Bioenergy Technologies Office FY 2016 Successes

The U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO) forms cost-shared, public-private partnerships to help sustainably develop cost-competitive biofuels and bioproducts in the United States from non-food biomass resources. The potential exists to sustainably produce at least 1 billion dry tons of non-food biomass resources by 2040—a sufficient quantity to produce 50 billion gallons of biofuels without impacting food or feed needs.[1] Biofuels are a major component of DOE's multipronged strategy to address energy security, harmful emissions from the transportation sector, and U.S. job growth.

Fiscal year (FY) 2016 realized advances in renewable jet fuel and feedstocks research, as well as other hydrocarbon biofuel research and development breakthroughs.

Aviation Industry Invests in Renewable Fuels Made from Waste Gases

Working with Pacific Northwest National Laboratory (PNNL), biofuel producer LanzaTech received $4 million in funding from BETO to develop a process that not only provides a sustainable source of renewable jet fuel, but also offers an innovative solution to industrial waste management. Carbon-rich industrial waste gases like carbon monoxide are captured or derived from the gasification of biomass and fed to microbes, which consume the gas and produce ethanol. The ethanol is then upgraded into synthetic paraffinic kerosene, a renewable jet fuel compatible with existing engines. The team has successfully produced 1,500 gallons of jet fuel so far using this process. Moving forward, LanzaTech has partnered with Virgin Atlantic, Boeing, and a number of other industry colleagues to complete additional aircraft and engine testing with the hopes of making a "proving flight" as early as 2017. If successful, this will enable the partnership to seek approval to use the fuel on routine commercial flights.

With BETO funding, PNNL and industry partner, Lanzatech, developed a technology that will be used to produce renewable jet fuel for Virgin Atlantic airlines. *Photo courtesy of H. Michael Miley, Creative Commons CC BY-SA 2.0.*

The DuPont Cellulosic Ethanol facility in Nevada, Iowa, opened October 15, 2015. To date, it is the world's largest cellulosic ethanol facility. *Photo courtesy of DuPont.*

World's Largest Commercial-Scale Cellulosic Ethanol Facility Opens

On October 30, 2015, DuPont opened the world's largest commercial-scale cellulosic ethanol plant in Nevada, Iowa. At full capacity, DuPont's biorefinery is capable of producing 30 million gallons of cellulosic ethanol per year. Situated in a prime agricultural location, the facility is collaborating with approximately 500 local corn growers to establish a high-quality, cost-effective, and sustainable supply of corn stover (corn cobs, leaves, and stalks) that will be harvested from within 30 miles of the plant. This achievement represents a culmination of nearly a decade of cutting-edge research and development on biomass conversion technology. Since the early 2000s, DuPont has received approximately $51 million from BETO to work with DOE's National Renewable Energy Laboratory (NREL) to optimize its technology. Now, more than 10 years later, the completion of this biorefinery marks a

key milestone for the commercial production of cellulosic ethanol in the United States.

2016 Billion-Ton Report Confirms U.S. Potential to Produce 1 Billion Tons of Biomass Annually

In July 2016, DOE and Oak Ridge National Laboratory (ORNL) jointly released the *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy*, Volume 1, which concludes that the United States has the potential to sustainably produce at least 1 billion dry tons of non-food biomass resources annually by 2040. Specifically, models used for the report predict that the United States could increase its use of dry biomass resources from a current 400 million tons to 1.5 billion tons under a high-yield scenario. This report is the third in a series, preceded by the 2011 *U.S. Billion-Ton Update* and the 2005 *Billion-Ton Study*, and is split into two volumes. Volume 2. focuses on the environmental sustainability effects of scenarios presented in Volume 1. New to the 2016 report are novel assessments of potential biomass supplies from algae, new energy crops (miscanthus, energy cane, eucalyptus), and municipal solid waste. For the first time, the report also considers how the cost of pre-processing and transporting biomass to the biorefinery may impact feedstock availability.

BETO's research with high-octane fuels is helping to enable the Co-Optimization of Fuels and Engines Initiative, which seeks to design efficient engines alongside renewable fuels. *Photo courtesy of Sandia National Laboratories.*

Benefits of High-Octane Fuels Verified

Researchers at ORNL, along with NREL and Argonne National Laboratory (ANL), verified a 5%–10% improvement in fuel efficiency using an optimized bio-based blend of gasoline with a modified car engine. This blend increases the octane rating of the fuel, which also translates to vehicle performance benefits such as faster acceleration and greater towing capacity. The ethanol in the gasoline blend increases the octane level, and the fuels' high octane rating offsets the lower energy density of the fuel. Increased concentrations of ethanol can also mean significant reductions in harmful tailpipe emissions. When using gasoline with 40% cellulosic ethanol—made from non-food biomass resources such as corn husks and stalks, grasses, forestry residues, organic wastes, and algae—researchers have found a way to reduce harmful tailpipe emissions by 30%. Cellulosic ethanol has become cost-competitive in the past few years, enabling a path to commercialization. Moving forward, national laboratory researchers are building off this work for the DOE's Co-Optimization of Fuels and Engines Initiative.

Pathways to Biofuels and Bioproducts Expanded

During 2016, BETO continued to focus on flexible conversion pathways for producing bioproducts alongside biofuels. Bioproducts can play an important role in enabling biofuel development, as profits from these value-added materials and diversification of market risks can help alleviate challenges with biofuel-related production costs. In March 2016, BETO competitively awarded funding to industrial biotechnology company Lygos, Inc. through the DOE Small Business Vouchers Pilot to further scale up its patented malonic acid fermentation pathway. In 2015, Lygos won an award for its bio-based method to produce malonic acid, which it demonstrated at the BETO-funded Advanced Biofuels Process Demonstration Unit at Lawrence Berkeley National Laboratory. In 2016, BETO also announced several funding opportunities to advance development of bio-based chemicals and products.

Six Years of Algal Research Released

In May 2016, the Consortium for Algal Biofuel Commercialization (CAB-Comm), led by the University of California, San Diego, released its final report, detailing the many accomplishments and impactful contributions it achieved in its six years of operation. CAB-Comm made substantial progress on three key aspects of algal biofuels production: (1) development of genetic tools, (2) crop protection, and (3) nutrient utilization and recycling. In addition to accomplishments in basic research, CAB-Comm engaged the commercial sector to develop and demonstrate the production of high-value, sustainable fossil fuel replace-

ment products. Its education programs have trained more than 200 research scientists and laboratory technicians for employment in the algal biofuels industry. The results of CAB-Comm—together with feedback from public workshops and results from the National Alliance for Advanced Biofuels and Bioproducts—were used to produce the *2016 National Algal Biofuels Technology Review*, released by BETO in June 2016. This review captured achievements to date, lessons learned, new challenges, and critical next steps on the path to commercialization of algal biofuels.

Next-Gen Biomass Conversion Technology Unveiled

In June 2016, NREL researchers added new capabilities to its state-of-the-art Thermochemical Users Facility. Partnering with Particulate Solids Research, Inc., NREL installed a recirculating regenerating riser reactor (R-Cubed) in its pilot-scale Thermochemical Process Development Unit. Funded by BETO, this unique unit significantly improves the efficiency and reduces the costs associated with converting biomass into a finished fuel product. The front end of this innovative pilot-scale system makes use of fast pyrolysis—the rapid heating of biomass to 400°–500°C in the absence of oxygen followed by cooling the resulting vapors into a liquid bio-oil. This bio-oil intermediate must then undergo additional processing in order to produce upgraded hydrocarbon "drop-in" fuel. However, these downstream upgrading steps are quite challenging, as bio-oil contains a variety of reactive oxygenated organic compounds. These challenges could be alleviated by improving the quality of the bio-oil intermediate by upgrading the vapors, prior to condensation—which is exactly what the R-Cubed reactor is designed to do. Pyrolysis vapors are fed to the unit, where they are exposed to a catalyst that reduces oxygen content and improves chemical stability. The result is an upgraded bio-oil that could more easily integrate into traditional petroleum refineries for further processing. The new capabilities of the recently outfitted Thermochemical Users Facility demonstrate promising pathways for "drop-in" hydrocarbon biofuel production and can be used in the coming years to produce hundreds of gallons of upgraded pyrolysis oil.

Shrub willow integrated with corn agriculture effectively reduced nitrate fertilizer runoff by 30%. *Photo courtesy of ANL.*

Shrub Willow Provides Renewable Energy and Enhances Environmental Benefits

ANL partnered with the State University of New York, The Conservation Technology Information Center, the University of Michigan, and Southern Illinois University to examine the potential of energy crops like shrub willow to act as a buffer to intercept nitrate pollution to support its growth and improve water quality. Nitrogen is an important nutrient needed for plant growth. However, it can also pose environmental problems, particularly when heavy rains generate runoff, depositing these nutrients in nearby streams, lakes, and groundwater. By adding willow buffer strips in targeted locations in a corn field, ANL was able to reduce nitrate concentrations reaching shallow groundwater by over 30% relative to recorded losses from corn. ANL also determined that willow buffers could be cost competitive with commonly adopted nitrate-management conservation practices. This is a significant achievement that demonstrates that sustainable landscape design principles can be used to integrate bioenergy into existing farming systems in a way that improves ecosystem services, while maintaining food and feed production. Considering energy crops are projected to supply 41%–74% of the biomass in a billion-ton bioeconomy, studies like these can help the industry plan for the sustainable expansion of bioenergy systems.

Process Converts Sewage to Biofuel

PNNL developed a process that uses high pressure and temperature to convert wet sewage sludge to biocrude oil in less than 60 minutes. The process eliminates the need to dry the sewage first, which is what made converting wastewater to fuel too expensive and energy intensive. Wastewater treatment plants in the United States treat enough

sewage daily to produce approximately 30 million barrels of oil per year, and PNNL estimates that two to three gallons of biocrude per year could come from a single person. PNNL has licensed its hydrothermal liquefaction technology to Utah-based biofuel company Genifuel Corporation, which is working to build a demonstration plant with Metro Vancouver in British Columbia, Canada. PNNL first developed the technology in 2013.They also can use it to convert algae to biocrude.

Regional Feedstock Partnership Report Highlights Seven Years of Work to Enable Billion-Ton Vision

The *Regional Feedstock Partnership Summary Report*, released in July 2016, summarized the accomplishments of the Regional Feedstock Partnership throughout the seven-year period of 2008 through 2014. The Regional Feedstock Partnership was established to address information gaps associated with enabling the vision of a sustainable, reliable, billion-ton bioenergy industry. The partnership is composed of representatives from land grant universities organized under the Sun Grant Initiative, DOE, the U.S. Department of Agriculture, and industry.

Improved Process Boosts Algal Fuel Yield

In 2016, NREL scientists developed a process known as Combined Algal Processing, which is highly effective at producing ethanol from algae when compared to traditional methods. Typically, algae produce lipids that are then converted into fuels. However, NREL determined that total ethanol yield could increase markedly by using all algal cellular components instead of just relying on the lipids. In addition to lipids, microalgal biomass can produce carbohydrates and proteins that can also be converted into fuel products. This new process exposes all algae components directly to the fermentation process. This resulted in 126 gallons gasoline equivalents per ton of biomass, 32% more than the yield from lipids alone.

New Pilot Plant Demonstrates the Potential to Co-Process Biomass Streams with Petroleum

NREL partnered with leading petroleum refining technologies supplier, W.R. Grace, and leading pilot plant designer, Zeton Inc., to build a unique pilot-scale facility that can produce biomass-derived fuel intermediates using existing petroleum refinery infrastructure. This pilot plant, constructed in part with BETO funding, combines biomass pyrolysis with fluid catalytic cracking—one of the most important conversion processes used in petroleum refineries—to demonstrate the potential to co-process biomass-derived streams with petroleum at an industrially-relevant pilot scale. There are 110 domestic fluid catalytic cracking units currently operating in the United States. Using them to co-produce biofuel could enable the production of more than 8 billion gallons of bio-derived fuels, without construction of separate biorefineries.

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[1] U.S. Department of Energy. 2016. *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks.* M. H. Langholtz, B. J. Stokes, and L. M. Eaton (Leads), ORNL/TM-2016/160. Oak Ridge National Laboratory, Oak Ridge, TN. 448p. http://energy.gov/eere/bioenergy/downloads/2016-billion-ton-report-advancing-domestic-resources-thriving-bioeconomy.

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