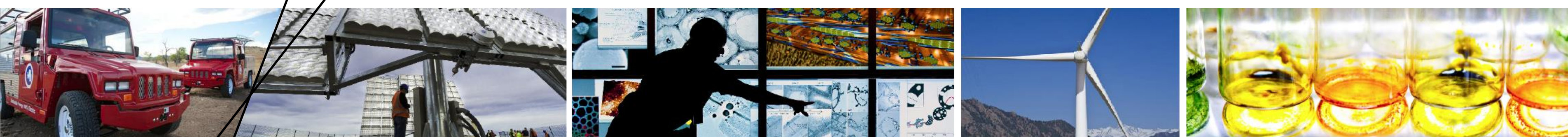
Overview of the National Renewable Energy Laboratory's Strategic Analysis Project Portfolio



Mary J. Biddy, Yimin Zhang, Ling Tao, Michael Talmadge

National Renewable Energy Laboratory

May 20, 2013
Analysis and Sustainability Peer Review
2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Goal Statement

- **Develop tools and applications that bolster the analytic capabilities of the DOE Bioenergy Technologies Office**
- **Provide comparative economic analysis for the production of biofuels and bioproducts to support the goals of the DOE Bioenergy Technologies Office**
- **Conduct analysis that compares biomass utilization by different pathways across multiple metrics of interest**

Quad Chart Overview

Timeline

- Start Date: October 2010
- End Date: Ongoing

Barriers

- Barriers addressed
  - At-A: Lack of comparable, transparent, and reproducible data
  - At-B: Limitations of analytical tools and capabilities for system level analysis
  - At-C: Inaccessibility and unavailability of data

Budget

- Funding for FY11: $900k
- Funding for FY12: $1,100k
- Funding for FY13: $900k
- Project has been funded 3 years, average funding $967k/year

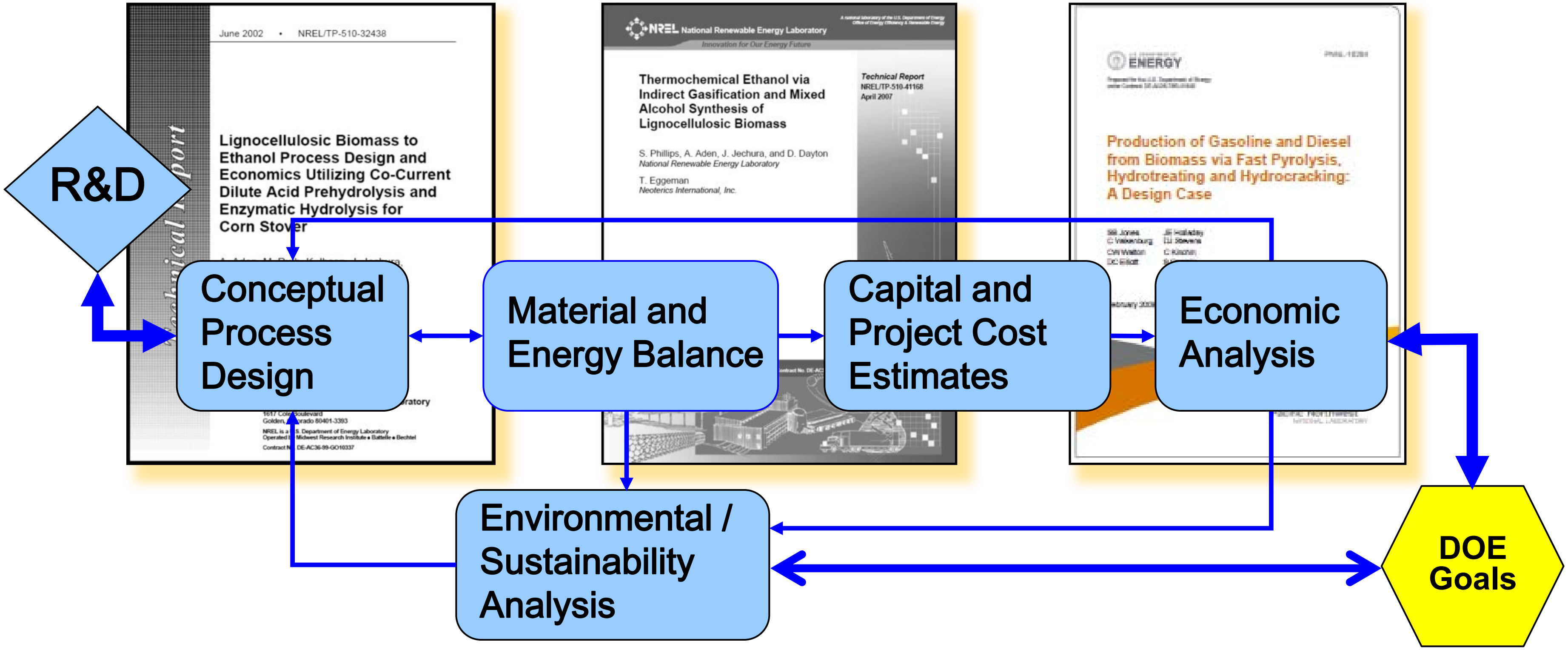
Partners

- Pacific Northwest National Laboratory
- Oak Ridge National Laboratory
- Virent
- Conoco Phillips
- Iowa State University
- NREL Platform Analysis Tasks

Project Overview

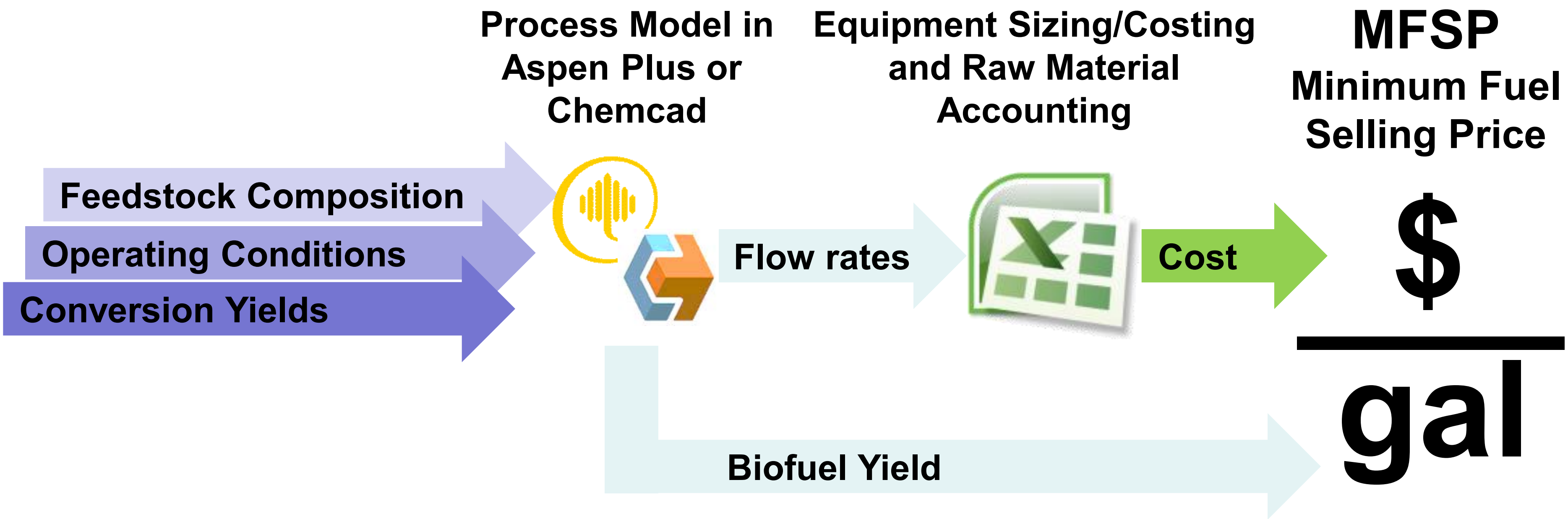
- **Conduct cross-cutting and systems-level analyses to inform program planning, decision-making, and R&D investments**
  - Techno-economic analysis in support of strategic programmatic technology expansion and novel technologies
  - Market and barriers analysis to identify drivers and uncertainties in the expansion of the biofuels and bioproducts portfolio
  - Integrated biorefinery optimization to guide the program on the development of bioproducts
  - Comparative analysis to understand energy production economics on a levelized cost basis
  - Estimation of jobs growth and the broader impact of developing industries
  - Evaluation of key drivers of land use change for biomass conversion
- **Developing state of the art modeling tools and analysis using the highest quality data that is available**

Techno-Economic Analysis: *Approach*



- Collaboration with engineering and construction firms to enhance credibility and quality
- Conceptual design reports are transparent, peer reviewed
- Iteration with researchers and experimentalists is crucial

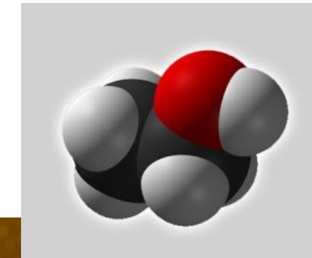
Techno-Economic Analysis: *Approach*

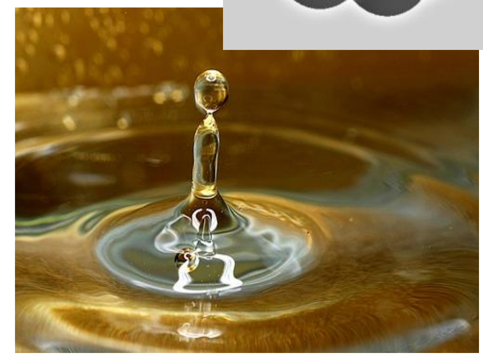


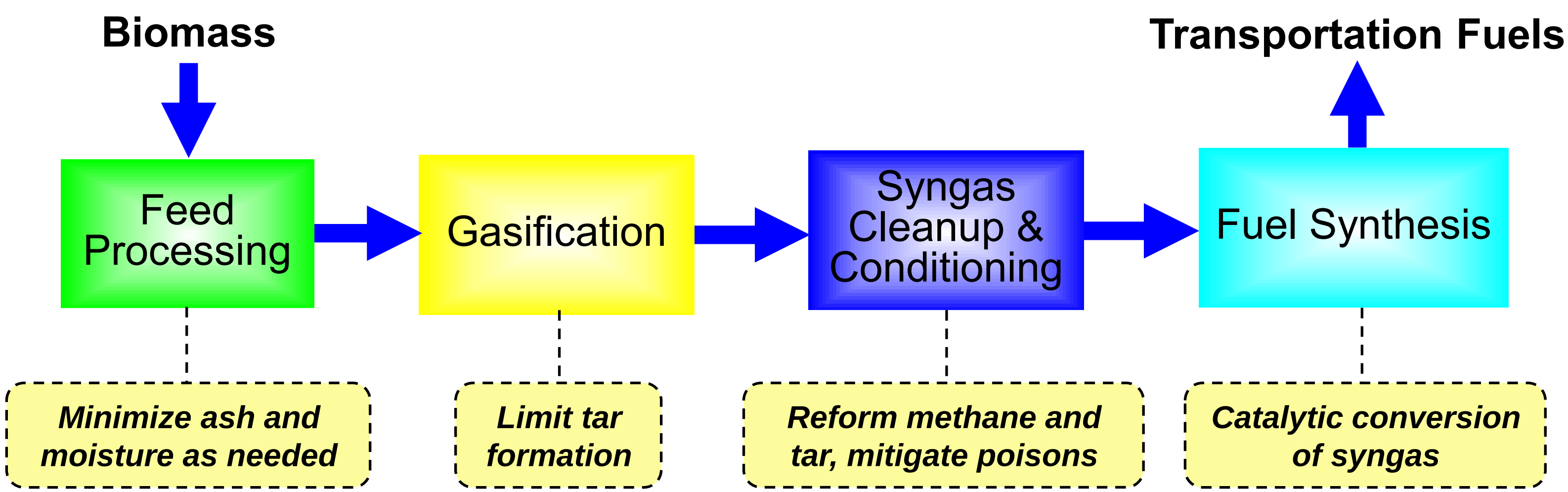
- Modeling is rigorous and detailed with transparent assumptions
- Assumes nth-plant equipment costs
- Discounted cash-flow ROR calculation includes return on investment, equity payback, and taxes
- Determines the minimum selling price required for zero NPV

2011 Thermochemical Design Report for Cellulosic Ethanol

- **Biomass via synthesis gas to fuels**
  - Deconstruct biomass to light gases
    - (CO & H_2)
  - Convert syngas to liquid fuels



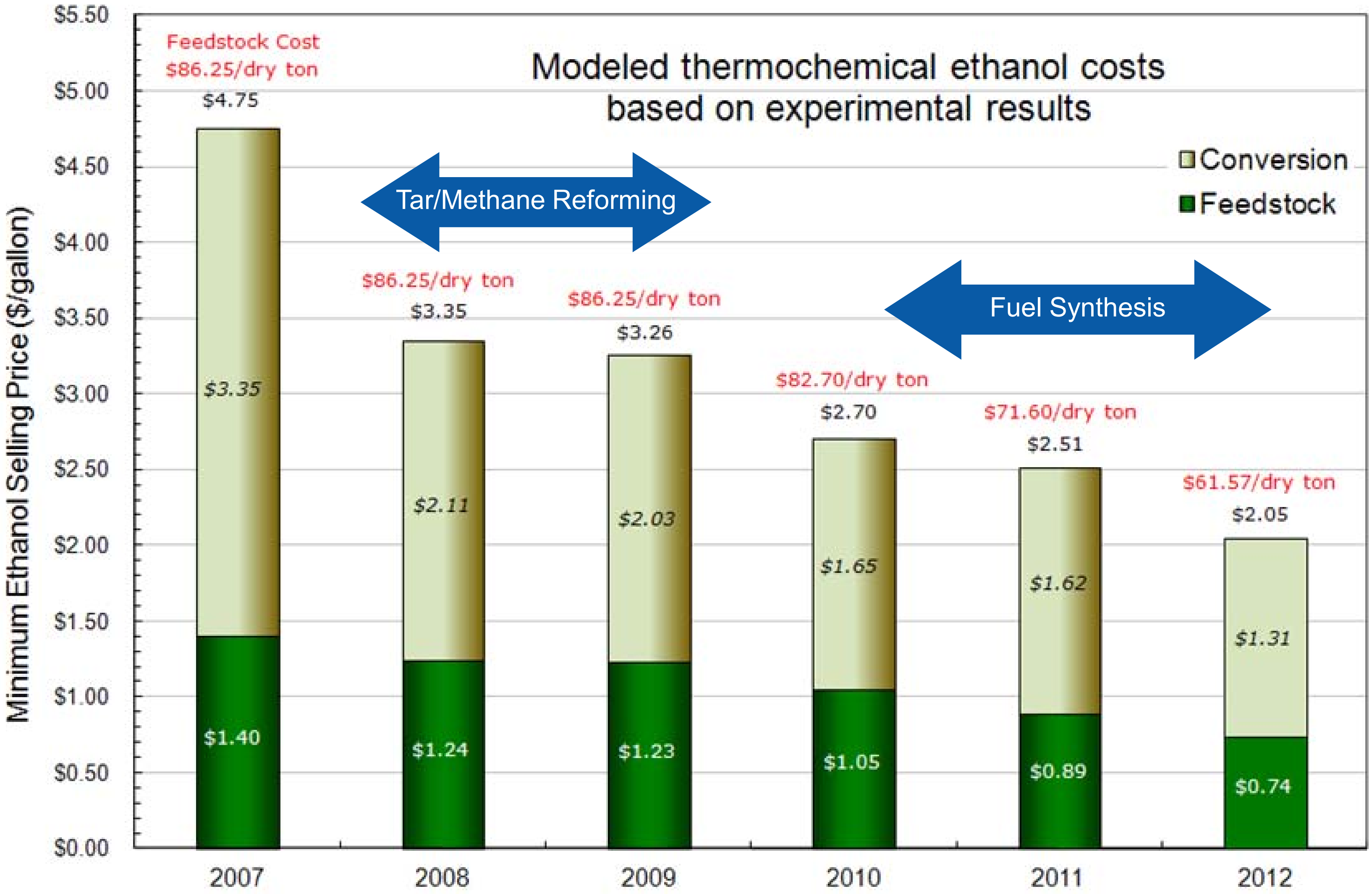




Thermochemical Design Report: *Technical Target Table*

	2007	2008	2009	2010	2011	2012 (Target)
Minimum Ethanol Selling Price ($/gal)	**$4.75**	**$3.35**	**$3.26**	**$2.70**	**$2.51**	**$2.05**
Feedstock Contribution ($/gal)	$1.40	$1.24	$1.22	$1.05	$0.90	$0.74
Conversion Contribution ($/gal)	$3.35	$2.11	$2.03	$1.65	$1.62	$1.31
Ethanol Yield (Gallon/dry ton)	62	70	70	79	80	84
Mixed Alcohol Yield (Gallon/dry ton)	67	77	78	88	89	94
Feedstock						
Feedstock Cost ($/dry ton)	$86.25	$86.25	$86.25	$82.70	$71.60	$61.57
Syngas Generation						
Syngas Yield (lb/lb dry feed)	0.78	0.78	0.78	0.78	0.78	0.78
CH_4 Concentration in raw syngas(mol%-dry basis)	15	15	15	15	15	15
Syngas Cleanup and Conditioning						
Tar Reformer – CH_4 conversion (%)	20	50	56	80	80	80
Tar Reformer – Benzene conversion (%)	80	98	98	99	99	99
Tar Reformer – Total Tar conversion (%)	97	97	97	99	99	99
Tar Reformer – Exit CH_4 concentration (mol%)	13	5	4	2	2	2
Catalyst Replacement (% inventory/day)	1.0	1.0	1.0	1.0	1.0	0.1
Catalytic Fuel Synthesis						
Compression for fuel synthesis (psia)	3,000	3,000	3,000	3,000	3,000	3,000
Single pass CO conversion (%)	25	24	25	26	29	29
Overall CO conversion (%)	55	68	70	80	79	79
CO Selectivity to alcohols - CO_2 free basis (%)	78	81	81	81	81	81
Total Alcohol Productivity (g/kg/hr)	282	330	337	360	358	368
CO Selectivity to ethanol - CO_2 free basis (%)	59	63	63	63	63	63
CO Selectivity to methanol - CO_2 free basis (%)	13.6	12.4	12.2	11.8	10.4	10.2
Ethanol Productivity (g/kg/hr)	101	128	132	143	153	160

Thermochemical Design Report:
Historic State of Technology



Project Approach

- **This project has 5 separate tasks:**
  - Task 1 (11.2.1.2) – Biomass Utilization Pathways: Techno-economics to support technology pathway analysis (NREL & PNNL)

    PI: Mary Biddy
  - Task 2 (11.2.1.4) – Advanced Biofuels and Bioproducts Modeling: Techno-economics to support advanced biofuels and bioproducts modeling

    PI: Ling Tao
  - Task 3 (11.2.1.3) – Biomass Applications Analysis: JEDI Model

    PI: Yimin Zhang
  - Task 4 (11.2.1.5) – BIOREFINE Linear Programming Model

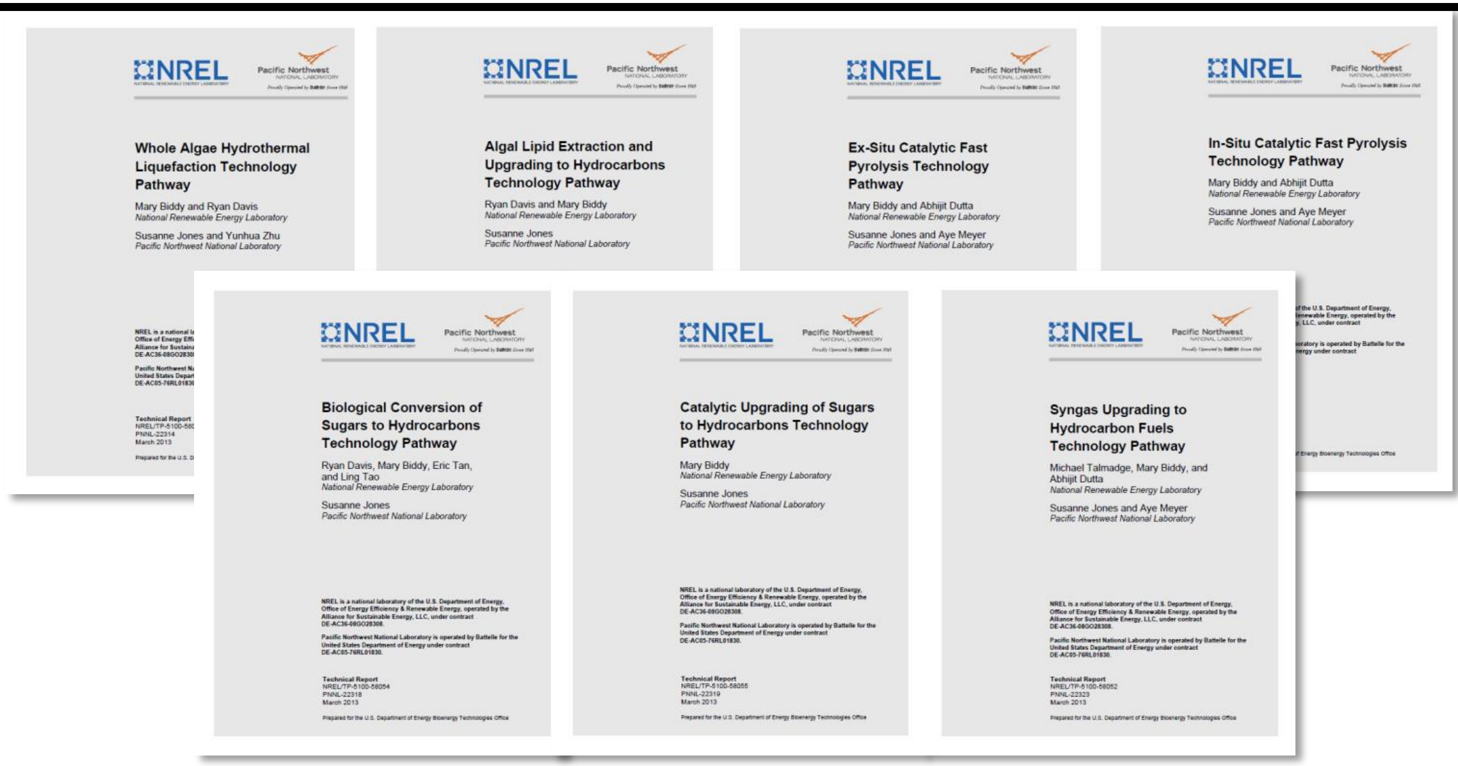
    PI: Michael Talmadge
  - Task 5 (11.2.1.1) – Land Use Change Modeling

    PI: Daniel Inman (presented later in the review session)
- **Management approach**
  - Develop annual operating plans coordinated with the DOE BETO goals with clearly defined metrics for milestones and deliverables
  - Quarterly reports and updates on progress to DOE BETO

Technology Pathways Technical Memos: *Approach* (WBS 11.2.1.2)

- **FY12 NREL and PNNL collaboration to perform analysis for hydrocarbon biofuels pathways**
- **Integrated efforts with INL for feedstock interface and costs**
- **18 pathways identified with 13 TEAs performed**
- **Consistent economic assumptions utilized to estimate preliminary MFSP**
- **DOE BETO selected 7 pathways for further development**
- **Vetted assumptions and basis with researchers and scientists for pathways**
- **Reviewed by key stakeholders in DOE BETO**

Technology Pathways Technical Memos: *Technical Accomplishments* (WBS 11.2.1.2)



- **FY13 collaborative TEA efforts between NREL and PNNL to document and publish 7 technology pathways**
- **Provides process design details and identifies data gaps, uncertainties, and future research needs**
- **Starting point for developing joint NREL and PNNL design reports for hydrocarbon biofuels pathways in FY13 and FY14 for core platform tasks**

Advanced Biofuels and Bioproducts Modeling: *Approach* (WBS 11.2.1.4)

- **Provide strategic and comparative economic analysis for advanced biofuels and bioproducts conversion technologies**
- **Compare and understand the transition from pioneer plant to nth-plant cost estimates**
- **Establish strategic modeling to focus R&D on key technology targets**

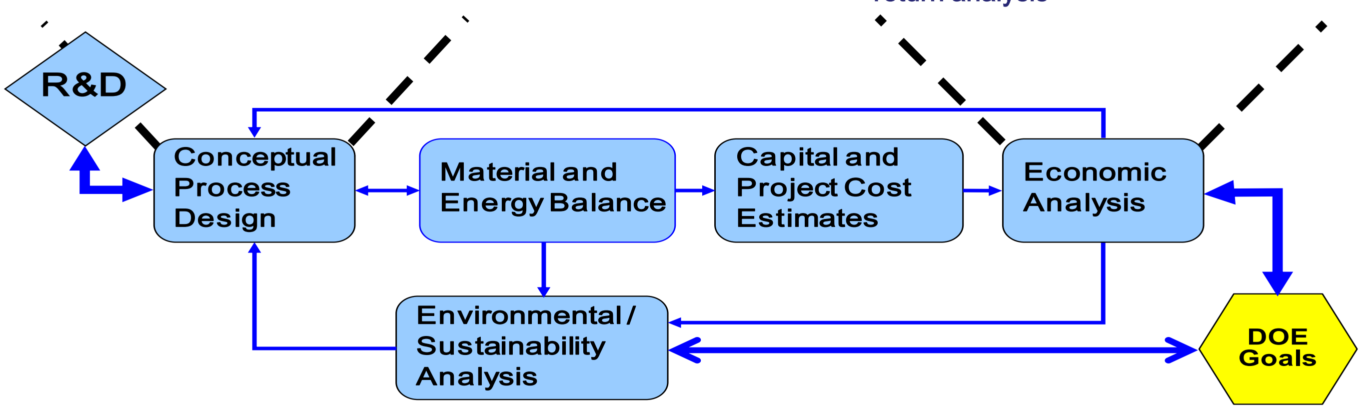
✓ Early Stage: Simple spreadsheet, back of the envelope estimates

✓ Mid Stage: Industry-relevant ASPEN Plus™ process simulation

✓ Kinetic modeling and regression analysis tools

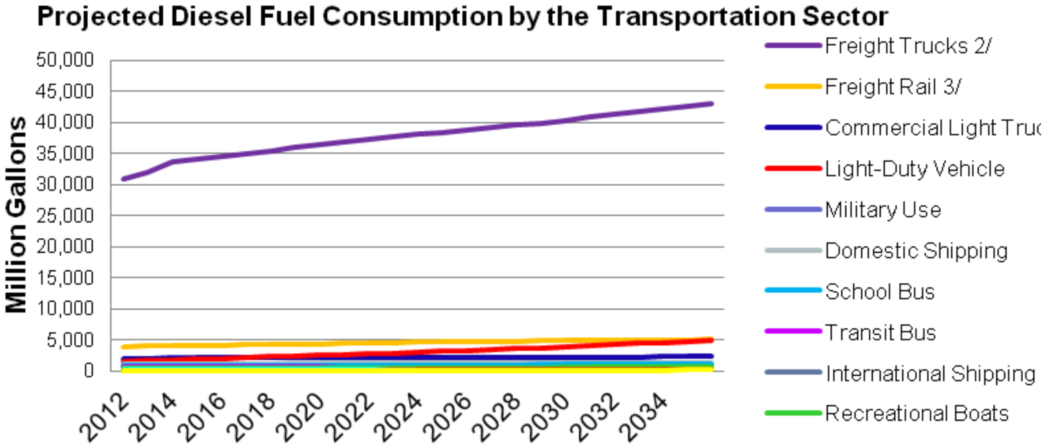
✓ Early Stage: Simple cash flow analysis

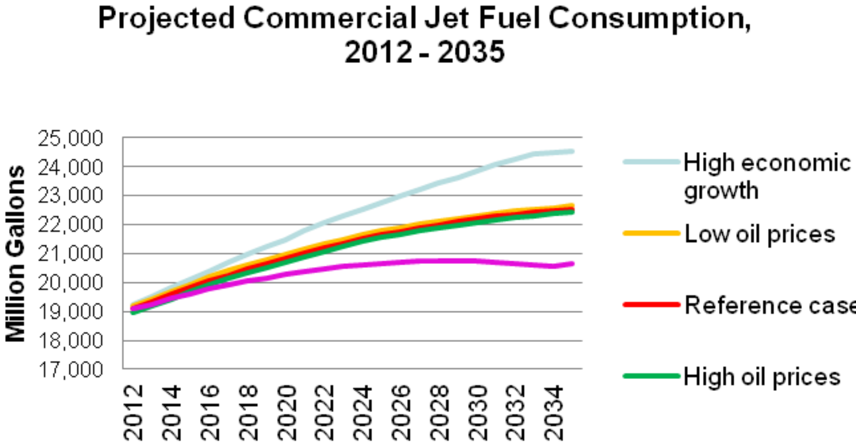
✓ Mid Stage: Discounted cash flow rate of return analysis



Advanced Biofuels and Bioproducts Modeling: *Technical Accomplishments* (WBS 11.2.1.4)

- **Analysis efforts**
  - Supported the MOU between NREL, Iowa State, and ConocoPhillips to develop comparative techno-economics (4 peer review articles)
  - Evaluated feasibility of producing and using biomass-based diesel and jet fuel in the United States, including implications of RFS2 production, capacity, cost, market demand, and feedstock availability
- **Ongoing efforts focused on techno-economic analysis of jet fuel conversion routes**

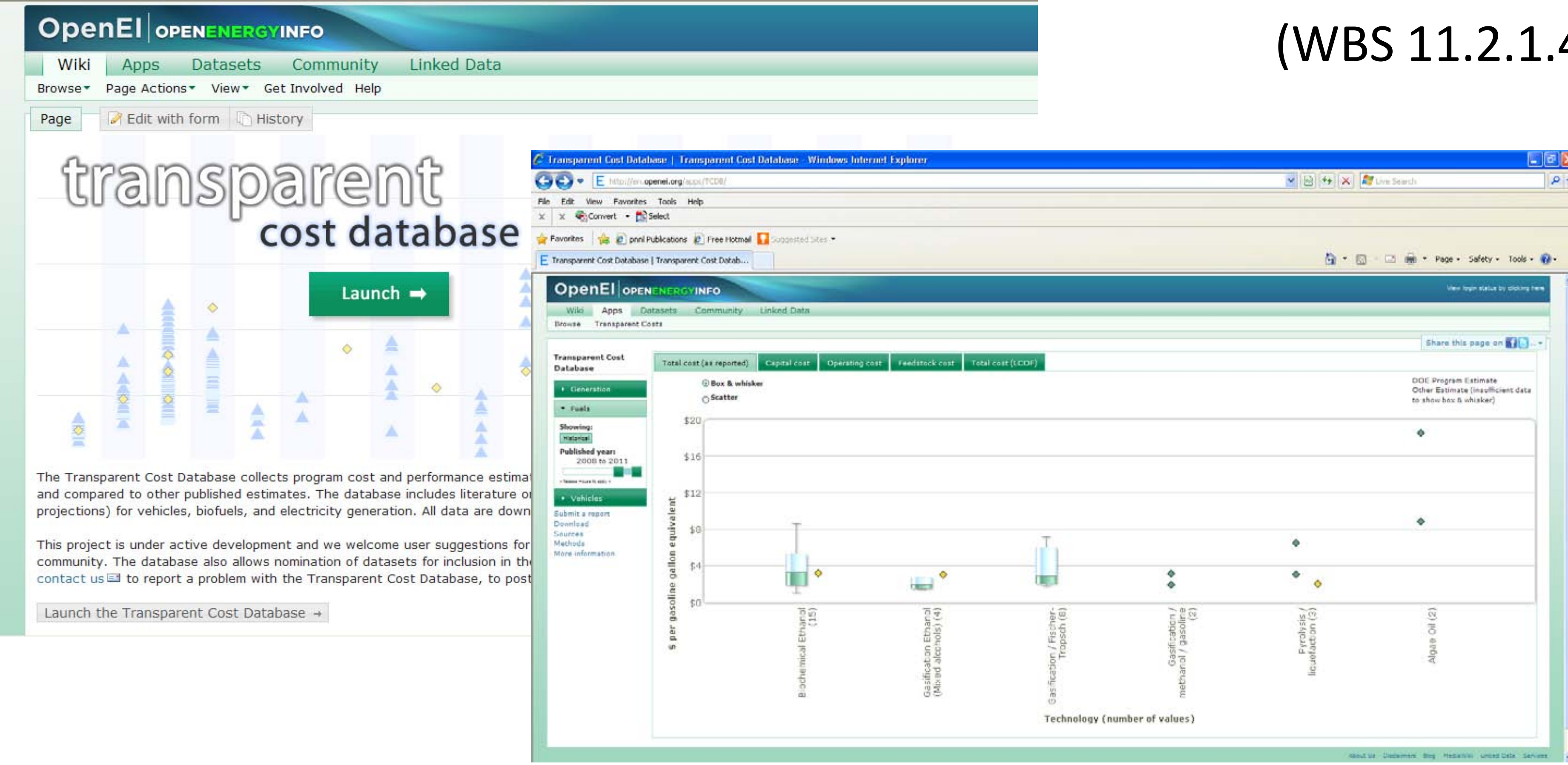




•Data source: EIA

•1/ Commercial trucks from 8,500 to 10,000 pounds.
•2/ Does not include military distillate. Does not include commercial buses. 3/ Does not include passenger rail.

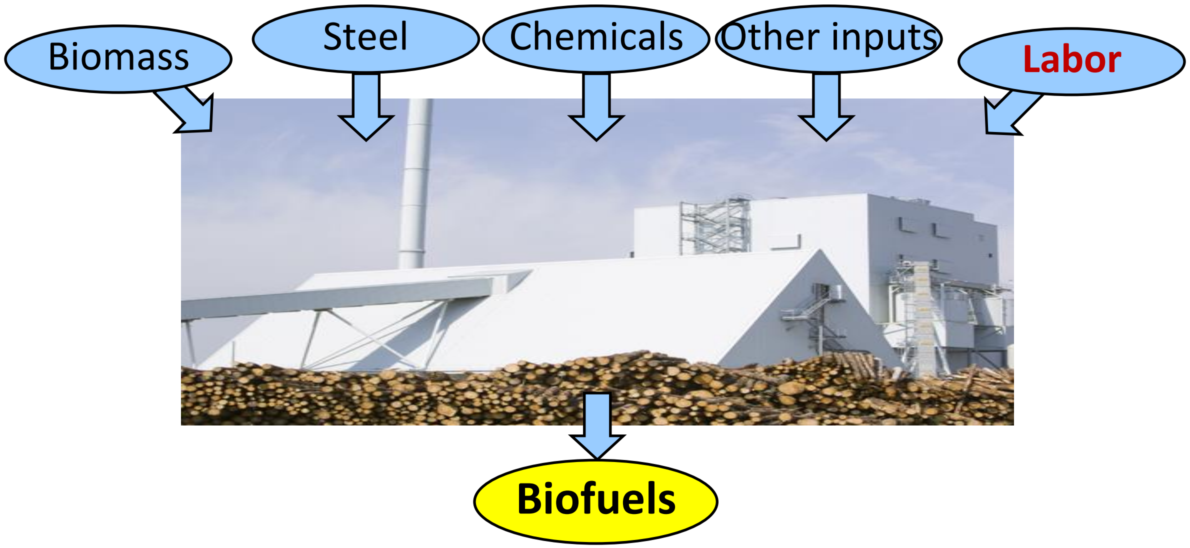
(WBS 11.2.1.4)



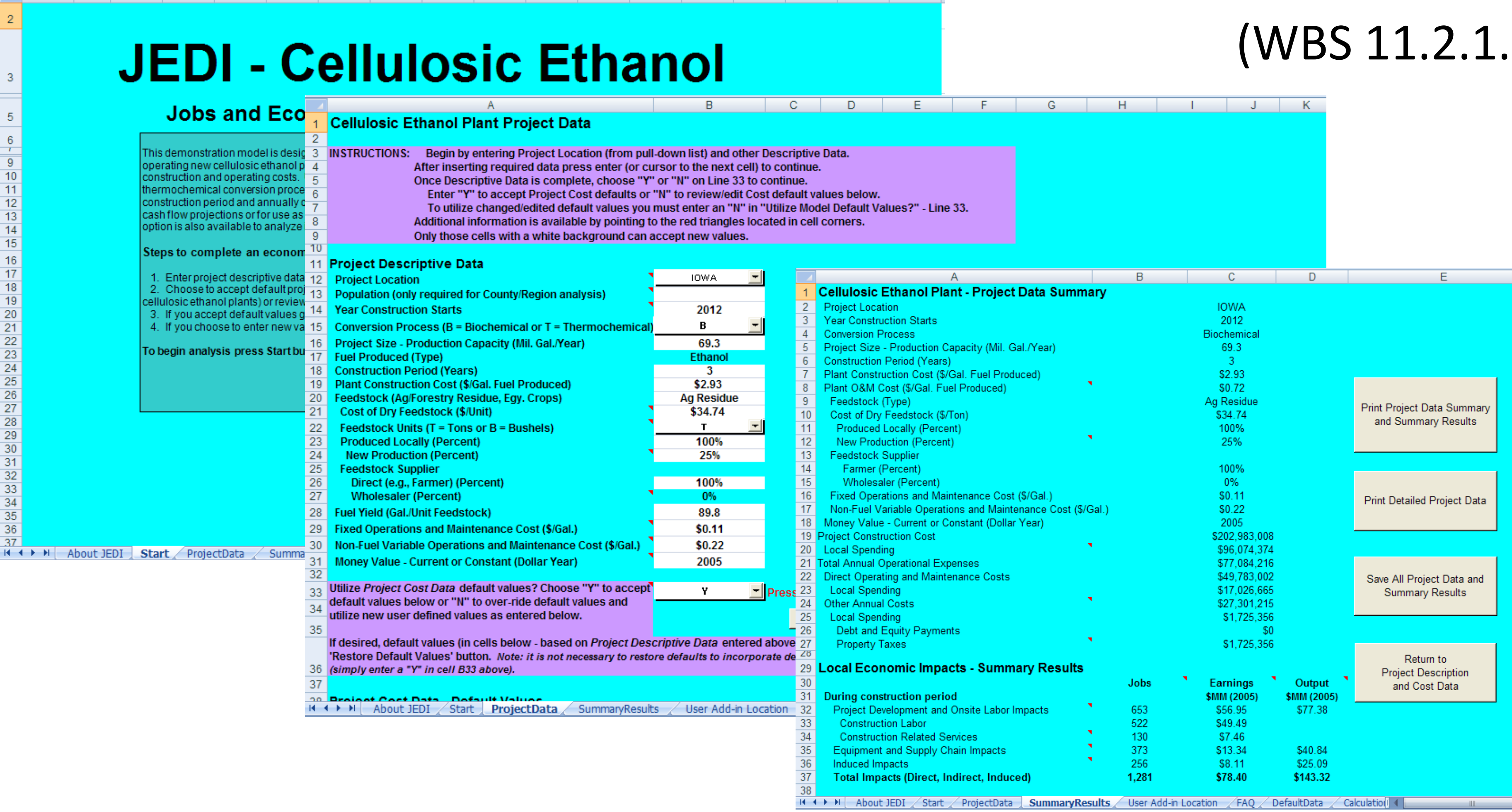
- **Support the Office of Energy Efficiency and Renewable Energy's (EERE) Transparent Cost Database web application:**
  - Collecting cost and performance estimates for EERE technologies in a public forum where they can be viewed and compared to other published estimates
  - Providing support for methodology development and data utilization

Biomass Applications Analysis: *JEDI Approach*
(WBS 11.2.1.3)

- **Development of a suite of Jobs and Economic Development Impact (JEDI) models using input-output analysis to estimate the number of jobs that will accrue to the state/region from a project**
  - Available at http://www.nrel.gov/analysis/jedi/
- **JEDI captures the interconnectedness of the industries, households, and government entities**

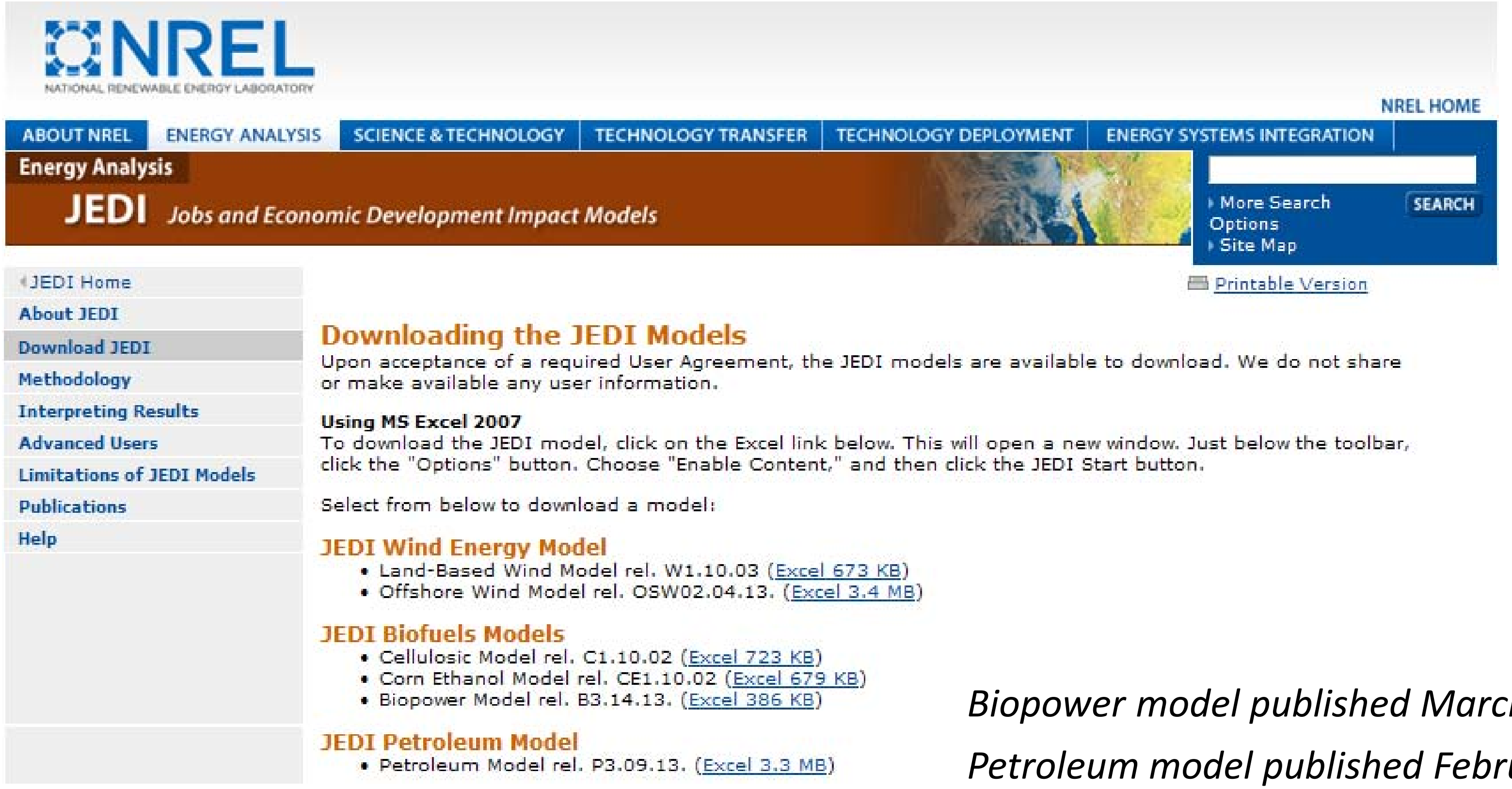


(WBS 11.2.1.3)



- Publicly available Excel-based, user friendly models
- Based on project-specific data, JEDI estimates the number of jobs and economic impacts to a local area supported by the supply chain associated with a power plant, fuel production facility, or other project
- Summarizes interpretation of results and limitations of tool

JEDI Technical Accomplishments (WBS 11.2.1.3)



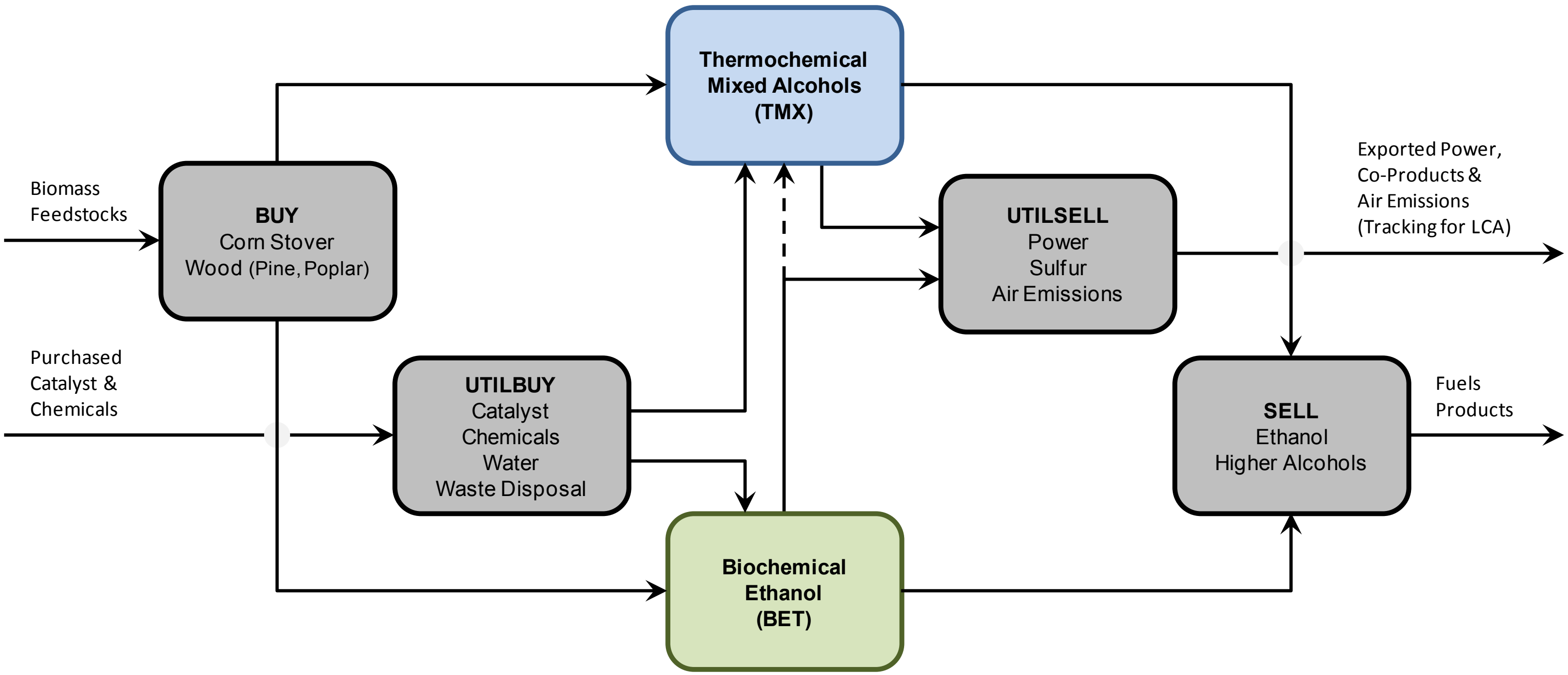
Biopower model published March 2013

Petroleum model published February 2013

- Benchmarked the number of jobs supported by the U.S. corn ethanol industry *(milestone completed March 2012)*
- Enhanced cellulosic ethanol JEDI models for biochemical and thermochemical conversions *(completed October 2012)*
- Estimated potential jobs supported by the development of a domestic cellulosic ethanol industry from 2011 to 2022 *(completed October 2012)*

BIOREFINE LP Modeling: *Approach* (WBS 11.2.1.5)

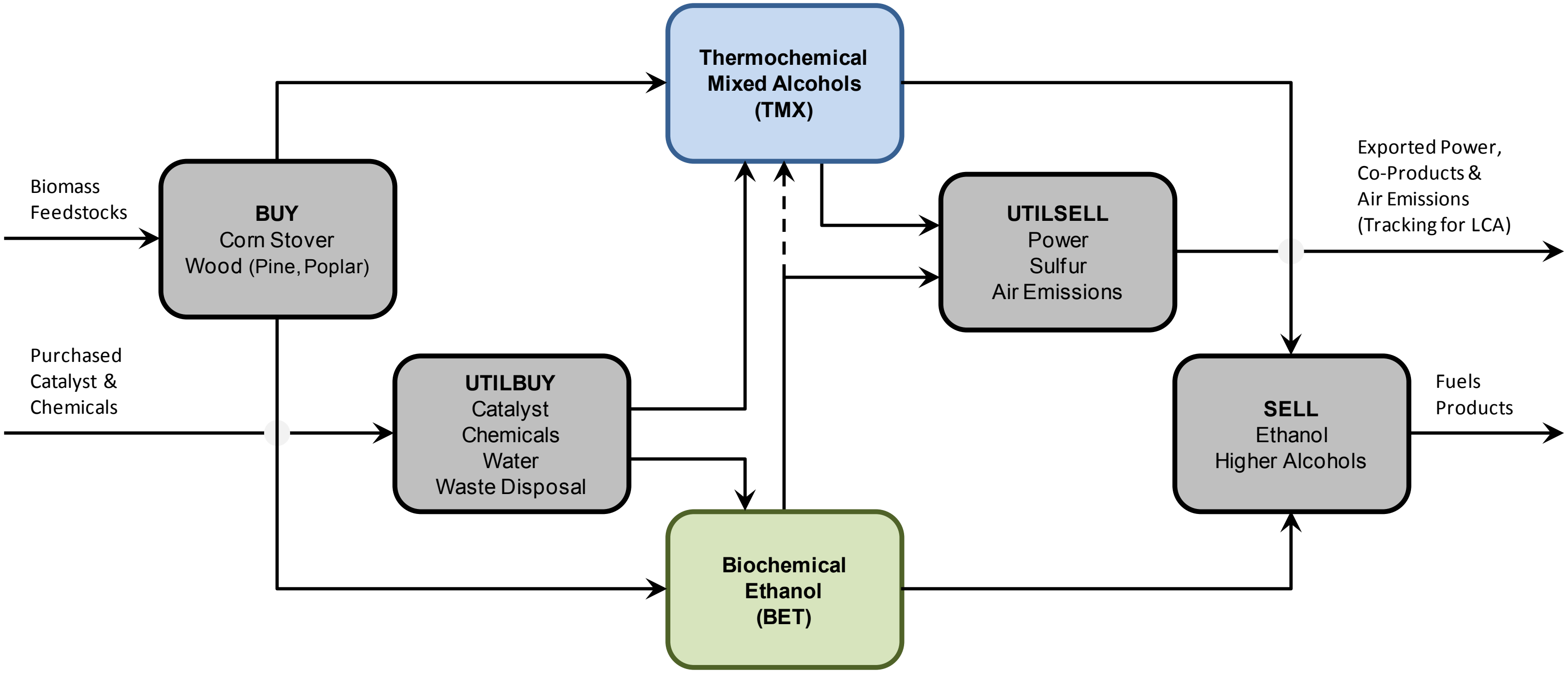
- **Aspen PIMS Platform**
  - **Overall approach is to utilize petroleum refinery linear programming (LP) models as examples to simulate biofuels pathways within complex biorefinery configurations**
  - Solver applies matrix-solving techniques to maximize profit
  - Profit = SELL + UTILSEL – BUY – UTILBUY



BIOREFINE LP: *Technical Accomplishments*

(WBS 11.2.1.5)

- **Technical accomplishments for FY13 include:**
  - Completed successful migration of LP model to Aspen PIMS
  - Demonstrated functioning sub-models for biochemical and thermochemical ethanol cases
  - Validated results of ethanol pathways with NREL design reports
  - Incorporated several advanced biofuels pathways into LP model



Relevance

- **These projects contribute to the strategic goals of the Bioenergy Technologies Office by:**
  - Developing models and methodologies to advance understanding of bioenergy's economic and societal impacts
  - Applying these models to conduct systems-level analyses, which support decision-making at different levels (*e.g.*, policy, industry, and bioenergy projects)
  - Defining and validating performance targets for biomass technologies and systems
  - Providing the analytical basis for Program planning and assessment of progress
  - Communicating results of analyses to various stakeholders (*e.g.*, policy makers, bioenergy technology developers, and investors)

Critical Success Factors

- **Develop detailed analyses of economic costs and benefits, sustainability metrics, and environmental impacts**
    - Models, methodologies, and results are public allowing for transparent and reproducible analysis
    - Document the basis for data, limitations of the tools/models, uncertainties, and methods for interpretation of the results
    - The models take into account the entire supply chain to enable a comparison to other life-cycle environmental metrics
    - JEDI models are a unique tool to evaluate and compare economic and societal benefits resulting from the development of different biofuel and biopower projects
- **Account for the latest information and data on technical status and barriers in order to weigh benefits against costs and risks**
    - Engage key stakeholders, including DOE, industrial collaborators and national lab researchers, in developing and vetting analysis
    - Published in the technology pathways technical memos

Future Work

- **Developing tools and analysis focused on technology pathways to hydrocarbon products**
  - Expand JEDI, LCOE, and BIOREFINE LP portfolios to include new pathways as design reports are developed
  - Track and compare alternative analysis
  - Understand the role of bioproducts in an economically viable and sustainable biorefinery
  - Support researchers by performing the initial feasibility assessment and modeling for novel conversion concepts
- **Planned peer reviewed journal articles and public milestone reports by the end of FY13**
  - Journal article on jobs analysis (JEDI) for the development of a cellulosic ethanol industry
  - Milestone report and journal article on the feasibility of producing and using biomass-based diesel and jet fuel in the US
  - Milestone report on LCOE methodologies documentation
  - Review article on current jet and diesel fuel production pathways

Summary

- **Cross-cutting set of tasks focused on a wide breadth of analysis approaches and methodologies**
- **Developing models and methodologies to advance the understanding of bioenergy's economic/societal impacts**
- **Key deliverables include**
  - Publication of the technology pathways technical memos
  - Support of the EERE Transparent Cost Data Base
  - Release of multiple JEDI models and updates for biofuels and biopower
  - Development of state of the art biorefinery linear programming tools
- **Future work will expand analysis tools focused on hydrocarbon technology pathways**
- **Critical success factor focused on using latest information and high quality data for analysis**
  - Document sources of data, understand uncertainties, and qualify impact of uncertainties

Acknowledgements

- **Thank you to…**
  - Bioenergy Technologies Office:
    - Alicia Lindauer, Kristen Johnson, Zia Haq (Strategic Analysis and Sustainability Platform)
    - Valerie Sarisky-Reed, Dan Fishman, Melissa Klembara, Paul Grabowski, Liz Moore, Leslie Pezzullo, Neil Rossmeissl, Joyce Yang
  - NREL researchers:
    - Adam Bratis, Ryan Davis, Abhijit Dutta, Daniel Inman, Chris Kinchin, Anelia Milbrandt, Steve Phillips, Michael Talmadge, Joan Tarud, Eric Tan, Ling Tao, Wei-Cheng Wang, Yimin Zhang, Andy Aden, Austin Brown, Helena Chum, Mark Davis, Rick Elander, Tom Foust, Philip Pienkos and NREL technology platform researchers
  - PNNL collaborators:
    - Sue Jones, Jonathan Male, Aye Meyer, Corinne Valkenburg, Yunhua Zhu
  - National Laboratory Partners (PNNL, INL, ORNL)
  - Industrial and Academic Partners

Additional Slides

Publications

- Biddy, M.; Dutta, A.; Jones, S.; Meyer, A. 2013. Ex-Situ Catalytic Fast Pyrolysis Technology Pathway 9 pp.; NREL Report No. TP-5100-58050; PNNL-22317.
- Biddy, M.; Davis, R.; Jones, S. 2013. Whole Algae Hydrothermal Liquefaction Technology Pathway. 10 pp.; NREL Report No. TP-5100-58051; PNNL-22314.
- Biddy, M.; Dutta, A.; Jones, S.; Meyer, A. 2013. In-Situ Catalytic Fast Pyrolysis Technology Pathway. 9 pp.; NREL Report No. TP-5100-58056; PNNL-22320.
- Biddy, M.; Jones, S. 2013. Catalytic Upgrading of Sugars to Hydrocarbons Technology Pathway. 9 pp.; NREL Report No. TP-5100-58055; PNNL-22319.
- Davis, R.; Biddy, M.; Jones, S. 2013. Algal Lipid Extraction and Upgrading to Hydrocarbons Technology Pathway. 11 pp.; NREL Report No. TP-5100-58049; PNNL-22315
- Davis, R.; Biddy, M.; Tan, E.; Tao, L.; Jones, S. 2013. Biological Conversion of Sugars to Hydrocarbons Technology Pathway. 14 pp.; NREL Report No. TP-5100-58054; PNNL-22318.
- Talmadge, M.; Biddy, M.; Dutta, A.; Jones, S.; Meyer, A. 2013. Syngas Upgrading to Hydrocarbon Fuels Technology Pathway. 10 pp.; NREL Report No. TP-5100-58052; PNNL-22323.
- Milbrandt, A., Kinchin, C., and McCormick R. 2013. The Feasibility of Producing and Using Biomass-Based Diesel and Jet Fuel in the United States. Technical Report, NREL/TP-6A20-58015 (pending DOE approval).

Publications

- Anex, R.P., Aden, A., Kazi, F.K., Fortman, J., Swanson, R.M., Wright, M.M., Satrio, J.A., Brown, R.C., Daugaard, D.E., Platon, A., Kothandaraman, G., Hsu, D.D., Dutta, A. 2010. Techno-economic comparison of biomass-to-transportation fuels via pyrolysis, gasification, and biochemical pathways. Fuel, 89, S29-S35.
- Kazi, F.K., Fortman, J.A., Anex, R.P., Hsu, D.D., Aden, A., Dutta, A., Kothandaraman, G. 2010. Techno-economic comparison of process technologies for biochemical ethanol production from corn stover. Fuel, 89, S20-S28.
- Kazi, F. K.; Fortman, J.; Anex, R.; Kothandaraman, G.; Hsu, D.; Aden, A.; Dutta, A. (2010). Techno-Economic Analysis of Biochemical Scenarios for Production of Cellulosic Ethanol. 102 pp.; NREL Report No. TP-6A2-46588.
- Wright, M. M.; Satrio, J. A.; Brown, R. C.; Daugaard, D. E.; Hsu, D. D. (2010). Techno-Economic Analysis of Biomass Fast Pyrolysis to Transportation Fuels. 73 pp.; NREL Report No. TP-6A20-46586.
- Swanson, R. M.; Platon, A.; Satrio, J. A.; Brown, R. C.; Hsu, D. D. (2010). Techno-Economic Analysis of Biofuels Production Based on Gasification. 165 pp.; NREL Report No. TP-6A20-46587.