analysis

Current technical research into processes and conversion systems is not producing important data to inform public discussion and permitting related to positive or negative effects on local and regional populations. Questions being asked in local listening sessions, zoning hearings, and siting reviews cannot be answered with scientifically credible and appropriately peer-reviewed data. For example, the benefits of biofuels to reduce toxic aromatic emissions from conventional fossil fuels are not well understood by the public.

Lack of Communication of Research and Engineering Results in the Context of Investment Communities

Availability of capital, loan guarantees, and even willingness to participate in the many financial transactions necessary to stand-up an advanced biofuels industry are dependent upon perceptions and quantifiable values related to the concepts of risk and uncertainty. Risks arise from technical, feedstock supply, public policy, operational, and may other sources. Current BETO programs and projects only address and attempt to quantify a few of the risk factors that the financial community considers. BETO is encouraged to increase its efforts to understand how various elements of the financial community define and assess risk that leads to their willingness to participate in the advanced biofuels space, set required returns and interest rates, etc. That information should then be used to add analysis and data reporting requirements that provide vital information to this important stakeholder group.

Co-Products to Reduce Costs of Advanced Biofuels

The economic sustainability of first generation ethanol biofuel producers is known to be dependent on production and sale of value-added co-products such as feed, industrial raw materials, and oils. Insufficient effort is being spent on development of co-products related to supply chains and biorefineries producing advanced biofuels. The Steering Committee encourages support for development of co-products that can reduce the cost, reduce wastes and emissions, and/or improve the sustainability of cellulosic biofuel producers.

Lack of Balance between Mega-Biorefineries and Downscaling for "All Biomass is Local"

There is a need to explore decoupling, discontinuities in economies of scale based on local contexts, co-location, and other factors that may enable cost-effective production of biofuels, intermediates, and bio-products at local and community scales. Regional and local bio-economies must be developed and supported to ensure public support for bioenergy on a national level, and to enable optimal use of local biomass sources. Urban and rural community-based production of biofuel intermediates and bio-based products necessarily will involve smaller scale operations and much lower environmental/capital footprints than are the current IBR focus of the BETO programs. Many early-stage firms have business models that involve local production of hydrolysate, sugars, pyrolysis oil, and densified commodity feedstocks. Others envision niche fuels, high value biochemicals, marine fuels, and the like, which have the potential to use local biomass to produce fuels and products that meet local needs, often at a premium willingness-to-pay price than national commodities.

2 Does BETO's portfolio of projects adequately address key "threats" to the commercialization of an advanced bioenergy industry?

Achievement of National Objectives of Energy Security, and Global Environmental Sustainability

The BETO program is well-focused on the goal to replace imported fossil fuels with renewable liquid biofuels in a sustainable manner. Start-up of pioneer facilities in several different states and with different biomass feedstocks demonstrates the reality of a bio-based alternative to imported oil. Additional algal, thermochemical, biochemical, and hybrid production pathways are improving the robustness, adaptability, and viability of advanced biofuels to changing business environments, feedstocks, and new contexts.

Biofuel Cost and Sustainability Challenges

The technical and operational ability of biorefineries to deliver mandated volume goals is a decreasing risk, but new cost and sustainability challenges are emerging. The cost of domestically produced oil and natural gas is not only more volatile than in previous planning horizons, but the downside swings in price of competing fuels have reached new low levels.

National and international expectations for sustainability metrics, social well-being, and control of greenhouse gas emissions are ever-changing and generally ratcheting upward. Waste use, minimization and handling of effluents, aerial emissions, and carbon balance are ongoing challenges.

The Office has done a commendable job in remaining aware of and engaging in national and international dialogs about costs, benefits, and sustainability. Unfortunately, much of the public and many policy makers do not have the information they need to "monetize" or otherwise rationalize the benefits of home-grown biofuels, improved sustainability, improved public health and other soft factors when making personal decisions to support or not support biofuel use in their own homes and vehicles.

Societal License to Operate and Local Siting Challenges

Lack of broad societal acceptance for production and use of advanced liquid biofuels is a critical weakness that is non-technical in nature. This is critical to the development of the necessary feedstock infrastructure as well as the siting and development of IBRs. Interagency coordination and cooperation, such as with the USDA, should be encouraged to help address such barriers. Increased outreach to the public and communities that will likely be impacted by both the growth and development of the feedstock infrastructure as well as the development of larger scale IBR's should be considered.

Capital Markets Wary of Investing in Advanced Biofuel Firms and Facilities

Although global capital markets are strong, venture capital is readily available to "good deals," and interest rates are exceptionally low at commercial banks, capital is generally not available to advanced biofuel and bioenergy firms and projects. One would expect positive effects from the tremendous reductions in technical risk over the past two years that accrue from completed IBR projects, pilot-scale results at national labs and private firms, and targeted research to reduce costs. Unfortunately, those positive events are trumped by non-technical risk factors being considered by the investment and banking community.

Lack of cohesive, long-term supportive public policies is a major risk factor for investors at all levels. Price volatility for competing energy sources, particularly downside potentials, poses a risk to the profitability of new and existing biofuel producers. BETO is encouraged to better understand the sources of concern and risk that can be addressed with appropriate facts, data, and demonstrations. Specific risk factors may be identified that can be mitigated with targeted technical, social, or economic research. Additional work must be done with the investment community and capital markets with respect to a developing biofuels industry to allow economic risks to be evaluated and mitigated.

Public Perception of the Viability of Advanced Biofuels

While we are celebrating the start-up of several pioneer biorefineries that represent the culmination of technical and financial support from BETO, the public and investment community are awaiting proof of sustainable, cost-efficient, high-volume, routine production. The public is very aware of the few past failures and abandonments.

It is not clear to the Steering Committee how the Office is maintaining close communication with the pioneer and demonstration facilities to ensure lessons are learned to improve future technologies and programs, or to anticipate and appropriately respond to issues and process upsets. BETO clearly shares a reputation risk with the private firms moving to commercial biofuel production.

2a Does the portfolio seek to appropriately capitalize on key opportunities?

Localized Areas of Support and Need

The Steering Committee recognizes the need for very large industrial biorefineries to deliver ambitious national targets for advanced biofuels and to materially improve national energy security. However, there is a strong sector of communities with feedstock resources that would like to see community-scale production of biofuels for local use. Some communities seek local control of their energy. Others do not have cost-effective access to natural gas or home heating oil, or face exceptionally high cost for transportation fuels. In many cases, this would call for economical production at the 10 million or 100 million gallons per year level.

BETO is encouraged to continue to support efforts to downscale economical biofuel production such as the joint projects on home heating oil, marine fuel oils, syngas-derived fuels, and other liquid fuels that can be made locally to fill local needs. We expect that local successes will engage more of the public in the biofuel dialog.

Collaboration and Partnering with Other Federal Agencies, Stakeholder Groups, Industry, and Others

Efforts to collaborate with and leverage the expertise of other agencies and groups are to be commended. BETO is encouraged to take advantage of the current trend toward cooperation and collaboration at all levels in the emerging biofuels arena. Direct strategic alliances, such as those with DOD/DPA and USDA to support the next-round of IBR projects, are commendable, *subject to* *earlier comments made regarding the risks of subordinating program goals and or the reporting standards of BETO to those of strategic partners*. Engagement of BETO staff and their supported research community with other stakeholder groups, public policy development efforts, standards efforts, and the like is warranted to leverage limited BETO resources and maximize outreach efforts. Engagement is anticipated to uncover new unexpected needs for data, research knowledge, and demonstrations that can reduce real and perceived risks for biofuel industry growth.

Opportunities to Capitalize on Environmental, Public Health, and Sustainability Benefits of Biofuels

There is a rapidly increasing body of knowledge on the positive health, environmental, and sustainability benefits of advanced biofuels in comparison to petroleum-derived fuels. Health effects of aromatics from fossil fuels may be substantially mitigated by increased use of certain biofuels. High octane biofuels may enable smaller, lighter engines in future vehicles. There is an opportunity for BETO to better catalog and communicate the positive benefits to individuals, communities, and the nation. There is a commensurate need to ensure that new biofuel molecules and pathways are adequately tested to mitigate potentially new and unknown negative effects.

3 Are there any gaps in the funding portfolio?

A number of areas noted a need to adjust research emphasis. Both the Algal and Terrestrial Feedstocks areas note that increased focus on the upstream supply chain rather than downstream conversion is warranted. The program review panels observed, and the Steering Committee concurs, that if the feedstock supply chain cannot achieve economic and environmental viability, the downstream development becomes meaningless or is unlikely to move forward.

Intermediates and Gathering Systems

Augmentation of IBR production capacity with liquid intermediates produced at biomass depots, algae producers, and independent firms is an emerging business model in the industry. The BETO analysis, modeling, and technical programs do not appear to include this model at appropriate levels. Questions about product standards, transport and storage safety, emergency response, inter-firm transactional structures, and the like will need to be addressed at a higher level than is likely to be dealt with by the private firms adopting this model.

High Moisture Biomass Supply Chains for Wet Conversion Processes

Drying of high moisture biomass, such as sugar cane, sorghum, green wood chips, wet urban waste streams, manures, biosolids, and the like, is energy intensive and can upset the energy balance for advanced biofuels. New conversion pathways such as anaerobic digestion/gas fermentation, high moisture gasification, hydrothermal liquefaction, hydrothermal carbonization, and others, are now complementing conventional biochemical pretreatment as outlets for high moisture feedstocks.

Previous supply chain work supported by the Office has focused on low moisture crop residues such as corn stover, switchgrass, and straw. There is a need to design and optimize high moisture supply chains for green and wet feedstocks. Of particular relevance to the BETO mission will be to concurrently design feedstock supply chains and the front-end of appropriate conversion reactors.

Waste Streams to Liquid Transportation Fuels

Although two notable IBR projects feature municipal and regional solid wastes as feedstocks, there is public concern shared by the Steering Committee that other low cost, negative cost, and opportunity waste streams are not receiving consideration as viable feedstocks. Use of waste streams provides important public benefits through reduced landfill demand and recycling of biomass having no other markets. The high-tonnage feedstock programs are moving to successful completion and demonstrate cost-effective viability for supplying agricultural residues and purpose-grown crops to large biorefineries. We encourage BETO to invest in technical solutions that enable collection, storage, and use of waste streams that are locally, regionally, and nationally relevant.

Co-products

Essentially all research area panels noted the need to increase the emphasis on high value co-products rather than narrowly focusing on transportation fuels as the revenue-generating product of biorefineries and depots. There is a need to support co-optimization of process operations and facility designs to produce liquid transportation fuels and other valuable bioproducts/chemicals. By taking advantage of such synergies in the bioenergy space, this has a high probability of leveraging opportunities for development and economic growth.

Co-location of Biofuel Producers with Other Facilities

Techno-economic analyses and designs for biorefineries have only considered "greenfield" locations and not adequately evaluated the technical, capital, and operating cost implications of logical co-location opportunities. The existing stand-alone biorefinery models and design cases provide a useful benchmark for the Office. We encourage BETO to identify logical co-location opportunities such as pulp and paper mills, power plants, food processors, and first generation ethanol facilities, then evaluate the potential benefits and needed new knowledge to support co-location for appropriate advanced biorefinery platforms.

3a Are there areas along the bioenergy supply chain where BETO should place more or less focus?

Demonstration and Market Transformation Projects

As noted earlier, funding for DMT projects is declining to unacceptable levels, at the same time as multiple promising new pathways are emerging from the labs. The Steering Committee considers this a gap in program support and vital to reducing the technical and financial risk of advanced biofuel investments.

Feeding Feedstocks across Temperature and Pressure Boundaries

The challenge to design, manufacture, and operate devices that enable feeding of fibrous wet or dry feedstocks into and out of reactors has been a longstanding issue that remains a major impediment to cost-effective operation of biorefineries. Incremental improvements to commercially available devices are having some impact, although widespread ongoing operational issues that cross brands and feeder technologies remain. We encourage BETO to increase emphasis to co-develop feedstock pre-processing and feeding technologies in a cooperative effort to create commercially viable solutions.

Less Emphasis on Algae Conversion Technologies

The Steering Committee concurs with program review panel recommendation to reduce, but not eliminate, support for algae conversion technologies until algal biomass production yields and economics achieve target levels.

4 Is there adequate coordination between the different technology areas? Are there synergies or lessons learned that BETO should be better taking advantage of?

Coordination between technology areas and through the supply chain from genetics to end-use appears to be strong and effective. This was identified in previous reviews as a weakness. It was readily evident to the program review panels and to the Steering Committee that communication and collaboration are minimizing hand-offs and boundary transitions through the biofuel supply chain.

While there appears to be reasonable coordination between different technology areas within BETO, there is a need for greater interagency cooperation and coordination such as with the USDA and the Terrestrial Feedstocks area. Improved outcomes were noted where larger groups of researchers were able to coordinate rather than having smaller groups working in relative isolation. Efforts to improve coordination and cooperation would appear to be something that should be encouraged.

Improved systems are needed to capture lessons learned from demonstrations and IBR projects and translation of issues to new research questions for the appropriate technology areas. High turnover both in DOE/BETO as well as within the research participants creates risks that learnings may not be captured or retained for future use.

5 Overall, is BETO funding high impact projects that have the potential to significantly advance the state of technology for the industry?

BETO is reaching the culmination of six-plus years of funding research, development, and demonstration projects.

- Several of the BETO supported pioneer commercial-scale cellulosic biofuel facilities are undergoing start-up and commissioning.
- The high-tonnage feedstock supply projects are leading to new commercially viable equipment and logistics systems, some of which are already in use to supply the new IBRs.
- Substantial progress has been made to identify the conditions for success in algae production to focus future public and privately funded R&D.
- Conceptual approaches have been developed and presented for using depots and commodity uniform format feedstocks to supply the build-out of the "billion ton" biomass infrastructure.

The Steering Committee is concerned that a number of research projects appeared to focus more on studying problems rather than providing data and/or knowledge that enables industry to solve problems. All projects should be encouraged to focus on meaningful economic goals as well as their technical research goals. Improved project management with standardized metrics is also suggested. There appears to be relatively weak accountability for claims made and stewardship toward achieving these claims.

5a Does BETO's portfolio include novel and innovative projects that represent the newest industry thinking?

An effort has been made to fund incubator research and step-out concepts that may have breakthrough potential if their technical goals can be reached. This effort should be continued and possibly expanded. However, program management should attempt to ensure that the research would have technical and economic relevance should it be successful.

The Office appears to have been slow to react to biofuel industry trends toward distributed production of intermediates, and efforts to fill small, local biofuel niches. However, there is evidence that projects at the National Laboratories and other regional projects are cognizant of the need to make their work products relevant to emerging industry thinking and business models.

5b Is the focus of BETO support appropriate in light of private sector investments in these technologies?

BETO is to be commended for its use of workshops, Requests for Information (RFI), and round-table events to obtain industry and stakeholder input into program directions, needs, and content. Increased presence of BETO leadership and program managers at industry events and on conference panels provides additional opportunities to share BETO's ideas and obtain direct industry insights into what BETO should support or not support.

The Steering Committee recognizes the difficult challenge faced by BETO leadership to manage limited resources to create enabling technologies/knowledge/systems and to reduce the risks for industry investors to tolerable levels. As noted earlier, private sector investment in the bioenergy industry is much lower than for other technology sectors and for other renewable energy technologies. The Office is encouraged to study the problem of low investor confidence in advanced biofuels and to refocus as needed to provide outputs or information that mitigates unacceptable investment-risk factors.

It is somewhat disturbing to observe U.S.-based bioenergy technology and biorefinery firms moving offshore for their pioneer and commercial facilities. BETO is encouraged to better understand the international finance and policy drivers that are driving the offshoring movement.

6 What feedback can you provide on BETO's technology pathways, as described in the Wednesday morning (3/25) plenary session? Can you provide feedback on the pathways themselves and BETO's Techno-Economic Analysis?

There is a need to identify common-core technical questions and process elements that span pathways and conduct R&D relevant across the matrix of beneficiaries. The new "matrix" approach to technology mapping with pathways is likely to lead to crisper identification of cross-cutting needs for science, technological innovations (such as feeding and catalysts), assessments of environmental impacts, needs for facility permitting data, engineering data, etc.

The matrix approach is much more realistic than earlier single-path analyses, and is more accommodating to the myriad of business/technology models being pursued in the private sector. However, the number of logical pathways through the matrix will require new modular approaches to TEA modeling and regulatory approval by EPA or others for pathways under federal standards.

7 Are there new technology areas that you would recommend BETO start to invest in more significantly? What feedback can you provide on BETO's proposed new areas of focus, including fuels/vehicles systems optimization, aviation and marine biofuels, and other early market adopters?

The Steering Committee applauds BETO for its proactive planning activities and frequent updating of the Multi-Year Program Plan that guides priorities and investments by the Office. We support expansion of the areas of focus beyond conventional transportation fuels as included in the recent Plan.

Early market adopters are likely to include the aviation and marine industries, as well as communities/businesses in need of bio-based heating oil. Note that work is still needed to meet fuel and cost specifications for these markets. However, early market adopters outside of automotive fuel users are likely to improve biofuels acceptance by the public and diffuse debates over renewable versus fossil fuels.

Many of the early adopter industries are currently aligned with other federal agencies; thus, provide natural opportunities for increased cooperation with USDA, DOD, Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), and the Department of Commerce. The caveat with aviation and DOD marine use is that they would adopt biofuels if the molecules were the same as their base case and cost the same or less. With this caveat, any industry, including automotive, would accept biofuels. The risks of new or off-spec molecules in aviation and marine fuels is huge and it may be optimistic to suggest these areas will be early adopters of something other than identical biomolecules at a reduced cost.

We also would like to encourage increased emphasis on use of waste streams of all types as feedstock for advanced biofuels. Increased use of high visibility waste streams as biofuel feedstocks is likely to diffuse debates about land use and crop selections.

8 Are BETO budget priorities adequately aligned to overcome key barriers and meet the goals and objectives of the Office? In which technology areas should BETO put more or less focus on for future budget planning?

As noted previously, the Steering Committee applauds the Office's use of plans, outreach activities, and other efforts to ensure alignment of its limited resources with the highest priority research, development, and demonstration needs. The current science program within the Office appears to be appropriately focused and funded. Strategic leveraging of BETO resources with those of other cooperating federal agencies, state governments, and international partners is needed to make meaningful progress toward applied research, development, and deployment objectives.

Upstream Supply Chain vs. Conversion Rebalancing

There is increasing acceptance that many costly conversion and downstream issues (ash, separations, effluents, feeding, etc.) need to be jointly addressed with or solved in the feedstock supply chain. Current funding within the Office is skewed in favor of conversion-related technologies. The Steering Committee recommends rebalancing toward terrestrial feedstock supply chain improvements and tightly-coupled collaborative efforts.

Investor Risk Reduction and Mitigation

There appears to be a gap between funding research and demonstration plants and the actual commercialization of larger-scale biofuels developments. Many pathways and technologies are moving to higher levels of readiness for commercialization (TRL Levels 8-9), yet are unable to attract private investors to support commercial deployment. Unless technical and business models can be developed that are attractive to the investment community and the capital markets, it is difficult to understand how large-scale development in this area will occur. The BETO program should emphasize quantifying and reducing uncertainties and risks to ensure other financing parties (government and/or private sector) can move promising projects to demonstration and pioneer facilities.

Information Dissemination to Stakeholders, Decision-makers, and Public

The Office has developed a strong track record and vehicles such as the KDF for dissemination of scientific and technical information to highly technically-competent audiences. However, there is a need to deliver accurate data, knowledge, and insights to non-technical audiences in a format and lexicon that is useful for informing public debates and decisions.

More Focus on Issues Limiting Build-Out

Project developers who are working to site and build first-of-a-kind and subsequent biofuel facilities are faced with a lack of information and data to successfully navigate necessary community and regulatory approvals. BETO is encouraged to put more focus on analysis and generating new knowledge about social, community, site selection, environmental permitting, and related topics that will delay or preclude siting of depots, producers of intermediates, or IBRs in the near future. Data that is required by local and regional regulatory agencies needs to be identified and gathered in the normal course of higher TRL research supported by the Office.

9 Are there other technologies and market trends that could impact BETO's goals, such as the increase in natural gas production and the fall in oil prices? Can you provide recommendations on ways to mitigate the impact of these technologies and market trends on achieving the goals of the Office?

As noted, price and supply volatility in the fuels markets in general and the transportation fuels markets in particular have been a major concern in these market sectors for decades. This volatility introduces economic risks that the capital markets currently appear to find unacceptable with respect to the large and long-term investments needed for development of a biofuels industry.

It is unlikely that cellulosic or algal biofuels (other than those with negative cost waste stream feedstocks) will be able to achieve cost parity with the marginal cost of oil and natural gas extraction. The Office is encouraged to balance efforts toward cost reduction and yield improvement with quantifying and communicating the "non-market" public health, national strategic and public policy benefits that accrue from increased production and use of biofuels.

Although it is difficult to manage, the Office is encouraged to maintain its "long-view" of the inevitable societal need for sustainably produced biofuels to meet the global needs for energy into the future. Many of the technical, environmental, and social research needs demand consistent investment over many years or decades in anticipation of a future where biofuels will be fully valued by society. The Office is encouraged to engage its various supportive stakeholders to carry and reinforce that message.

BETO OVERALL PROGRAMMATIC RESPONSE

Introduction

The Office of Energy Efficiency and Renewable Energy (EERE), Bioenergy Technologies Office (BETO or the Office) would like to thank the Steering Committee for its work, technical support, and critical insights throughout the implementation of the 2015 Project Peer Review and Program Management Review. BETO leadership has reviewed the Steering Committee Final Report and will work with the program and technology managers to implement a number of the recommendations and address many of the Committee's concerns in the coming year. The Office appreciates all of the feedback provided and is encouraged by the Committee's support for many of the current research activities undertaken by the Office. This section represents BETO's response to the Steering Committee Final Report.

BETO appreciates the recommendations of the Steering Committee and will consider these in developing and implementing a coordinated framework for managing its portfolio based on systematically investigating, evaluating, and selecting the most promising opportunities across a wide range of emerging technologies and technology-readiness levels. This approach will support a diverse technological portfolio in applied research and development, while identifying the most promising targets for follow-on industrial-scale demonstration, with increasing integration and complexity. Key components of the portfolio will include the following: R&D on productive and competitive advanced algal systems and sustainable, high-quality feedstock supply systems; R&D on biomass conversion technologies; demonstration and validation of integrated biorefinery technologies up to industrial scale; crosscutting sustainability, analysis, and strategic communications activities.

As noted by the Steering Committee, BETO has shifted its focus toward developing other advanced biofuels that will contribute to the Renewable Fuel Standard (RFS) volumetric requirements. By focusing on these biomass-based hydrocarbon fuels and hydrocarbons from algae, the Office seeks to engage the refinery industry in developing solutions, while utilizing existing infrastructure as much as possible. The R&D achievements for cellulosic ethanol production provide the groundwork for the development and optimization of biomass conversion technologies and techniques capable of producing hydrocarbon liquids that are virtually indistinguishable from gasoline, diesel, jet fuel, and other petroleum products, and that are fully compatible with existing fuel handling and distribution infrastructures. These breakthroughs will be repurposed and leveraged to accelerate the commercialization of new, renewable fuels and chemicals derived from biomass and other carbon carrying wastestreams.

Algal Feedstocks

The Algal Feedstocks Program also recognizes the need for disruptive technologies to be developed within the industry, and our goal is for the majority of our projects to meet these ambitious targets. To address this, BETO is specifically seeking potentially disruptive and "off-roadmap" technologies through the Incubator solicitations. Successful Incubator projects will reduce the risk associated with potentially breakthrough approaches and technologies so that they may be "on-ramped" to future program roadmaps and portfolio. BETO will also continue to work closely with stakeholders and our federal collaborators at DOE and the National Science Foundation (NSF) to learn more about technologies that have been developed at the basic science level to help inform the technologies that show the most promise.

We find the Committee Panel's emphasis on carbon-based products to be informative and will consider placing emphasis on upgrading the value of carbon and may also support additional sustainability modeling to understand the potential for carbon storage. We also agree with the recommendation that productivity should be reported across our projects using standardized metrics and, going forward, BETO will work with the projects selected from future FOAs to encourage the use of a standardized set of metrics for reporting important parameters, such as productivity. Regarding the recommendation to focus projects on improving productivity and the kinetics of biomass production, we agree that it is important to improve productivity, which has been a program focus for the last several years. For example, the Algal Biomass Yield (ABY) FOA focused on productivity in outdoor relevant conditions, and those projects are currently working on genetic improvements and other fundamental strain work. BETO will also address the perceived programmatic gaps, which we began focusing on through the FY15 Targeted Algal Biofuels and Bioproducts (TABB) FOA to improve the utilization of carbon.

Going forward, improved productivity will remain a top priority and, in FY16, the Algae Program will continue efforts initiated in FY13 and fund improvements in biomass yield, productivity, and incorporation of downstream logistics, using pre-existing facilities and infrastructure. BETO has been working to decouple funding for terrestrial feedstocks with respect to algal funding, which historically has been mandated by Congress. Further, BETO will work toward more tightly coordinating of projects for techno-economic and lifecycle assessment and sustainability modeling and identify additional synergies to leverage and evaluate methods to encourage increased collaboration among these projects.

BETO also recognizes that, in order to enable cost-competitive algal biofuels and bioproducts, improvements and advancements are needed across the entire algae-to-biofuels and bioproducts process. To address this, BETO issued a FOA in January 2016 for advancements in algal biomass yield. Up to $15 million in funding will be provided to develop technologies that are likely to succeed in producing 3,700 gallons of algal biofuel intermediate per acre per year on an annualized average basis through multiple batch campaigns or on a semi-continuous or continuous basis, in an outdoor test environment by 2020.

Terrestrial Feedstocks

The Terrestrial Feedstock Program recognizes the need for environmental stewardship for biomass production and will continue to emphasize this among project performers. We will continue and increase collaborations with the Sustainability and Strategic Analysis Program to ensure advantageous coordination between programs. An example of BETO's commitment to sustainability is the Landscape Design Funding Opportunity that was released in 2014. A gap that was identified is the need to research advanced supply systems (e.g., depots). It is widely acknowledged that sustainable, lower-risk, long-term, commercial-scale biomass feedstock supply is one of the largest barriers to the development of a bio-industry capable of supporting a bioeconomy. To overcome this barrier, BETO will continue to research a depot model for gathering, treating, and delivering various feedstocks to customers.

There is currently little understanding of the costs associated with operating a biomass depot at scale. BETO recognizes that development of an advanced biofuels industry will require development and demonstration of advanced supply systems with depots so that the technology is proven and financing for such facilities is more easily obtained. To this end, the Terrestrial Feedstock Program is partnering with the DMT Program to better understand feedstock challenges that biomass end users are facing, and develop R&D programs to solve these upstream barriers. The program will continue to work toward the design, operation, and validation of advanced processing technologies and integrated supply chain components at demonstration scale to meet the needs of integrated biorefinery operations.

BETO is also interested in broadening the feedstocks beyond terrestrial sources. For example, wet feedstocks of interest include the non-recyclable wet organic fraction of landfill solid wastes; food wastes from landfills, as they constitute the largest single fraction of currently unrecovered wastes; biosolids and sludges from municipal wastewater treatment processes; manure slurries from concentrated livestock operations; and organic wastes from industrial operations, including but not limited to food and beverage production and cellulosic biorefineries. Other industries such as pulp and paper, forest products, and pharmaceuticals also generate streams that might be suitable for incorporation. In the area of waste-to-energy, BETO conducted a series of three technically detailed workshops in 2014 and 2015 to solicit extensive stakeholder input. One of these workshops was a joint effort with DOE's Fuel Cell Technologies Office and another workshop was in collaboration with EPA and NSF, which led to additional collaborations with NSF, EPA, and the Water Environment Research Foundation (WERF). The entire series will inform the FY16-FY17 DOE Waste-to-Energy Roadmap.

BETO will also work toward developing multi-scale integrated models and seek to obtain necessary data through collaborations with its partners at USDA, NSF, and EPA to ensure continued coordination. These include interactions and collaborations with the USDA/DOE Biomass Feedstocks Coordination Group; Interagency Feedstock Logistics and Biofuels Distribution Working Group; Interagency Feedstock Production Working Group; and the Woody Biomass Utilization Group. Current targeted coordination between agencies centers on the Biomass R&D Initiative (BRDI) Solicitation development and execution; Regional Feedstock Partnership and USDA's NIFA AFRI Coordinated Agricultural Projects information sharing; and BETO strategic planning efforts around feedstocks, and specifically, business cases for bioenergy crops. In the area of wet and gaseous organic waste streams as feedstocks for biofuels and bioproducts, BETO collaborations include the following: (1) working with USDA and EPA to continue advancing the aims set forth in the 2014 Biogas Opportunities Roadmap, and the subsequent 2015 progress report; (2) participating in EPA's Nutrient Recycling Challenge, along with USDA and the private sector; (3) continuing collaboration with NSF and EPA on facilitating the development and deployment of the Energy-Positive Water Resource Recovery Facilities of the Future; and (4) working with DOE's Office of Fossil Energy to pursue shared interests in using gaseous waste streams as a feedstock.

Conversion R&D

BETO appreciates the comments and recommendations of the Steering Committee and the Review Panels on Biochemical and Thermochemical R&D programs.

The focus of the Conversion R&D Program is to develop commercially viable technologies for converting biomass feedstocks via biological and chemical routes into energy-dense, fungible, finished liquid transportation fuels such as renewable gasoline, diesel, and jet fuel, as well as bioproducts and chemical intermediates and biopower. Historically, these pathways have been roughly classified as either biochemical or thermochemical to reflect the primary catalytic conversion system employed, as well as the intermediate building blocks produced.

Generally, biochemical conversion technologies involve pathways that use sugars and lignin intermediates, while thermochemical conversion technologies involve pathways that use bio-oil and gaseous intermediates. Moving forward, however, the traditional division between biochemical and thermochemical conversion technologies will not encompass the diversity of innovative technologies, and BETO's strategy focus has shifted to a simpler process flow in which the polymeric feedstock is deconstructed into intermediates, which are then upgraded into products. Multiple technologies along several pathways are under development to address the broad range of physical and chemical characteristics of various feedstocks and to reduce the risk that any specific technology could fail to reach commercial viability.

In February 2016, BETO released a FOA entitled, "MEGA-BIO: Bioproducts to Enable Biofuels." This FOA will provide up to $11.3 million in funding to develop flexible biomass-to-hydrocarbon biofuels conversion pathways that can be modified to produce advanced fuels and/or products based on external factors, such as market demand. This FOA supports BETO's goal of meeting its 2022 cost target of $3/gasoline gallon equivalent for the production of hydrocarbon fuels from lignocellulosic biomass and biomass derived from algae. One approach BETO has taken previously to achieve this goal was to focus on conversion pathways that produce biofuels, with little or no emphasis on coproducing bioproducts. As BETO increasingly focuses on hydrocarbon fuels, it is examining strategies that capitalize on revenue from bioproducts as part of cost-competitive biofuel production.

Conversion and feedstock interface activities include the R&D necessary to determine a desirable specification range for feedstocks intended for conversion processes, and linking feedstock logistics with conversion processes will allow evaluation of technology options and tradeoffs. Additionally, BETO is investigating the development of preprocessing options (e.g., densification, blending of an expanded pool of feedstocks, and physical formats, such as pellets, shredded material, and slurries) and simultaneously assessing the impact on conversion efficiency when such preprocessed feedstocks are introduced into a conversion process.

Key focus areas of the Conversion R&D include developing a better understanding of the fundamentals of gasification, pyrolysis, and hydrothermal liquefaction processes (including reaction mechanisms); exploring new and/or improved reactor designs; improving the quality of deconstructed intermediates; developing more robust catalysts and catalyst regeneration processes; and developing catalysts with improved specificity. BETO is developing technologies to create more efficient hydrolysis and cleaner separation of intermediate streams at lower cost, e.g., developing better pretreatment conditions; creating lower cost hydrolytic enzymes; as well as technologies to purify intermediate streams to improve yield from catalytic upgrading in subsequent steps.

The primary objective with biological upgrading is identifying and developing robust microorganisms capable of converting complex intermediates to desired target molecules in the presence of inhibitors at high rates, titers, selectivity, and yields. BETO is also pursuing technologies to improve conversion routes that involve metabolism of syngas and biogas by microorganisms and other hybrid technologies that combine the best of chemical and biological approaches.

Other current and upcoming program activities and initiatives include the following:

- Pursuing technologies to enable product streams to conform to standards for off-take agreements. This research involves the removal of problematic contaminant compounds and further finishing.
- Undertaking integration and intensification activities to ensure seamless transition between unit operations and improve whole plant efficiency.
- Investigating the interaction of pretreatment and deconstruction technologies together with downstream upgrading technologies.
- Working to establish clear product specifications that will enable bio-oil, bio-intermediates, fuel-blendstocks, finished fuels, and products to seamlessly integrate with existing petroleum infrastructure, and will encourage industry acceptance of bio-based replacements.
- Pursuing R&D on novel methods for reducing the number of process steps required to produce product-improving process economics through reduced capital and operating costs.
- Developing new analytical and modeling tools that enable more efficient production of fuels and products across conversion, e.g., modeling of new and modified organisms, enzyme modeling, and development of novel analytical tools.
- Developing standards and protocols to increase researchers' ability to reproducibly replicate experiments both within and between laboratories and to better characterize intermediate and final material

provided to industry.

- Developing new and improved catalyst and enzyme systems under industrially relevant conditions to reduce the cost of both deconstruction and upgrading, e.g., catalysts offering improved yield, productivity, selectivity, and product slate.
- Pursuing improved economic separations processes to enhance yields and intermediate/product purity in all steps of the conversion pathway.
- Pursuing research on innovative technologies that can broadly enable conversion of feedstock to fuels and products and that do not readily fall into other areas.

Demonstration and Market Transformation

The DMT Program appreciates the Steering Committee's endorsement of the work performed and that the strength of the program can be attributed to a large number of projects engaged in developing technologies. Historically, DMT performance goals were focused on validation of production capacity in a given year; however, future performance goals and milestones will focus on validating a specific number of technologies at various scales instead of a projection of production capacity. The following areas are critical and will be emphasized in DMT efforts: validation of proof of performance at integrated pilot-, demonstration-, and pioneer-scales; reduction of biorefinery capital and operating costs; product specification, qualification testing, and off-take agreements; and risk reduction through integration of complex systems and demonstration of process capability.

DMT will focus on integrated production and scale-up of drop-in hydrocarbon biofuels, with new investments that will accelerate the momentum for advanced biofuel and bioproduct manufacturing and will broaden the portfolio of hydrocarbon fuel production at pilot- and demonstration-scale.

Validating performance at integrated pilot, demonstration, and pioneer scales is essential to de-risk technology and enable financing that will catalyze the transition to large-scale renewable fuel production. The DMT Program will continue focusing on reducing risk to the consumer and the private sector and helping overcome challenges to financing the follow-on expansion of the industry, which is required to make a major contribution to our nation's reinvestment in America and reduce foreign oil imports, together with environmental benefits for future generations.

BETO is uniquely positioned to leverage both legislative authority for financial assistance and DOE's successful track record in commercialization to assist developers in de-risking technologies through validated proof of performance at the pilot-, demonstration-, and pioneer-scales. This assistance is critical to enable equity holder and lender confidence to invest in facility construction and replication at the commercial-scale through private investment and loan guarantee programs. In addition to the significant risks involved with scale-up of new biorefinery technology, other market barriers related to infrastructure and end use also limit the amount of advanced biofuel production.

DMT also works toward developing novel methods for expanding the end use market for biofuels. BETO efforts in this area will focus on enabling higher rates of renewable fuel usage in current markets while addressing barriers for expansion into new markets, such as renewable jet fuels. Markets for advanced biofuels will be considered, including co-designing next-generation engines to better utilize biofuels through the Fuel and Vehicle Systems collaboration with EERE's Vehicle Technologies Office. Co-optimization of fuels and engines could result in expanded markets for renewable fuels, improvements in vehicle engine efficiency, and reductions in life-cycle GHG emissions. Working closely with the Vehicle Technologies Office, BETO will help identify the opportunities and challenges associated with the development of new fuel specifications and work to assist stakeholders in the development and market transformation of co-optimized vehicle systems, new fuel compositions, and compatible infrastructure needed to achieve increased use of advanced biofuels in the U.S. transportation system, both in today's and future vehicles.

Sustainability and Strategic Analysis

BETO appreciates the Steering Committee's recognition of improvements that have been made in this area since 2013. These include the evidence that techno-economic, sustainability, and environmental analyses are becoming increasingly integrated into decisions guiding technical R&D, and the greater coordination among teams at the various national labs to create more comprehensive and cohesive analyses. Regarding the coordination, BETO has created a coordination group of analysts and researchers from multiple national laboratories involved in sustainability and techno-economic analysis of advanced biofuel pathways. This group has worked to create more consistency and integration across these analyses. The national labs also coordinate to develop supply chain sustainability analyses in order to facilitate comparison of life-cycle energy and environmental impacts across biofuel pathways in BETO's R&D portfolio.

Sustainability and Strategic Analysis activities play a critical role in understanding the feasibility, sustainability, and scalability of new feedstock logistics and conversion routes to renewable hydrocarbon fuels and biobased chemicals. Analysis and Sustainability activities, such as process simulation, environmental sustainability assessments, techno-economic analysis, and life-cycle models, are used to establish baselines, identify the most impactful areas of research, develop performance targets, monitor the progress of the research portfolio, and aid in understanding the tradeoffs among technology options within a systems context. Examples of environmental sustainability metrics include life-cycle greenhouse gas emissions, fossil energy consumption, consumptive water use, wastewater generation, air pollutant emissions, biomass carbon-to-fuel efficiency, renewable energy production, value of additional products, and total fuel yield.

Communication and Outreach

While recognizing that BETO has greatly increased numbers of media releases and presentations to industry, scientific and technical audiences, the Steering Committee identified that there is a need to better communicate with the public, decision-makers, the financial community, and other stakeholders. The Committee felt communication through mass media is not effectively reaching local stakeholders, who influence siting decisions, permitting, and the views of elected representatives. BETO is fully appreciative of the need to effectively convey its message to the public and to Congress. BETO invests resources in its messaging and outreach efforts by communicating success stories; participating in and hosting industry conferences;posting regular blog and social media updates; developing technology area fact sheets and state fact sheets; providing regular briefings to Congressional committees and staff, and DOE leadership; and actively maintaining its website and other communications materials.

BETO agrees effective communication is critical to informing stakeholders, and educating the public and decision-makers. BETO has intensified its communication and outreach efforts and will apply additional resources to enhance its ability to deliver important technical and sustainability knowledge to non-technical stakeholders and beneficiaries of advanced biofuels and bioproducts. Further, in response to misconceptions about bioenergy, BETO's Strategic Communications team is focused on amplifying facts, based on sound science about bioenergy, along with identifying and addressing market and other non-technical barriers to bioenergy adoption and utilization. BETO is currently focusing on:

- Increasing awareness of and support for the Office's advanced biomass RD&D and technical accomplishments, highlighting their role in achieving national renewable energy goals;

- Educating audiences about the environmental, health and economic opportunities and social benefits of biofuels, bioproducts, and a growing bioenergy industry; and
- Increasing the use of new communications vehicles and outlets and disseminating messaging through graphical and interactive formats, including infographics, animations, and videos.

Collaborations and Partnerships

The Steering Committee commended BETO's efforts to collaborate with and leverage the expertise of other agencies and groups and encouraged taking advantage of the current trend toward cooperation and collaboration at all levels in the emerging biofuels arena. BETO recognizes that coordination with other DOE offices and government agencies involved in bioenergy development is essential to avoid duplication, leverage limited resources and different expertise housed within other agencies, optimize the federal investment, ensure a consistent message to stakeholders, and meet national energy goals.

BETO coordinates with other DOE offices and federal agencies through a range of informal and formal mechanisms. For example, the Biomass R&D Board (the Board) is a particularly important coordination mechanism. The Board is an interagency collaboration that is co-chaired by the USDA and DOE, which jointly implement the Biomass R&D Initiative annually. Other Board partners include the Departments of Interior, Transportation, and Defense; EPA; NSF; and the President's Office of Science and Technology Policy. The Board members meet quarterly to discuss updates and implementation strategies across federal agencies in biofuels, bioproducts, and biopower R&D. In addition, as an independent body for the Board, the Technical Advisory Committee provides input to agencies regarding the technical focus and direction of the Initiative.

Internal DOE collaborations include coordination with the Office of Science, Loan Programs, ARPA-E, Office of Fossil Energy, Energy Information Administration, as well as other EERE program offices, i.e., Advanced Manufacturing Office (AMO), Vehicle Technologies Office (VTO), and Fuel Cell Technologies Office (FCTO). AMO works with BETO to research and develop renewable, low-cost carbon fiber for lightweight vehicles. VTO partners with BETO on fuel infrastructure characterization and new work on the co-optimization of fuels and engines. FCTO and BETO coordinate on renewable hydrogen production, in conjunction with biomass, and the use of algae to produce biofuels and hydrogen. In December 2015, BETO and VTO have released a request for information (RFI) titled, "Co-Optimization of Fuels and Engines," to gather input from industry, academia, and other stakeholders on this initiative, which is focused on the development of new fuels and engine architectures that are co-optimized—designed in tandem to maximize performance and carbon efficiency.

These collaborations will play an increasingly important role and BETO considers the open solicitation of stakeholder inputs to be essential to understanding the needs of the industry, non-governmental organizations, universities, and the broader bioenergy community. Understanding these needs, and working with partners to proactively facilitate their redress, is an essential part of the agency's functional role and is critical to achieving BETO's overarching goals for accelerating the commercialization of advanced bioenergy and bioproduct technologies.

As for international collaborations, BETO requires that these emphasize tangible benefits to the U.S. while also looking to better understand market drivers that could enable U.S. bioenergy and bioproducts industry within a global context. This topic was discussed in a plenary session at the Bioenergy 2015 conference that was held in July 2015.

Active Project Management

BETO has implemented EERE's Active Project Management (APM) to enhance project management functions in order to be an effective steward of taxpayer dollars and produce the highest impact from its investments. APM is becoming increasingly focused on impacts, meeting milestones, and alignment with BETO's MYPP. The APM requires approaches that provide clearer accountability through:

- More clearly defined roles and responsibilities in project execution by establishing uniform position requirements across the organization;
- Enhanced project management standard operating procedures;
- Guidance to more effectively negotiate detailed statements of project objectives for each project, including quarterly progress reviews and annual "Go/No-Go" milestones; and
- End-of-project deliverables clearly oriented around accomplishments that can impact the bioenergy marketplace.

Strategic Planning

BETO has initiated a strategic planning process during 2015 with a program vision for 2040. The strategic planning effort is a multi-stage, iterative endeavor and will incorporate inputs and comments received from a wide range of program stakeholders. BETO believes that reaching its vision requires the participation of a broad range of public and private stakeholders of the evolving bioenergy sector, including the general public, the scientific and research community, trade and professional associations, environmental organizations, the investment and financial community, existing industries, and government policy and regulatory organizations. These stakeholders possess valuable perspectives that can help identify the most critical challenges and better define strategies for effectively deploying bioenergy and bioproducts. The framework for success also requires extensive coordination and collaboration across multiple federal stakeholder agencies.

The recommendations of the Steering Committee, as well as those received from other committees, will play a role in shaping the future direction of the Office. The Strategic Plan will be consistent with and utilize a similar format as that of the EERE Strategic Plan (released December 2015) and is expected to be released during 2016.

Closing Notes

BETO sincerely appreciates all of the Steering Committee's work. The straight-forward layout of specific, actionable recommendations have been extremely helpful and valuable. BETO is committed to address and take action on a number of these recommendations and will continue to incorporate others into its overall thinking for continuous improvement of its approach and research strategy.

BETO looks forward to continuing to leverage the active participation of all its stakeholders as it seeks to educate the American people and their representatives in Congress of the significant achievements of, and enormous potential for, an emerging bioeconomy.

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