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

Bioenergy Technologies Office Fiscal Year 2014 Annual Report

May 2015

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Table of Contents

Letter from the Director 1

List of Acronyms 2

Introduction 3

Bioenergy Technologies Office Budget Overview 5

Investment Benefits Realized 8

- Workshops 8
- Competitive Funding Opportunities and Awards 9
- Impacts of National Laboratory Research and Development 11
- Biomass 2014 Conference 12
- Project Peer Review Report 13

Key Technology Area Accomplishments 13

- Terrestrial Feedstock Supply and Logistics 14
- Algal Feedstocks 17
- Conversion 19
- Demonstration and Market Transformation 21
- Analysis and Sustainability 24

Progress and Looking Ahead 26

Letter from the Director

Dear stakeholders and colleagues,

It is an exciting time for renewable energy—especially bioenergy! In fiscal year (FY) 2014, the U.S. Department of Energy's Bioenergy Technologies Office (BETO), researchers, the bioenergy industry, and all of our public and private sector partners made substantial progress toward achieving national bioenergy goals and reaching critical technical milestones, including the following:

- Opening a commercial-scale cellulosic ethanol biorefinery
- Reducing feedstock logistics costs
- Increasing algal feedstock yields
- Achieving conversion research and development cost targets for biofuel production.

The *Bioenergy Technologies Office Fiscal Year 2014 Annual Report* reinforces our determination to advance bioenergy technologies, to share and promote our collective scientific knowledge, and to demonstrate the current and future benefits of clean energy.

I am immensely proud of the advancements in the research, development, and production of bioenergy that were made possible by the collaboration among BETO, our national laboratories, universities, industry, federal agencies, and our other stakeholders. I am tremendously grateful for their many years of hard work and dedication to develop sustainable alternatives to oil and other non-renewable energy sources and to make such a positive impact on our energy future—many of these feats came to fruition in FY 2014. The importance of their accomplishments was not just evident to those of us already vested in this field, but to the Administration, investors, the public, and even our critics.

In FY 2014, we made great strides to secure the future of bioenergy research and development through interagency partnerships. With the U.S. Department of Agriculture (USDA) and the Federal Aviation Administration, we will develop a commercially viable aviation biofuel industry through the Farm-to-Fly Initiative. Under the Defense Production Act initiative and our collaboration with USDA and the U.S. Navy, we will produce advanced renewable jet and diesel fuel for our military.

As we look ahead to 2015, we see both opportunities and challenges to the bioeconomy in a changing and volatile energy landscape. I am optimistic, however, that sound, fact-based scientific research, advanced bioenergy technology, federal commitment to clean energy, and public support for energy efficiency and renewable energy will lead us toward an improved and sustainable quality of life for the people of our nation and our world.

Sincerely,

Jonathan Male

Director, Bioenergy Technologies Office
Energy Efficiency and Renewable Energy

List of Acronyms

ANL – Argonne National Laboratory

BETO – Bioenergy Technologies Office

BFNUF – Biomass Feedstock National User Facility

CPC – Computational Pyrolysis Consortium

DOE – U.S. Department of Energy

EERE – Office of Energy Efficiency and Renewable Energy

EISA – Energy Independence and Security Act of 2007

FAA – Federal Aviation Administration

FOA – funding opportunity announcement

FY – fiscal year

GGE – gasoline gallon equivalent

GHG – greenhouse gas

GREET – Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

INL – Idaho National Laboratory

KDF – Knowledge Discovery Framework

LANL – Los Alamos National Laboratory

LBNL – Lawrence Berkeley National Laboratory

NAABB – National Alliance for Advanced Biofuels and Bioproducts

NREL – National Renewable Energy Laboratory

ORNL – Oak Ridge National Laboratory

PNNL – Pacific Northwest National Laboratory

R&D – research and development

RD&D – research, development, and demonstration

RIN – Renewable Identification Number

RFS – Renewable Fuel Standard

SBIR – Small Business Innovation Research

SNL – Sandia National Laboratories

SOT – State of Technology

STTR – Small Business Technology Transfer

SUNY-ESF – The State University of New York College of Environmental Science and Forestry

USDA – United States Department of Agriculture

WATER – Water Assessment for Transportation Energy Resources

Introduction

Growing concerns over climate change, along with the desire to stimulate a new bioenergy economy, the need for the United States to maintain a competitive advantage in renewable technologies, and the development of future generations of green jobs, have continued to fuel the urgency for developing sustainable bioenergy and bioproducts. The potential exists to sustainably produce at least one billion dry tons of domestic, non-food biomass resources by 2030—a sufficient quantity to displace approximately 30% of current U.S. petroleum consumption without impacting food or feed needs.[1]

Biofuels are a major component of the U.S. Department of Energy's (DOE's) multipronged strategy that addresses energy security, transportation-related greenhouse gas (GHG) emissions, and U.S. job growth. The Bioenergy Technologies Office (BETO)—one of the 10 technology development offices within DOE's Office of Energy Efficiency and Renewable Energy (EERE), forms public-private partnerships to help sustainably develop cost-competitive biofuels and bioproducts in the United States from non-food biomass resources and non-recyclable waste streams.

BETO's near-term goals are focused on the conversion of biomass into liquid transportation fuels and on bioproducts and biopower that enable renewable fuels production. Historically, BETO's focus has been on research, development, and demonstration (RD&D) for ethanol production from lignocellulosic biomass. In 2012, BETO successfully demonstrated two biofuel pathways that can produce cellulosic ethanol at a modeled n^{th} plant cost of approximately $2 per gallon—a 77% reduction in cost from an estimated $9.16 (2007 dollars) in 2001.[2] This milestone was accomplished through DOE support of research and development (R&D) at national laboratories, academic institutions, and industry, with bipartisan federal support across two presidential administrations. In 2013, the nation's first cellulosic ethanol biorefinery, the Indian River BioEnergy Center in Vero Beach, Florida, held its grand opening. This was made possible by $50 million in DOE funding and more than $80 million in cost-shared funding provided by the facility's owners, INEOS Bio and New Planet Energy.

Building on previous successes, fiscal year (FY) 2014 was a year of many BETO achievements, including the grand opening of a second commercial-scale cellulosic ethanol biorefinery and significant reductions toward cost goals for RD&D of hydrocarbon fuels. The investments BETO has made in technologies that reduce the recalcitrance of lignocellulosic biomass are now being leveraged toward developing new, advanced drop-in, hydrocarbon biofuels, bioproducts, and biopower that can directly replace products created from the whole barrel of oil. By focusing on biomass-based hydrocarbon fuels, such as renewable gasoline, diesel, and jet fuel, as well as hydrocarbons from algae, BETO seeks to engage the refinery industry in developing solutions, while utilizing existing infrastructure as much as possible.

A minimum profitable fuel selling price of $3 per gallon gasoline equivalent (GGE) can compete on an energy-adjusted basis with gasoline derived from oil costing $75–$90 per barrel.[3] BETO is working to make drop-in hydrocarbon fuels competitive with petroleum-based fuels at a modeled price of mature technology of $3 per GGE (2011 dollars), with a GHG emissions reduction of 50% or more compared to petroleum-derived fuel. To achieve these goals, BETO supports RD&D and market transformation activities on sustainable feedstock supply and logistics systems; cost-competitive conversion processes; and cost-shared scale-up and construction of pilot- and demonstration-scale integrated biorefineries that will reduce the risk of this "first-of-a-kind" technology to enable further private investment critical to scale-up and market penetration. Early market adopters of bioenergy technology, specifically the military and aviation sectors, help to provide a demand for the growing industry, thereby reducing the risk involved in bringing successful research to market. Furthermore, the Energy Independence and Security Act of 2007 (EISA) sets aggressive goals to reduce the nation's dependence on fossil fuels and reduce GHG emissions from the transportation sector by increasing the supply of renewable transportation fuels—including advanced and cellulosic biofuels and biomass-based diesel—to 36 billion gallons per year by 2022.[4] The EISA-legislated national renewable fuel standard (RFS) caps corn starch-derived ethanol at 15 billion gallons, and thus supports a market for 21 billion gallons of advanced biofuels by 2022.

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1. U.S. Department of Energy (2011), *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*, R.D. Perlack and B.J. Stokes (Leads), ORBL/TM-2011/224, Oak Ridge National Laboratory, Oak Ridge, TN. 227p, http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf.

2. BETO (2015), Bioenergy Technologies Office Multi-Year Program Plan March 2015. DOE/EE-1193, http://www.energy.gov/sites/prod/files/2015/03/f20/mypp_beto_march2015.pdf

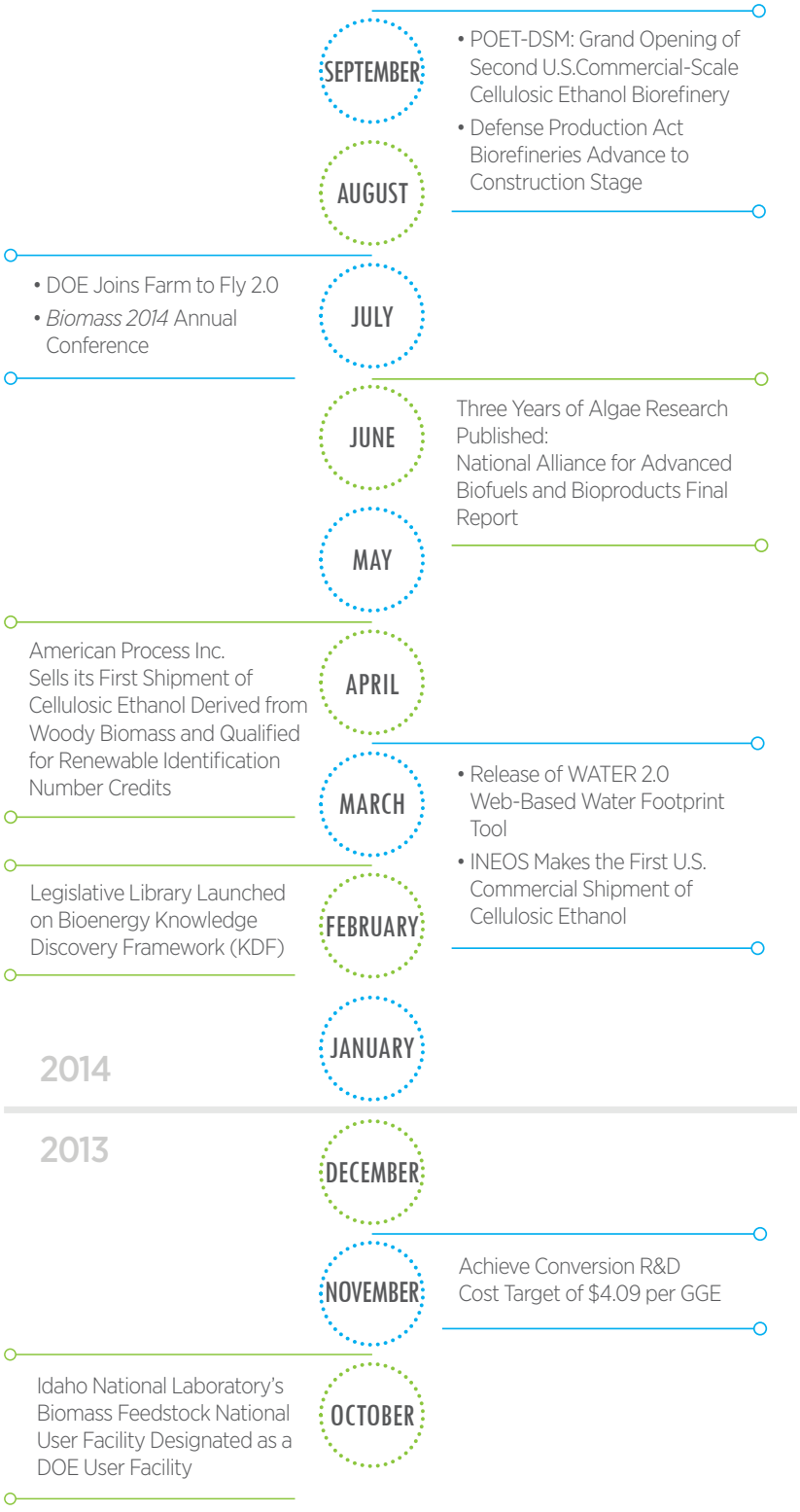
3 BETO (2015), Bioenergy Technologies Office Multi-Year Program Plan March 2015. DOE/EE-1193, http://www.energy.gov/sites/prod/files/2015/03/f20/mypp_beto_march2015.pdf.

4. United States Congress, *Energy Independence and Security Act of 2007* (2007), Washington: Government Printing Office, http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf.

While the RFS is certainly a major driver for the biofuel industry, it is not the only one. A number of states have established grants, tax incentives, and regulations that encourage the use and production of biofuels. For example, California's Low Carbon Fuel Standard, which was established in 2007, requires producers of petroleum-based fuels to reduce the carbon intensity of their products by 10% by 2020 from a 2010 baseline, as measured on a life-cycle basis.[5] Oregon may initiate a similar program in 2015. While the use of biofuels is not mandated by California's Low Carbon Fuel Standard, fuel suppliers may choose this option to comply with the standard.

Expanding the production and use of affordable biofuels offers the opportunity to diversify the fuel mix and increase economic security, as significant amounts of sustainable, domestically produced feedstocks are directed to the production of renewable energy. In addition, the environmental and social benefits of biofuels include reductions in GHG emissions and increased economic activity across the entire supply chain. From new jobs in the farms and forests of rural America to growing U.S. construction and manufacturing jobs in the production of biofuels, bioproducts, and biopower, investing in new technologies maintains national competitive advantage and enables jobs in the renewable energy sector for future generations.

To deliver the broad benefits of advanced biofuels, BETO works to understand all critical linkages along the supply chain, explores new approaches, and helps guide technology development along the most promising pathways to a robust and sustainable domestic bioeconomy. *The Bioenergy Technologies Office Fiscal Year 2014 Annual Report* reviews BETO's FY 2014 activities and highlights RD&D accomplishments realized through collaborations with public and private partners along the pathway toward achieving a goal of a mature, modeled price of $3 per GGE advanced biofuel.



[5] California Energy Commission, Low Carbon Fuel Standard, http://www.energy.ca.gov/low_carbon_fuel_standard/

Bioenergy Technologies Office Budget Overview

BETO puts U.S. taxpayer funding to work by bringing together the nation's best capabilities and utilizing a coordinated RD&D approach for developing the bioindustries of tomorrow. This section provides an overview of BETO's historical budget allocations and shows how its FY 2014 funding was implemented across technology areas and activities.

Between 2010 and 2014, BETO's annual budget varied between a low of $182.7 million in 2011 to a high of $232.4 million in 2014. Within BETO, funding is allocated to its technology areas. These technology areas have evolved over time, reflecting BETO's changing RD&D priorities. For example, BETO's algae R&D efforts were originally split between Algal Feedstocks and Algae Conversion, but starting in 2011, these initiatives were consolidated into the Algal Feedstocks technology area. Other changes include the establishment of the Analysis and Sustainability technology area that same year.

In 2014, BETO began supporting National Renewable Energy Laboratory (NREL) facilities and infrastructure operating needs through direct funding for basic NREL site services, functions, and infrastructure for site operations (NREL Site-Wide Facilities). BETO's contribution to direct funding for site-wide facility support is equivalent to the estimated contribution the office otherwise would have made through overhead charges.

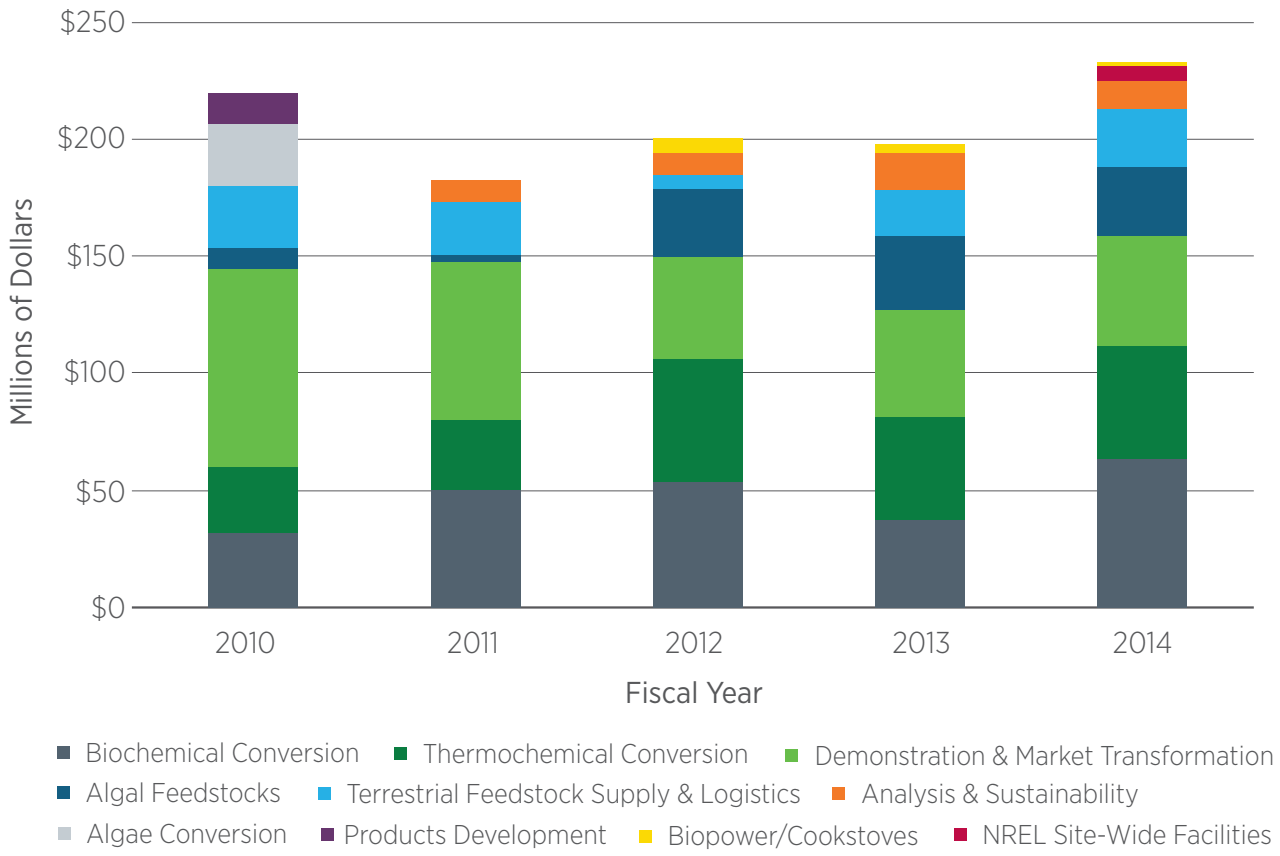


Figure 1. Chart illustrating BETO's annual budget allocations by technology area from 2010–2014

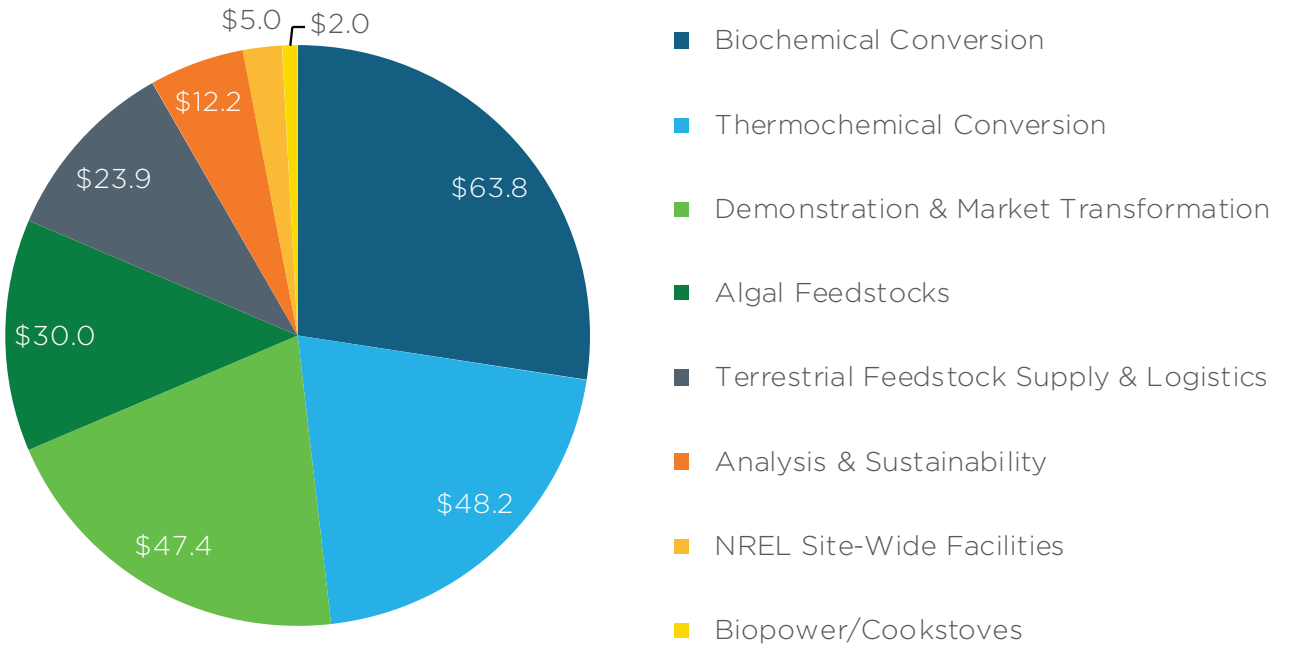


Figure 2. Chart illustrating BETO's FY 2014 distribution of funding by technology area (in millions)

BETO's technology areas fund RD&D projects conducted by DOE's national laboratories, for-profit organizations, non-profit organizations (including educational institutions), government agencies, and other entities. In addition, BETO funding is also allocated to various operational expenses and outreach activities. (Administrative costs, such as staff salaries, are not included, as they are funded through other DOE sources.) Figure 3 presents an overview of BETO's 2014 funding by activity type, which provides some context for understanding how the office's technology areas spend their designated funds.

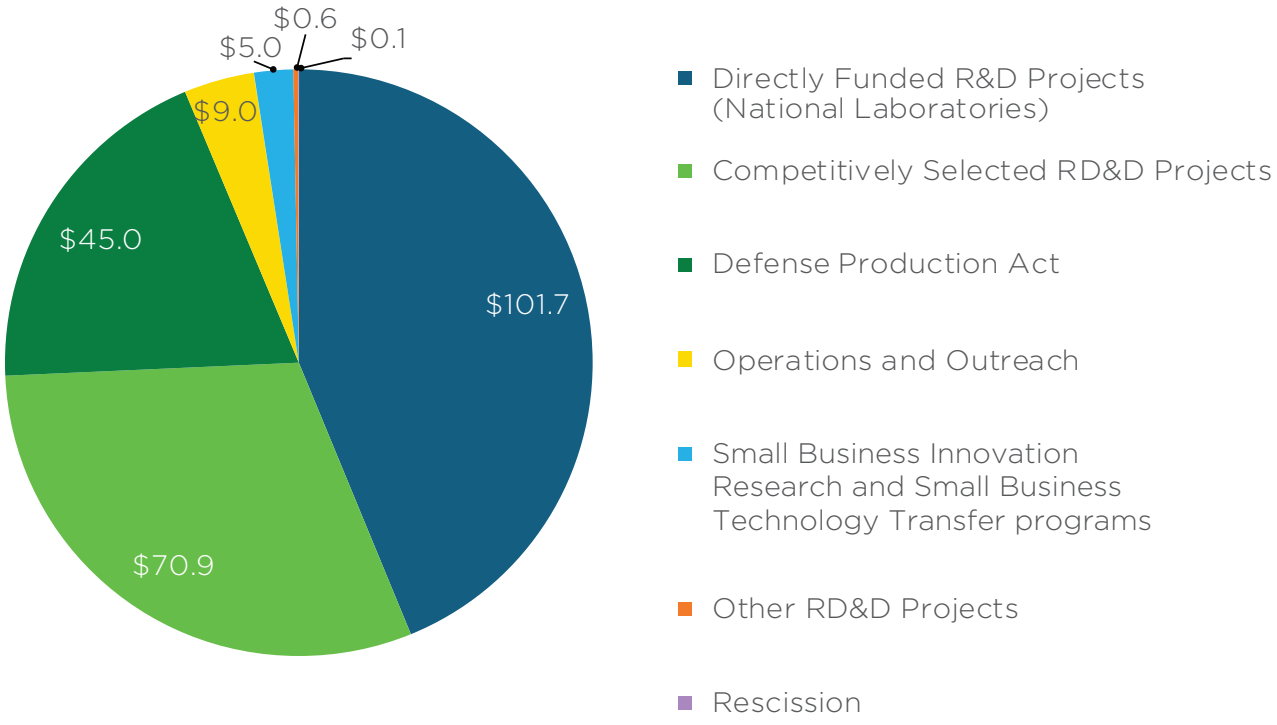


Figure 3. Chart illustrating BETO's FY 2014 distribution of funding by activity type (in millions)

BETO employs several funding mechanisms to support bioenergy RD&D activities, including the following:

- **Direct funding** is provided to DOE's national laboratories to conduct specific R&D projects to further BETO goals. BETO and EERE have a commitment to long-term stewardship of laboratory core capabilities to enable meaningful collaborations and accomplishments. Therefore, BETO regularly funds projects at Argonne National Laboratory (ANL), Idaho National Laboratory (INL), Lawrence Berkeley National Laboratory (LBNL), Los Alamos National Laboratory (LANL), NREL, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL). In FY 2014, 44% of BETO's budget was used for direct funding of national laboratory projects.
- **Competitive funding** for RD&D projects can be awarded to private companies, academic institutions, national laboratories, and other entities, as defined in the specific funding opportunity announcement (FOA). When BETO issues a FOA, applicants apply for assistance, and applications are reviewed on their technical merits. After applicants are selected to receive funding, BETO negotiates and issues a funding award, which includes a cost-share requirement. In FY 2014, 30% of BETO's budget was designated for competitively selected RD&D projects. See pages 9–10 for details about competitive funding opportunities that were published and projects that were selected for awards in FY 2014.
- **Other RD&D projects** are supported through the following additional funding mechanisms:
  - Interagency agreements are established to fund other federal agencies to conduct work on behalf of BETO. Coordination with other government offices involved in bioenergy development is essential to avoid duplication, leverage limited resources, optimize federal investment, ensure a consistent message to stakeholders, and meet national energy goals. BETO managed interagency agreements with the U.S. Forest Service and the International Energy Agency in 2014.
  - Congressionally Directed Projects are projects for which Congress has specifically allocated funds. Projects funded in this manner are reviewed for technical merit, awarded funds using Determination of Non-competitive Financial Assistance processes, and are subjected to active project management within BETO's overall program.
- **Defense Production Act** funding ($45 million) was authorized by Congress for FY 2014 to support the memorandum of understanding between the U.S. Departments of Energy, Navy, and Agriculture to pursue the production of biofuels for defense purposes. See page 23 for details about the biorefinery projects that were awarded in 2014.
- **Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)** are U.S. government programs in which federal agencies with large R&D budgets, including DOE, set aside a small fraction of their funding for competitions among small businesses only. In FY 2014, 2.1% of BETO's budget was set aside to support DOE's SBIR/STTR programs. See pages 17 and 20 for specific achievements.

Beyond support for RD&D work, BETO's annual funding is also directed to activities that enable general program operations, education, and outreach. **Operations and Outreach** funding supports the following types of activities:

- BETO contributes to EERE crosscutting initiatives, including the Clean Energy Manufacturing Initiative, which brings together a wide array of relevant EERE and DOE offices, federal agencies, research institutions, and private sector partners to map out and implement a strategy to ensure that U.S. manufacturers are competitive in the global marketplace.
- BETO sponsors bioenergy-related conferences as a means of fostering stakeholder engagement. Event sponsorship generally involves the display of a BETO information booth, which is staffed by a representative who educates attendees about BETO's work. In FY 2014, BETO co-sponsored 10 events with a combined total of nearly 7,000 attendees.
- BETO funds fellowships through the Association for the Advancement of Science and the Oak Ridge Institute for Science and Education. This enables individuals who have recently completed their doctoral studies to contribute to BETO's work through short-term fellowship positions.
- Other operations and outreach activities include BETO's annual conference, the merit review process for competitive funding applications, and contractor support, among others.

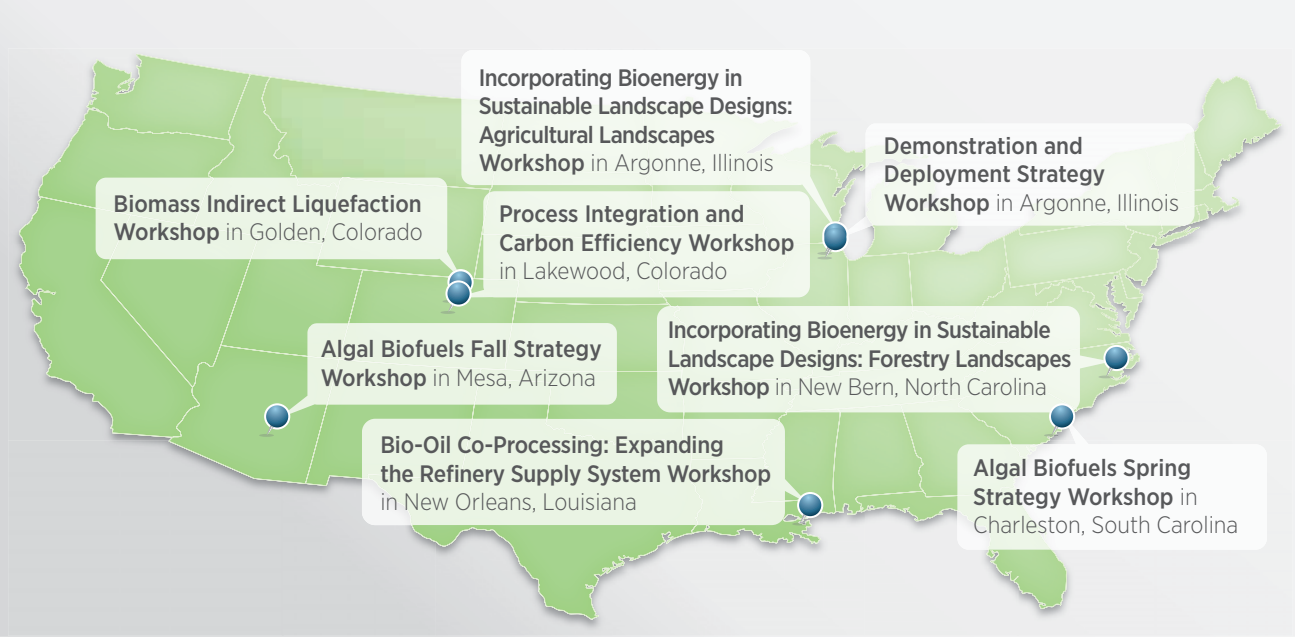
Rescissions are also included in this budget summary. Rescission is legislative action that permanently cancels new budget authority or the availability of unobligated balances of budget authority before the authority would have automatically expired. Budget authority proposed for rescission must be held in DOE reserves pending a decision on the proposed rescission. In FY 2014, $138,650 was removed from the BETO budget for rescissions.

Investment Benefits Realized

Workshops

To overcome R&D challenges and barriers to the commercial viability of biofuels, the bioenergy industry needs significant resources and investments. BETO holds stakeholder workshops to understand what the challenges are and what is needed to overcome them. These workshops are valuable tools that enable BETO to better understand the specific technological challenges the bioenergy industry faces and how to best prioritize activities to overcome key barriers. Throughout FY 2014, BETO held eight workshops across the country to gather stakeholder input on various bioenergy topics.

- **Algal Biofuels Fall Strategy Workshop** (November 19–20, 2013; Mesa, Arizona): The first of two algal biofuels strategy workshops addressed the R&D needed to achieve affordable, scalable, and sustainable algae-based biofuels. The workshop provided a forum to discuss, reassess, and reprioritize technical R&D needs in light of the progress made across the industry in the five years since DOE organized the National Algal Biofuel Technology Roadmap Workshop. The fall workshop convened university, national laboratory, industry, advocacy, and government stakeholders to consider algal biofuel research priorities and current barriers to commercialization. The second workshop was held in March 2014 in South Carolina.
- **Incorporating Bioenergy in Sustainable Landscape Designs: Forestry Landscapes Workshop** (March 4–6, 2014; New Bern, North Carolina): BETO hosted this workshop in collaboration with ORNL, ANL, and the National Council for Air and Stream Improvement, Inc. The workshop convened interdisciplinary experts to explore the current state of the science, research needs, tools, and methodologies for implementing landscape designs for bioenergy systems across the supply chain and across sustainability metrics. Participants learned how a landscape design approach might focus on bioenergy production systems and how it could be integrated with other components of the land, environment, and socioeconomic system. The March workshop focused on forestry landscapes and began with a field trip that highlighted forestry activities in eastern North Carolina. A second workshop, focusing on agricultural landscapes, was held in June 2014 in Illinois.
- **Demonstration and Deployment Strategy Workshop** (March 12–13, 2014; Argonne, Illinois): The workshop brought together a broad spectrum of experts from industry, academia, national laboratories, and government to discuss the technical and economic barriers impeding the demonstration and deployment of technologies for the commercial production of drop-in hydrocarbon fuels and products. The wealth of information generated at the workshop will inform BETO's strategic planning and prioritization efforts. Workshop participants identified key barriers, as well as activities to address those barriers.



- **Biomass Indirect Liquefaction Workshop** (March 20–21, 2014; Golden, Colorado): The workshop focused on discussing and detailing the R&D needs for biomass indirect liquefaction. Discussions focused on full indirect liquefaction pathways, including feeder systems through fuel finishing. Attendees included representatives from government, national laboratories, academia, and industry.
- **Algal Biofuels Spring Strategy Workshop** (March 26–27, 2014; Charleston, South Carolina): The second of two algal biofuels strategy workshops convened stakeholders to discuss 5–10–year strategies to achieve affordable, scalable, and sustainable algal biofuels. Approximately 125 university, national laboratory, industry, advocacy, and government stakeholders participated in the event.
- **Bio-Oil Co-Processing: Expanding the Refinery Supply System Workshop** (April 3, 2014; New Orleans, Louisiana): The workshop explored the resource expansion potential for conventional refineries by considering biomass-derived oils as a supplemental feedstock. BETO sought to identify the next steps in gathering information about the physiochemical properties, reactivities, and compatibilities of intermediates to petroleum refineries. Understanding and specifying bio-oil intermediate requirements for use in petroleum refineries and the limitations of the distribution infrastructure is critical. The workshop brought together university, national laboratory, industry, advocacy, government, and other stakeholders from both the renewable energy and petroleum refining industries to discuss the potential for bio-oil co-processing, the challenges currently facing the refining industry, and the advantages that could be realized in a co-processing partnership.
- **Process Integration and Carbon Efficiency Workshop** (June 11–12, 2014; Lakewood, Colorado): The workshop explored advances in biological and chemical conversion of lignocellulosic feedstocks to biofuels and bioproducts. BETO collected information from key industry, university, and national laboratory stakeholders regarding the critical R&D needs for various processes. These processes included the breakdown of biomass to usable intermediates, upgrading of intermediates to fuels and chemicals, separations technologies, and process integration.
- **Incorporating Bioenergy in Sustainable Landscape Designs: Agricultural Landscapes Workshop** (June 24–26, 2014, Argonne, Illinois): BETO hosted an agriculture-focused workshop to assess the state of the science, current research needs, tools, and methodologies for deploying landscape design for bioenergy systems. This workshop assembled experts to discuss principles for landscape design, how landscape design can assist in the deployment and assessment of sustainable bioenergy, and how to move forward in a manner that best serves industry, decision makers, and producers, while achieving environmental goals.

Competitive Funding Opportunities and Awards

BETO supports the advancement of bioenergy technologies by offering financial assistance for RD&D. BETO publishes FOAs through which the public may submit applications for funding. Applicants that submit high-value proposals are selected to negotiate an award with EERE. In FY 2014, BETO announced three funding opportunities totaling up to $45 million and selected five projects from across the bioenergy supply chain to receive up to $20.8 million in total cost-shared funding.

Funding Opportunity Announcements

- **Bioenergy Technologies Incubator** (published February 25, 2014): BETO announced up to $10 million to support innovative technologies and solutions that could help achieve bioenergy development goals but that are not significantly represented in its existing multi-year program plans or current R&D portfolio. BETO intends to issue seven awards to reduce the risk associated with these potential breakthrough approaches and technologies to facilitate their inclusion in future BETO roadmaps.
- **Biological and Chemical Upgrading for Advanced Biofuels and Products** (published April 15, 2014): BETO announced up to $10 million to advance the production of advanced biofuels, substitutes for petroleum-based feedstocks, and bioproducts made from renewable, non-food-based biomass, such as agricultural residues and woody biomass. This supports BETO's efforts to make drop-in biofuels more accessible and affordable, as well as meet the cost target equivalent of $3 per GGE by 2022.
- **Targeted Algal Biofuels and Bioproducts** (published September 30, 2014): BETO announced up to $25 million in funding to reduce the cost of algal biofuels to less than $5 per GGE by 2019. This funding supports the development of a bioeconomy that can help create green jobs, spur innovation, improve the environment, and achieve national energy security. Algae biomass can be converted into advanced biofuels that offer promising alternatives to petroleum-based diesel and jet fuels. Additionally, algae can be used to make a range of other valuable bioproducts, such as industrial chemicals, bio-based polymers, and proteins. However, barriers related to

algae cultivation, harvesting, and conversion to fuels and products need to be overcome to achieve BETO's target of $3 per GGE for advanced algal biofuels by 2030. To accomplish this goal, BETO is investing in applied R&D technologies that achieve higher biomass yields and overall values for the algae.

Projects Selected for Funding

- **Carbon, Hydrogen and Separation Efficiencies in Bio-Oil Pathways** (selections announced July 15, 2014): Two R&D projects located in California and North Carolina were selected to receive up to $6 million to develop next-generation biofuels that will help drive down the cost of producing gasoline, diesel, and jet fuels from biomass. The projects will focus on lowering production costs by maximizing the renewable carbon and hydrogen from biomass that can be converted into fuels and improving the separation processes in bio-oil production to remove non-fuel components. These projects are a part of DOE's continued effort to develop technologies that enable the production of clean, renewable, and cost-competitive drop-in biofuels.
  - SRI International of Menlo Park, California, will receive up to $3.2 million to produce a bio-crude oil from algal biomass that will maximize the amount of renewable carbon recovered for use in fuel and reduce the nitrogen content of the product in order to meet fuel quality standards.
  - Research Triangle Institute of Research Triangle Park, North Carolina, will receive up to $3.1 million to maximize biomass carbon and energy recovery in a low-pressure process, thereby lowering production costs to produce a bio-crude oil that can be efficiently upgraded to a finished biofuel.
- **Advancement of Algal Biomass Yield** (selection announced July 17, 2014): Cellana, LLC, of Kailua-Kona, Hawaii, was selected to receive up to $3.5 million to develop a fully integrated, high-yield algae feedstock production system by integrating the most advanced strain improvement, cultivation, and processing technologies into operations at their Kona Demonstration Facility. This research project supports BETO's goal of producing 2,500 gallons of algal biofuel feedstock per acre per year by 2018, an important milestone toward reducing the cost of algal biofuels to cost-competitive levels of 5,000 gallons per acre per year by 2022.
- **Renewable Carbon Fiber** (funding opportunity announced February 4, 2014; selections announced July 30, 2014): Two projects, located in Alabama and Colorado, were selected to receive up to $11.3 million to advance the production of cost-competitive, high-performance carbon fiber material from renewable, non-food-based feedstocks, such as agricultural residues and woody biomass. Carbon fiber—a strong, lightweight material that can replace steel and other heavier metals—can lower the cost and improve the performance of fuel-efficient vehicles and renewable energy components such as wind turbine blades. The two projects seek to demonstrate new biomass conversion technologies that enable the manufacturing of acrylonitrile—an essential feedstock for high-performance carbon fiber—for less than $1 per pound.
  - Southern Research Institute of Birmingham, Alabama, will receive up to $5.9 million to innovate on a multi-step catalytic process for conversion of sugars from non-food biomass to acrylonitrile.
  - NREL of Golden, Colorado, will receive up to $5.3 million to investigate and optimize multiple pathways to bio-acrylonitrile.

The selectees for the Renewable Carbon Fiber FOA, announced at the *Biomass 2014* conference, are pictured here with BETO Conversion Program Manager Kevin Craig (third from left) and EERE Deputy Assistant Secretary for Transportation Reuben Sarkar (far right).

This funding supports DOE's Clean Energy Manufacturing Initiative, a crosscutting effort to ensure that U.S. manufacturers remain competitive in the global marketplace.

Impacts of National Laboratory Research and Development

DOE's national laboratories are at the core of BETO's R&D work. In FY 2014, nearly half of BETO's budget funded R&D projects at the national laboratories. These projects have led to key findings and technology breakthroughs, as evidenced by the resulting publications and patents. To achieve an even more significant industrial impact, BETO has placed renewed emphasis on bringing technology to market through targeted activities within the office's R&D portfolio.

Publications

In FY 2014, BETO-supported bioenergy R&D work at the national laboratories resulted in a total of 137 peer-reviewed publications appearing in scientific journals and collections of research. National laboratory partners developed 16 additional reports that did not appear in peer-reviewed journals, but were made available to the greater scientific community via laboratory websites, books, and other communication channels. These published works made innovative research findings more accessible to a larger stakeholder community and expanded the collective knowledge that enables researchers and industry to apply new technology in the field.

Patents

BETO is also tracking several key technology transfer metrics and outcomes within the DOE national laboratory portfolio. In FY 2014, BETO-supported national laboratories conducted activities with more than 110 industrial partners, were granted 15 patents, and filed and/or have pending 27 patent applications. Similar metrics are also being collected for prior fiscal years so that investment trends and technology transfer outcomes can be analyzed to enable active portfolio management.

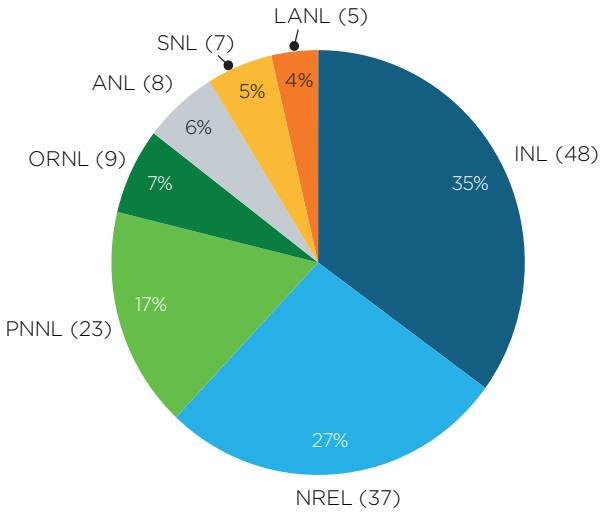


Figure 4. Chart illustrating FY 2014 national laboratory peer-reviewed publications resulting from BETO-funded research

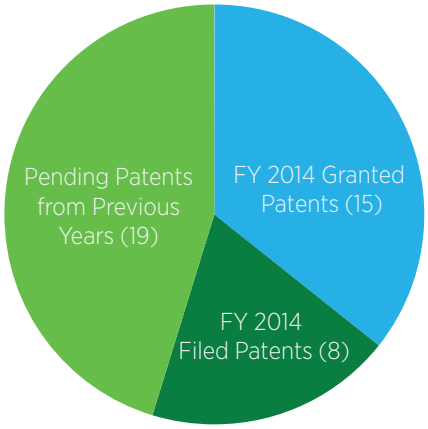


Figure 5. Chart illustrating FY 2014 national laboratory patent activity resulting from BETO-funded research

> What we're all in the business of doing is innovation. What innovation does is it expands what's possible. It takes you from a reality of today to a future that then becomes conventional wisdom.
>
> Jennifer Holmgren, CEO of LanzaTech, at *Biomass 2014*

Biomass 2014 Conference

On July 29–30, 2014, BETO held its seventh annual conference—*Biomass 2014: Growing the Future Bioeconomy*. Co-hosted by Advanced Biofuels USA, the event took place at the Walter E. Washington Convention Center in Washington, D.C., and brought together top government officials, members of Congress, industry leaders, and experts from across the bioenergy supply chain. Conference participants focused on the innovative technologies, priority pathways, financing strategies, and public policies needed to grow the future bioeconomy.

Biomass 2014 was the stage for the premiere of BETO's film, *Bioenergy: America's Energy Future*. This 15-minute documentary film, available online in full length and in a 3-minute version, tells the story of innovators across the United States helping to drive the bioenergy industry forward. This outreach product supports media initiatives to expand the public's understanding of the bioenergy industry and sustainable transportation.

Also at *Biomass 2014,* DOE's Assistant Secretary for Energy Efficiency and Renewable Energy David Danielson announced BETO's participation in Farm to Fly 2.0 (see page 23), and EERE's Deputy Assistant Secretary for Transportation Reuben Sarkar announced up to $11.3 million for two projects to develop renewable carbon fiber to lower the cost of fuel-efficient vehicles (see page 10).

BETO invited the winning team of the Imagine Tomorrow student competition—from STEM High School in Redmond, Washington—to present its project "Cellulosic Ethanol: A New Look at the Transition to Renewable Energy." Imagine Tomorrow, a competition hosted by Washington State University, brings together high school teams from across Washington, Oregon, Idaho, and Montana to develop creative, well-researched solutions to complex energy challenges, including bioenergy. The team's winning idea aligns with BETO's mission to help the nation transition to renewable forms of energy using cellulosic ethanol.

BETO Director Jonathan Male speaks at *Biomass 2014*.

BETO announced that to better align with its name and vision, the title of the 2015 conference will be *Bioenergy 2015*.

Biomass 2014 At A Glance:

- 580 attendees from across the country and bioenergy supply chain
- Notable speakers included the following:
  - Kate Brandt, White House Federal Environmental Executive
  - Nate Brown, Alternative Fuels Manager, Federal Aviation Administration
  - Captain James Goudreau, U.S. Navy
  - Jennifer Holmgren, CEO, LanzaTech
  - Deputy Director Byron Paez, U.S. Navy
  - Senator Debbie Stabenow (D-MI)
  - Paul Woods, CEO, Algenol Biofuels
  - Catherine Woteki, USDA Chief Scientist and Under Secretary for Research, Education, and Economics

Project Peer Review Report

In the spring and summer of 2013, BETO implemented a comprehensive external review of its RD&D project portfolio. The 2013 Project Peer Review was held May 20–24, 2013, in Alexandria, Virginia, and was followed by the higher-level Program Management Review on July 30, 2013, in Washington, D.C. The comprehensive summary report detailing findings from BETO's 2013 Project Peer Review and Program Management Review was published in February 2014.

The reviews were conducted in accordance with the EERE peer review guidelines and were 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; to enhance active project management; and to modify, expand, or discontinue existing projects.

Key Technology Area Accomplishments

BETO accomplishes its mission to develop and transform renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through the combined work of five technology areas. Each technology area plays a vital role in accomplishing BETO goals and helping to reach the $3 per GGE cost goal for advanced hydrocarbon biofuels.

The first four technology areas follow the bioenergy supply chain: Terrestrial Feedstock Supply and Logistics, Algal Feedstocks, Conversion, and Demonstration and Market Transformation. These technology areas focus on addressing technical barriers to bioenergy commercialization, providing engineering solutions, and developing the scientific and engineering underpinnings of the emerging biofuels, bioproducts, and biopower industries. The last technology area, Analysis and Sustainability, includes crosscutting programs that interface with BETO's RD&D efforts.

Demonstration and Market Transformation was called "Integrated Biorefineries" during FY 2014; however, this report uses its new title, Demonstration and Market Transformation, which emphasizes BETO's focus on technology transfer to the marketplace.

The following pages present major FY 2014 accomplishments for each of these technology areas and describe how together they are helping BETO support an advanced biofuels and bioproducts industry that can reduce U.S. dependence on foreign oil, decrease GHG emissions, and drive economic growth.

Terrestrial Feedstock Supply and Logistics

The Terrestrial Feedstock Supply and Logistics technology area develops technologies to provide a sustainable, secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry, in partnership with the U.S. Department of Agriculture (USDA) and other key stakeholders. "Biomass" is defined as the raw, field-run material obtained at the site of production (e.g., field, forest, or pond), and "feedstock" denotes biomass materials that have undergone preprocessing, such as drying, milling, or chopping before being transported to the biorefinery for conversion to biofuel. Feedstocks are essential to achieving BETO's goals, as the quantity of biofuel that can be produced is directly dependent on the amount of accessible feedstock, which is determined by the cost, quality, and volume of feedstocks at any given time.

The Terrestrial Feedstock Supply and Logistics technology area focuses on reducing the cost, improving the quality, and expanding the volume of sustainably

produced feedstocks. BETO identifies efficient and economic systems for harvest, collection, and storage of biomass (as well as handling and preprocessing), and then develops, demonstrates, and validates these systems so that they can be used by industry.

FY 2014 Accomplishments

Five High-Tonnage Feedstock Logistics Projects Demonstrate Significant Cost Reductions

In FY 2014, five BETO-funded projects directed at lowering the cost of collecting, storing, and transporting cellulosic feedstocks were completed. These projects were awarded $21 million in 2010 as part of BETO's $80 per dry ton goal for sustainable feedstock and logistics costs. Each project has led to unique and innovative biomass harvesting technologies that save labor and machine costs in the biomass supply chain—as much as 34% cost reductions from the conventional systems—while also reducing GHG emissions from harvesting and logistics operations, soil compaction, and the potential for soil contamination of harvested biomass. Some of these technologies are already commercially available.

FDC Enterprises' self- loading/unloading trailer, developed with BETO funding in partnership with Kelderman Manufacturing, can pick up a stack of 36 corn stover bales in 5 minutes. Photo courtesy of Kelderman Manufacturing/Antares Group.

Cost Reductions

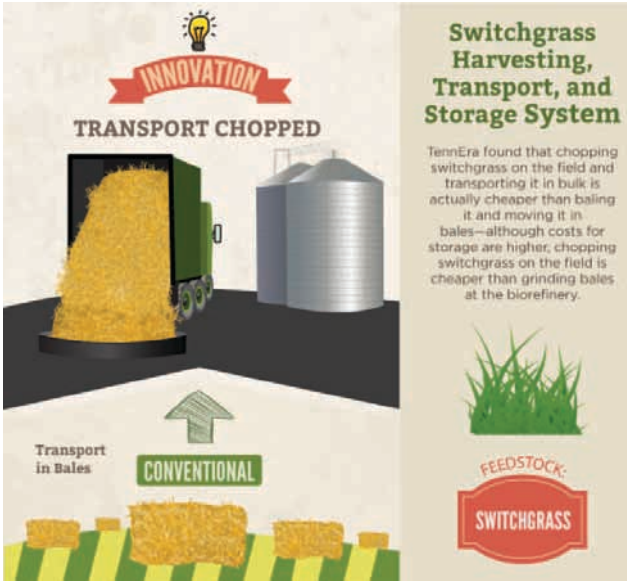
- **AGCO Corporation—**29% cost reduction (from $51.54 per dry ton to as low as $36.75 per dry ton) for corn stover
- **FDC Enterprises—**25% cost reduction (from $50.78 per dry ton to as low as $37.89 per dry ton) for corn stover
- **TennEra LLC—**7% cost reduction (from $56.38 per dry ton to $52.34 per dry ton) for switchgrass
- **The State University of New York College of Environmental Science and Forestry (SUNY-ESF)**—34% cost reduction (from $51.83 per dry ton to as low as $34.34 per dry ton) for woody biomass (shrub willow and hybrid poplar trees)
- **Auburn University**—22% cost reduction (from $76.46 per dry ton to $59.54 per dry ton) for woody biomass (loblolly pine).

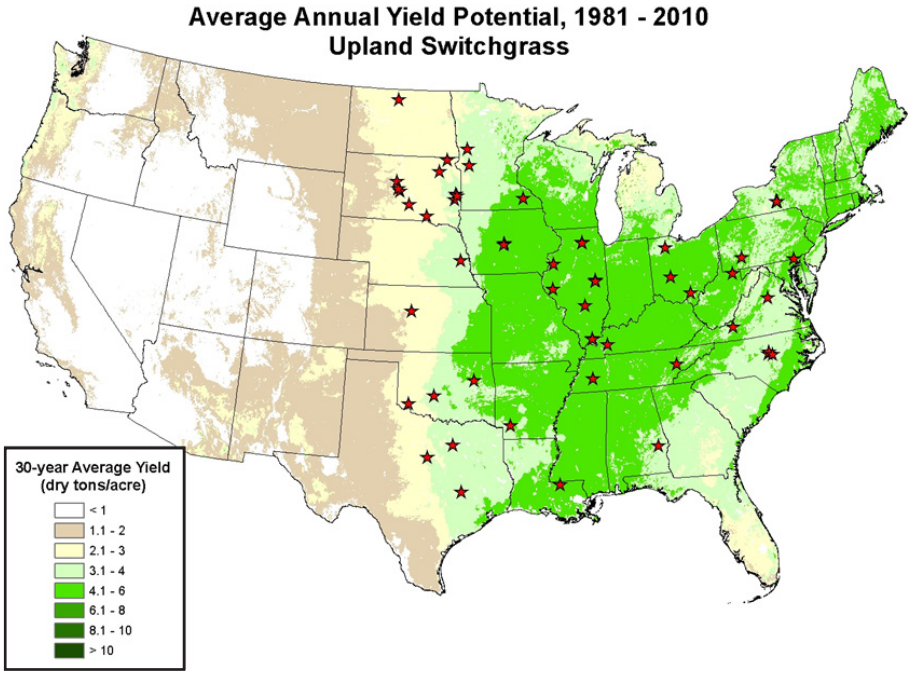
Each award recipient was required to partner with at least one biorefinery and at least one original equipment manufacturer. Original equipment manufacturers were responsible for designing, building, and demonstrating the equipment. They included Stinger (partnered with AGCO Corp.); Kelderman Manufacturing, Allied-Freeman, Vermeer, and Rotochopper (partnered with FDC Enterprises); Marathon Equipment, Laidig Systems, and Deere & Co. (partnered with TennEra); New Holland (partnered with SUNY-ESF); and Tigercat (partnered with Auburn University).

By eliminating steps in feedstock harvesting and transport, these five projects save money by reducing machine time, labor costs, and fuel costs for operating machinery, as well as enable associated reductions in GHGs.

A blog post on the BETO website features photos and infographics (several of which are displayed on this page) for each of the projects, including additional information about their innovative features and how they are reducing costs and associated GHGs. Several pieces of equipment are now available for purchase, including the TigerCat skidder and feller buncher, as well as the New Holland self-propelled forage harvester.

The Tigercat Feller Buncher (Auburn University) (top left) and Kelderman Manufacturing's Self-Propelled Bale Picking Truck (FDC Enterprises) (bottom left) are both explained by infographics to the right. *Photos courtesy of Auburn University and FDC Enterprises. Image credit BCS, Incorporated (infographics).*





A yield map of upland switchgrass, which is part of the collection of regional feedstock maps released by the Regional Feedstock Partnership. Map courtesy of Halbleib, M. D., Daly, C., & Hannaway, D. B. (2013), "Nationwide Crop Suitability Modeling of Biomass Feedstocks."

Eight High-Resolution Regional Feedstock Maps Released

In partnership with Oregon State University and principal investigators of the Regional Feedstock Partnership, BETO completed eight high-resolution maps of potential yield and yield variability for the following energy crops: energy cane, lowland switchgrass, upland switchgrass, biomass sorghum, Conservation Reserve Program "CRP" grasses, willow, poplar, and loblolly pine.

ORNL worked with crop modelers and met with field trial leaders to synthesize the results of five years of dedicated bioenergy crop yield trials. The goal of the meetings was to produce potential yield maps of these herbaceous and woody crop species using a uniform modeling approach.

Resulting from this effort was a document composed of draft maps of potential relative yields based on a 30-year weather history and a summary of key mapping assumptions. The clarity provided by these maps will allow for BETO's Terrestrial Feedstock Supply and Logistics technology area to better create strategic targets and ensure more accurate resource estimates feeding into more robust national models of biomass.

The Biomass Feedstock National User Facility Becomes a DOE User Facility

INL's Feedstock Process Demonstration Unit is now titled the Biomass Feedstock National User Facility (BFNUF) after its recent designation as a national user facility. This new status enables the BFNUF to engage with industry earlier in the R&D process by providing the knowledge base, expertise, analytical capability, and tools to reduce and mitigate the financial risk associated with the application of developed feedstock technologies. The change has already attracted new users and enhanced partnerships between INL, DOE, and industry.

The BFNUF is focused on creating commodity-scale feedstocks to meet the needs of producers of biofuels and bioproducts, such as plastics and cleaners, which are normally produced using petroleum. DOE's Assistant Secretary David Danielson visited the BFNUF in April 2014 to see its research progress and the laboratory's impact on the emerging feedstocks market.

Researchers at work at the INL Biomass Feedstock National User Facility. Photo courtesy of INL.

Algal Feedstocks

The Algal Feedstocks technology area is carrying out a long-term applied R&D strategy to increase the yields and lower the costs of algal biofuels. To attain this goal, BETO collaborates with industry and national laboratory partners to develop new technologies, integrate technologies at commercially relevant scales, and conduct crosscutting analyses to understand the potential and challenges of an algal biofuel industry that is capable of producing billions of gallons of renewable diesel, gasoline, and jet fuels annually.

Due to its high productivity on non-arable land and in brackish or salt water, algal biomass has significant potential. In addition, it can be particularly well suited for conversion into hydrocarbon-based fuels, such as renewable diesel and jet fuel.

BETO's strategy aims to help break down critical technical barriers and promote sustainable and affordable algal biofuels. Algae projects systematically address barriers along the algal biofuel supply chain to help advance the state of technology toward demonstrating cost competitiveness with fossil fuels. These activities are integrated with BETO's longstanding approach to accelerate the commercialization of lignocellulosic biofuels.

FY 2014 Accomplishments

Cornell Consortium Reaches FY 2014 Milestone for Improving Algal Productivity

The Cornell Consortium, which received DOE funding starting in 2010, has made significant progress toward improved algal productivity by designing a commercial-scale upstream algae cultivation and harvesting process. This year, the Cornell Consortium reached BETO's FY 2014 algal productivity milestone, increasing yields to an average of 1,500 gallons of algal feedstock per acre per year when modeled at n^{th} plant scale (from a baseline of 13 grams per square meter per day to greater than 20 grams per square meter per day). The Cornell Consortium consists of Cornell University, Cellana LLC, and several other key investigators.

Published Design Case Reports

The BETO Algal Feedstocks technology area funded the development of two design case reports from PNNL and NREL. These design cases, which focus on process improvements to conversion pathways for algae-based biofuel, help researchers identify key barriers and opportunities for cost improvement. The PNNL report focuses on the whole algae hydrothermal liquefaction technology pathway, and the NREL report details the algal lipid extraction and technology pathway upgrade. Both of these analyses suggest that the highest cost to the system is biomass cultivation. Improving biomass productivity, reducing capital expenditures, and using higher value co-products could decrease costs.

Agreement to Purchase Algae Crude Oil

Neste Oil—the world's largest producer of renewable diesel—agreed to purchase algae crude oil from Renewable Algal Energy, LLC in order to upgrade the oil to renewable algae-based biofuels. Renewable Algal Energy, LLC is a microalgae products company that received DOE funding for an SBIR project to prove the viability of its algal oil harvesting and extraction technologies. The project was successful, and the company expects to deploy these technologies at North America's first commodity-scale (5,000 acres) production site, which can produce more than 140,000 metric tonnes of dried algal biomass annually.

Advancements in Data Access

One of the most pressing and fundamental areas of standardization in the area of algal biofuels is the need for accurate measurement of algal productivity, biomass composition (protein, lipid, carbohydrate, and ash content), and fuel quality. These parameters are the basis for computing production costs and other analyses relevant to measure against success metrics.

Cover of the NAAB Report, detailing four years of algae research findings from BETO-supported research.

To address this need, the Algal Feedstocks technology area funded NREL to conduct the development and online publication of detailed standard test methods, as well as provide precision statements on repeatability and reproducibility of the methods based on review feedback.

BETO is also funding the Algae Testbed Public-Private Partnership's (ATP^3) open collaborative for the testing and evaluation of algae systems and technologies. ATP^3 provides public access to a geographically diverse network of algal biomass production facilities. They specialize in the comparison of the performance of systems under different climatic and operational conditions at outdoor scales. The ATP^3 network is generating data sets critical for supporting techno-economic analysis and life cycle assessment activities that will accelerate R&D.

Four Years of Algae Research Lays Out Path to $7.50 per Gallon

The National Alliance of Advanced Biofuels and Bioproducts (NAABB) released its close-out report, which details a combination of four years of research advancements. Together, these advancements have the potential to reduce the cost of algae-based biofuels to $7.50 per GGE, leading toward BETO's cost target for algal biofuels of $3 per GGE (2011 dollars) by 2030.

NAABB advancements include designing a higher-efficiency filtration system for harvesting algae from open pond systems, developing a hydrothermal liquefaction conversion process, and discovering and improving strains of algae that grow more quickly and have high lipid content.

The 39-institution consortium received $48.6 million in funding from the American Recovery and Reinvestment Act of 2009 and provided $19.1 million in cost-shared funding. This investment has established a new generation of algae researchers, resulted in seven new patent applications, and catalyzed the development of valuable intellectual property across the supply chain.

Aerial view of Cellana's demonstration facility in Kona, Hawaii. *Photo courtesy of Cellana, Inc.*

FY 2014 Funding Announcements

New Funding Opportunity
Targeted Algal Biofuels and Bioproducts

Funding Selection
Advancement of Algal Biomass Yield

See pages 9–10 for more detail.

Conversion

The Conversion technology area develops technologies for converting feedstocks into commercially viable liquid transportation fuels, as well as bioproducts and biopower. The diversity of biomass resources requires the development of multiple biochemical and thermochemical conversion technologies that can efficiently deal with the broad range of feedstock materials, as well as their physical and chemical characteristics. There are many possible variations of biochemical and thermochemical conversion processes, but the main differences in processing are the temperatures used to deconstruct the biomass, the biomass-derived intermediates produced from deconstruction, and the catalytic means used to upgrade those intermediates to finished fuels and products. BETO envisions that the combined use of technologies from both areas (hybrid processing) will also offer a tremendous opportunity for optimizing the conversion of biomass into a variety of different fuels, chemicals, and energy products.

FY 2014 Accomplishments

Achieved Mature, Modeled Conversion Cost Contribution of $2.70 per GGE

In FY 2014, BETO demonstrated via modeling that a combined gasoline and diesel blendstock could be produced for $4.09 per GGE through a thermochemical conversion pathway. This cost is based on a modeled conversion cost of $2.70 per GGE and reflects a total feedstock delivery cost of $101.45 per dry ton (all values in 2011 dollars). The $2.70 per GGE reduction was enabled by increasing bio-oil throughput in bench-scale hydrotreaters, which resulted in a 22% decrease in catalyst cost and reduced capital cost.

New Process Developed to Utilize Waste Stream Intermediates

BETO worked with NREL to develop a new process to utilize valuable intermediates from lignin, previously considered a waste stream. Researchers demonstrated an innovative technology to break down and convert lignin into key intermediate molecules that could enable the future development of cost-competitive products from lignin. Lignin represents approximately a third of the carbon available in biomass for conversion to cellulosic sugars and other intermediates, which can then be further biologically upgraded to hydrocarbon biofuels. Through the process of biological funneling, NREL was able to isolate and deconstruct the lignin fraction of the biomass that was converted into intermediates. This new process could ultimately help BETO to achieve its goal of $3 per GGE advanced biofuel.

Split-Stream Conversion Process Improves Efficiency of Furfural Production

Furfural is a sugar-derived compound that can be produced from a variety of biomass feedstocks and readily upgraded to create biofuels and bioproducts. It is typically produced from C5 sugars by way of a costly process, requiring intense heat and pressure. To circumvent this, researchers at NREL utilized a new, hybrid split-stream conversion approach for sugars derived from xylan and cellulose—the main components of plant cell walls. They separated available C5 and C6 sugars into two streams based on their chemical properties and applied tailored conversion techniques to each stream. The goal was to maximize furfural production from one stream and produce xylose and glucose (both sugars) from the other stream. The new approach resulted in a total furfural yield of 25%, which is a significant increase from the 8% yield achieved through traditional processes. The NREL team's research demonstrated that this split-stream process enables more efficient and cost-effective production of furfural from biomass, which could lead to increased availability of this high-value chemical for upgrading to biofuels and bioproducts.

Photo courtesy of Dennis Schroeder/NREL.

Gas Technology Institute Scales Up Conversion Process

The Gas Technology Institute announced an agreement with CRI Catalyst (a Shell subsidiary) for a second 500-ton-per-day facility using a hydropyrolysis and hydroconversion process that was first developed with BETO funding in 2009. The institute's IH^2 (Integrated Hydropyrolysis and Hydroconversion) process is a breakthrough process that can convert lignocellulosic feedstocks, such as woody biomass or corn stover, into gasoline and diesel range fuels.

Computational Pyrolysis Consortium off to a Strong Start

The Computational Pyrolysis Consortium (CPC) established by BETO in May 2013 has a lot to show for its first year. This collaboration among five DOE national laboratories published 10 papers, delivered 12 presentations at technical conferences, and developed a new database and website.

The database allows for a technically and geographically diverse group of researchers to share and store feedstock properties, operating conditions, reaction networks, kinetic parameters, and simulation results. The website allows researchers to share preliminary research with laboratory partners and fully vetted results with the broader biomass conversion community.

The CPC supports BETO's goal to develop a bio-oil pathway that achieves a modeled fuel cost of $3 per GGE by 2017 by developing computational tools that support ongoing experiments and analyses. In addition, the group is leveraging high-performance computational resources from DOE's Office of Science to support modeling and analysis activities. The CPC pursues pre-competitive technical interactions among bio-oil process modelers, analysts, and experimentalists to reduce the time and cost for planning and analyzing laboratory studies, as well as improve the accuracy and commercial relevance of experimental data.

The CPC is composed of NREL, PNNL, ORNL, ANL, and INL. The CPC also receives input from an industry advisory board that includes representatives from Virent, Research Triangle Institute, Babcock and Wilcox, Separation Design Group, BP, ExxonMobil, W.R. Grace, and Johnson Matthey.

So far, feedback has been positive. A member of the CPC's industry advisory board has described the initiative as "one of the most truly collaborative and crosscutting activities in the BETO portfolio."

Biofuels and Barbecue Chips: Small Business Develops Process to Create Versatile Chemicals

BETO also helps bring technology to market with funding through DOE's Small Business Innovation Research (SBIR) program. Through BETO cost-shared SBIR funding, Spero Energy—a small business started by researchers at Purdue University—created a cost-effective process that converts sustainable wood sources into renewable chemicals for the flavor and fragrance industry, including those used in barbecue potato chips and other smoky flavored foods.

Spero Energy's technology is effective at breaking down the lignin component of biomass—which is difficult to break down and often seen as a technical challenge to producing low-cost biofuels and bioproducts. United Airlines, Boeing, and Honeywell UOP presented Spero Energy with the 2014 Clean Energy Challenge's $50,000 Aviation Energy Prize for the breakthrough technology.

By developing novel ways to separate and utilize the lignin, Spero Energy is supporting industry efforts to expand and strengthen biofuels production processes.

Sustainable wood sources can be used to produce renewable chemicals. Photo courtesy of NREL.

FY 2014 Funding Announcements

New Funding Opportunities

Biological and Chemical Upgrading for Advanced Biofuels and Products

Bioenergy Technologies Incubator

Funding Selections

Carbon, Hydrogen, and Separation Efficiencies in Bio-Oil Pathways

Renewable Carbon Fiber

See pages 9–10 for more detail.

Demonstration and Market Transformation

The Demonstration and Market Transformation technology area (formerly called "Demonstration and Deployment" and "Integrated Biorefineries") culminates the RD&D work of all other BETO technology areas—from feedstocks to conversion to sustainability work along the supply chain. The goal is to de-risk bioenergy production technologies through validated proof of performance at the pilot, demonstration, and pioneer scales and to remove any additional barriers to commercialization. BETO achieves these goals through public-private partnerships that build and operate integrated biorefineries, as well as through projects focused on infrastructure and end-use market barriers.

Demonstration and Market Transformation activities are essential to resolving key issues in the construction and scale-up of integrated biorefinery systems and to commercial financing barriers to bioenergy technologies. By creating a pathway to market, Demonstration and Market Transformation helps to address the final links of the bioenergy supply chain and works to overcome market and infrastructure barriers to enable a robust demand for end products.

Tanks in the pretreatment area of POET-DSM's Project LIBERTY. Photo courtesy of POET-DSM.

FY 2014 Accomplishments

Grand Opening of Cellulosic Ethanol Biorefinery

POET-DSM's Project LIBERTY in Emmetsburg, Iowa, celebrated its grand opening September 3, 2014, becoming the first commercial-scale cellulosic ethanol plant to use corn stover (non-edible corn cobs, husks, stalks, and residue) as a feedstock. Developed through a joint venture between POET LLC in Sioux Falls, South Dakota, and DSM Royal, a Dutch enzyme manufacturer, the project uses biochemical conversion technologies (yeast and enzymes) to convert cellulosic biomass into transportation fuels.

DOE has supported Project LIBERTY since 2007 with $100 million in cost-shared funding—$12.1 million for the facility's design, construction, and operation, and an additional $87.8 million for its construction. It also received $20 million in grants from the State of Iowa for capital costs and feedstock logistics

Project LIBERTY is designed to produce 25 million gallons of cellulosic ethanol per year, which is enough to avoid approximately 210,000 tons of carbon dioxide emissions annually. The corn stover is harvested by local farmers in a 30–40-mile radius of the plant—creating enough energy to power the facility and a co-located bioethanol plant. Project LIBERTY is co-located with POET's existing corn ethanol plant to allow the facilities to share staff and infrastructure, thereby improving economies of scale.

These images feature excerpts from a tour of POET-DSM's Project LIBERTY in the short film *Bioenergy: America's Energy Future*, available on the BETO website.

Project LIBERTY is the nation's second commercial-scale cellulosic ethanol biorefinery to come on line—after INEOS Bio's Indian River BioEnergy Center opened in 2013 using vegetative, yard, and municipal solid waste. Project LIBERTY will serve as a test bed for producing cellulosic ethanol with biochemical conversion technologies, helping to inform future POET facilities and other advanced biofuels projects across the nation.

First U.S. Cellulosic Ethanol Commercial Shipment and Green Racing

In the spring of 2014, INEOS made the first U.S. commercial shipment of cellulosic ethanol to the International Motor Sports Association Green Racing Series. Using cellulosic E85 (up to 85% cellulosic ethanol blend), teams achieved a 62% petroleum reduction and 65% reduction of GHG emissions compared to the previously used petroleum-based fuels, demonstrating that renewable fuels are both sustainable and can provide superior performance.

INEOS produced the fuel at its Indian River BioEnergy Center in Vero Beach, Florida, which opened in July 2013, and was the first cellulosic ethanol biorefinery to open in the United States. INEOS received $50 million in cost-shared DOE funding in 2009 to design, construct, commission, and operate the biorefinery. More than 90% of its equipment was sourced by U.S. manufacturers across 10 states.

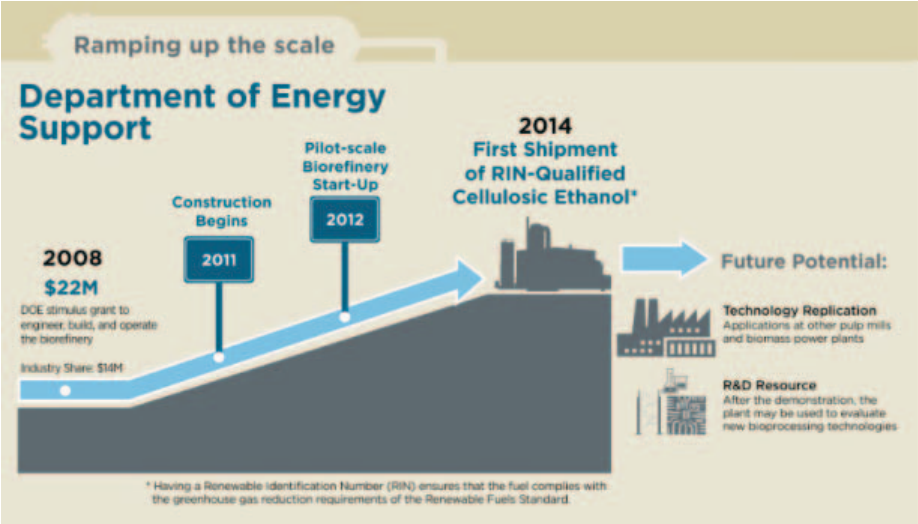
Green Racing fuels and technologies test the boundaries and push manufacturers to bring those high performing vehicles from the track to the showroom, and ultimately, to American driveways. Green Racing is one of many DOE efforts to make motorsports more sustainable.

EERE Principal Deputy Assistant Secretary Michael Carr (from left), Environmental Protection Agency Region IV Administrator Heather McTeer Toney, and BETO Director Jonathan Male pose with the Green Racing Challenge award. *Photo courtesy of Natalie Committee, Energy Department.*

First Woody Biomass Cellulosic Ethanol RINs

In April, American Process Inc. announced that it shipped its second commercial cellulosic ethanol shipment and sold renewable identification numbers (RINs) from it pilot-scale biorefinery Alpena Biorefinery in Alpena, Michigan. RINs ensure that the fuel meets RFS requirements. These RIN-qualifying shipments of cellulosic ethanol are among the first in the United States from woody biomass.

American Process Inc. engineered, operated, and built its Alpena Biorefinery with BETO funding through the American Recovery and Reinvestment Act of 2009. The project has been declared a Michigan Center of Energy Excellence and was also awarded a $4 million state grant. At full capacity, it is designed to produce about 894,000 gallons of cellulosic ethanol, using forest residue woodchips as a feedstock. The wood is sustainably harvested according to the RFS requirements for biomass.



The infographic shows BETO's cost-shared funding role in American Process Inc.'s Alpena Biorefinery. See the expanded infographic with economic impact information, as well as similar infographics for POET-DSM's and INEOS' cellulosic ethanol biorefineries on the BETO website. Image credit Energetics.

New biorefineries will produce renewable jet and diesel fuel for the military. Photo courtesy of the U.S. Navy.

Defense Production Act Biorefineries Progress to Construction Stage

U.S. Deputy Secretary of Energy Daniel Poneman joined U.S. Secretary of Agriculture Tom Vilsack, and U.S. Secretary of the Navy Ray Mabus on September 19, 2014, to announce awards for three commercial-scale biorefinery projects that will help meet the transportation needs of the U.S. military and private sector.

Together, these three projects will produce more than 100 million gallons of military-grade biofuel annually beginning in 2016 and 2017 at a price competitive with petroleum counterparts. This fuel can be blended up to 50% with traditional fuels and emits less than half the life-cycle GHG emissions of petroleum counterparts.

The following companies are receiving federal investment for the construction and commissioning of biorefineries:

- **Emerald Biofuels:** To build and operate an 82 million gallon per year refinery on the Gulf Coast to hydrotreat and upgrade waste fats, oils, and greases to create military-grade jet fuel and diesel.
- **Fulcrum BioEnergy:** To build and operate a refinery in McCarran, Nevada, to convert municipal solid waste, using gasification and Fischer-Tröpsch conversion technology, into more than 10 million gallons of renewable jet and diesel fuel a year.
- **Red Rock Biofuels:** To build and operate a 12 million gallon per year refinery in Lakeview, Oregon, using gasification and Fischer-Tröpsch conversion technology to turn forest biomass and wood wastes into renewable fuels for the military.

DOE Joins Farm to Fly 2.0

During *Biomass 2014*, Assistant Secretary David Danielson announced DOE's participation in Farm to Fly 2.0, the extension of the Farm to Fly initiative that was established to develop a commercially viable aviation biofuel industry for the United States.

For Farm to Fly 2.0, BETO is partnering with USDA, the U.S. Department of Transportation's Federal Aviation Administration (FAA), and major aviation industry partners including the Commercial Aviation Alternative Fuels Initiative. The goal of Farm to Fly 2.0 is to increase the nation's supply of renewable jet fuel with the end goal of producing about 1 billion gallons of drop-in aviation biofuels a year by 2018.

As part of the initiative, BETO will provide technical guidance on alternative fuel production and assist with the process of jet fuel certification, testing, and qualification. DOE is already funding R&D and pilot- and demonstration-scale projects to produce renewable diesel and jet fuel for military and civilian use.

Farm to Fly 2.0 will also enable DOE to strengthen its current role in the FAA's newly formed Center for Alternative Fuels and Environment.

At the announcement of Farm to Fly 2.0 (from left): Catherine Woteki, Under Secretary for Research, Education, and Economics, USDA; David Danielson, DOE's Assistant Secretary for Energy Efficiency and Renewable Energy; Steve Csonka, Executive Director, Commercial Aviation Alternative Fuels Initiative; Jim Hileman, Chief Scientific and Technical Advisor for Environment, FAA.

Analysis and Sustainability

Enabling long-term viability of bioenergy systems is a critical component of BETO's goal to reduce U.S. dependence on foreign oil. BETO 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 Analysis and Sustainability technology area is addressing the challenges related to sustainable bioenergy production and use by supporting analysis, data collection, modeling, and applied R&D projects. This technology area works collaboratively with industry, academia, national laboratories, other government agencies, nongovernmental organizations, and international partners.

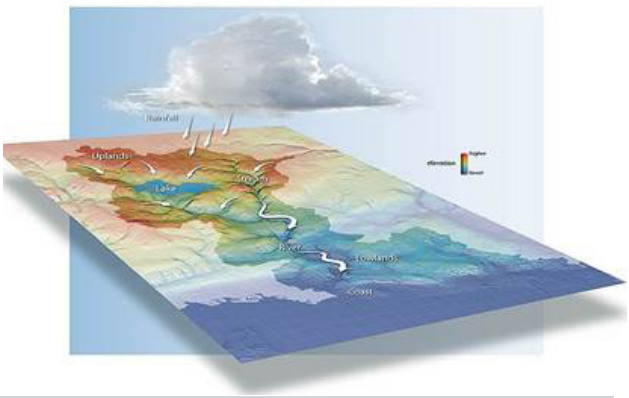
The Analysis and Sustainability technology area plays a crosscutting role both within and outside of BETO. It contributes to portfolio planning and works

with other 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.

FY 2014 Accomplishments

WATER 2.0 Online Tool Quantifies Water Footprint of Biofuels

BETO worked with ANL to release Water Assessment for Transportation Energy Resources (WATER) version 2.0. This Web-based water footprint tool can be used to assess water resource use and water quality across the stages of fuel production. The tool quantifies the water footprint of fuel from feedstock production through the conversion process, and includes geospatial data for analysis of water demand on the county, state, and regional scale. WATER not only offers the capabilities to analyze the water footprint of several biofuel pathways, but also offers a shale gas pathway as a basis for comparison. The WATER 2.0 release included new perennial grass pathways with six scenarios from the *Billion-Ton Update* for switchgrass- and miscanthus-derived biofuel.



A graphical representation of the WATER online tool. Photo courtesy of May Wu, ANL.

A new version of the tool (WATER 3.0) was subsequently released in early FY 2015 and is available online.

New GREET Model Aids Life-Cycle Analysis

ANL released a new version of the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model in 2014. The GREET model is a life-cycle analysis tool that is used by DOE, as well as other agencies, researchers, and industry stakeholders to quantify progress toward reducing transportation-sector

life-cycle petroleum use and GHG emissions from biofuel use.

Updates to GREET included four new modules for evaluating bioproducts, pretreatment, catalysts, and rail transport; several new biofuel pathways; and many updates to baseline and biofuel pathway data. Furthermore, ANL added water consumption as an additional life-cycle analysis metric for its major pathways. GREET can be accessed as an Excel spreadsheet or as a downloadable model at GREET.es.anl.gov.

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Stakeholders Convene to Discuss Sustainable Landscape Designs

In 2014, BETO hosted two workshops convening interdisciplinery experts to explore the state of the science, research needs, and tools and methodologies for implementing landscape designs for bioenergy systems across the supply chain and across sustainability metrics.

"Landscape design" refers to a methodology of integrating cellulosic feedstock production into existing agricultural and forestry systems. The purpose is to maintain or enhance environmental and socio-economic sustainability, including ecosystem services and food, feed, and fiber production, and the process includes convening multiple-stakeholders (i.e., landowners, feedstock producers, resource managers, and extension agents) to determine goals that are region specific.

The workshops were held in New Bern, North Carolina, and in Argonne, Illinois, in March and June. See pages 8–9 for more details.

BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK
U.S. DEPARTMENT OF ENERGY

Bioenergy Knowledge Discovery Framework Releases New Features

BETO and ORNL initially launched the Bioenergy Knowledge Discovery Framework (KDF) in January 2011 as a tool to support the development of a sustainable bioenergy industry. The Bioenergy KDF is an information-sharing, online collaboration toolkit and database for bioenergy data and maps.

In FY 2014, the Bioenergy KDF released the Legislative Library, a new database that tracks federal legislation related to the production and use of biofuels in the United States. Specifically, the database allows users to filter search results by congressional session, political party, state, chamber, or status to learn about the work being carried out by specific members and committees to advance the U.S. biofuels industry.

Since FY 2014, the Bioenergy KDF has released additional features, including a page tagging Bioenergy KDF publications and resources that are funded by DOE.

From the Legislative Library landing page (above), visitors can search bioenergy-related federal legislation by legislators, bills, or committees.

Progress and Looking Ahead

In FY 2015, BETO will build off the accomplishments of FY 2014 and look toward increasing RD&D partnerships; funding innovative approaches; and improving inter- and intra-agency collaborations in order to realize the aggressive goal of $3 per GGE advanced biofuel.

Specifically, BETO will focus on "drop-in" hydrocarbon fuel production and scale-up efforts, accelerating momentum for advanced biofuel production in the wake of pioneer-scale cellulosic ethanol successes. BETO has listened to industry input and is now investigating the potential of bioproducts (such as specialty or commodity chemicals, polymers, or proteins) to enable competitive biofuel production costs by improving the value proposition of biomass.

In addition, BETO will work in close coordination with the U.S. Departments of Agriculture, Defense, Transportation, and others on identifying the challenges and opportunities of the emerging "bioeconomy."

Environmental sustainability, as characterized by water use, nutrient demand, and lifecycle GHG emissions, remains a critical component for consideration in envisioning national-scale advanced biofuels. BETO will continue its commitment to not only economic feasibility, but also environmental stewardship, based on a foundation of sound science. ■

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For more information, visit: bioenergy.energy.gov

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