U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Bioenergy Technologies Office FY 2018 Successes

The U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO) focuses on early-stage applied research and development (R&D) to enable sustainable and cost-effective technologies capable of producing bioenergy from non-food sources, such as cellulosic biomass, algae, and waste. National laboratories and industry partners receive BETO funds for R&D to reduce the price of drop-in biofuels, high-performance bioproducts, and renewable biopower to enable a thriving U.S. bioeconomy. By working with public- and private-sector partners to advance the domestic bioenergy industry, BETO ensures American families and businesses have more affordable, reliable, and domestically-sourced energy and transportation options.

In fiscal year (FY) 2018, BETO achieved significant R&D advances in renewable fuels and bioproducts. These successes help to increase U.S. energy supplies, reduce imports of foreign oil, enhance energy security, create domestic jobs, and secure the nation's global leadership in advanced bioenergy and clean energy technologies.

The world's first commercial flight using groundbreaking sustainable aviation fuel made from recycled waste carbon gases flew from Orlando, Florida, to London, England. *Photo courtesy of PNNL*

First Commercial Flight Using Fuel from Recycled Waste Carbon Gases

In 2018, the bioenergy and aviation industries realized the world's first commercial flight using groundbreaking sustainable aviation fuel made from recycled waste carbon gases. Virgin Atlantic Airlines flew a Boeing 747 from Orlando, Florida to London, England using fuel that was developed through a partnership between DOE's Pacific Northwest National Laboratory (PNNL) and LanzaTech. PNNL and LanzaTech developed a unique catalytic process and proprietary catalyst to upgrade ethanol to alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK), a type of jet fuel. The catalyst removes oxygen from ethanol in the form of water, and then combines the remaining hydrocarbon molecules to form chains. The resulting hydrocarbon chains are large enough for jet fuel but do not form aromatics, which helps reduce soot emissions when burned in a jet engine.

Based in part on the work done by PNNL and LanzaTech, in 2018 ASTM International—an international standards organization that publishes voluntary consensus technical standards—added ethanol to a list of approved feedstocks for producing ATJ-SPK when they revised the specification for synthetic jet fuel (ASTM D7566 Annex A5). The updated standard will enable increased adoption of new sustainable aviation fuels—including LanzaTech's alcohol-to-jet fuel—in blends up to 50% with traditional jet fuels.

More info at Biomass Magazine and Energy.gov

Collaborating with Industry to Convey Feedstock Value, Improve Biomass Conversion Processes

Recognizing the importance of enhancing biomass conversion processes for industry, a team of NREL scientists partnered with Forest Concepts—a leading manufacturer of precision woody and herbaceous feedstocks for bioenergy and bioproduct applications—to perform detailed thermochemical conversion simulations for biomass feedstocks. The simulations relate feedstock attributes to expected product yields and necessary pyrolysis conversion process conditions. The work by NREL will allow industry to better evaluate the value of biomass feedstocks. Models based on mixed particle

NREL researchers review mesoscale simulations of biomass conversion at NREL's Biomass Surface Characterization Lab. The models combine computational methods and image data to capture the complex behavior of real feedstocks. *Photo courtesy of Vivek Bharadwaj/NREL*

sizes help determine the optimal residence times for maximum yield during biomass conversion, which can increase the process throughput and decrease cost for industry to create sustainable biofuels and bioproducts.

More info at NREL.gov

Integrated Landscape Management Reduces Biomass Production Costs and Improves Economic Outcomes for Farmers

A new techno-economic analysis by Idaho National Laboratory researchers demonstrated that by using integrated landscape management (ILM) techniques, biorefinery operators and other bioenergy stakeholders could reduce biomass production costs by 20 percent. ILM designs incorporate bioenergy crops to minimize soil erosion, harvesting crop residues such as corn stover or wheat straw in high-yield areas, and optimizing the operational efficiency of biomass harvest equipment by using Global Positioning System data and computers to guide their movements through fields.

Researchers modeled cost reductions in watersheds in Kansas, Iowa, and Illinois by leveraging ILM designs to prove that farmers could save money planting low-cost energy crops—such as switchgrass—in low-yield areas instead of traditional crops. This resulted in improved economic and sustainable outcomes—including increased profits for producers and reduced soil erosion—at the field level. Other ILM designs focused on protecting high-risk soils located on steep slopes using a farmland conservation practice known as "prairie strips," which are long, thin sections of fields where farmers would replace traditional crops with perennial energy crops. This was made possible with an advanced three-dimensional soil erosion computer modeling software.

Design Challenge Inspires Advances in Automated Wood Stove Technology

In 2018, BETO sponsored a Wood Stove Design Challenge to inspire the development of cleaner, more efficient, affordable wood stoves. Alliance for Green Heat—a Maryland based nonprofit that promotes clean and affordable biomass-based heating technology—hosted and coordinated the competition. Nine teams developed stoves featuring innovative technologies, including automated control systems and/or thermoelectric generators that convert excess heat into electricity. Competitors gathered on the National Mall in Washington, D.C., to install and operate their stoves over a 5-day period. A team of judges including experts from Brookhaven National Lab conducted stove performance testing, evaluated the designs against efficiency, emissions, and other performance criteria and selected the winners.

Wittus won first prize for both the automated and thermoelectric categories with a living room stove that also heated water for space heating. Stove Builders International received second place in the automated category for their simple, affordable stove that allowed operators to select heat output and use a low-cost control board and thermocouple sensors to ensure a clean burn. Second prize in the thermoelectric category went to Vulcan Energy, who developed a thermoelectric generator for its Wiseway pellet stove with its innovative gravity-based feed system that enabled a continuous feed of wood pellets for clean and efficient combustion.

More info at the Alliance for Green Heat

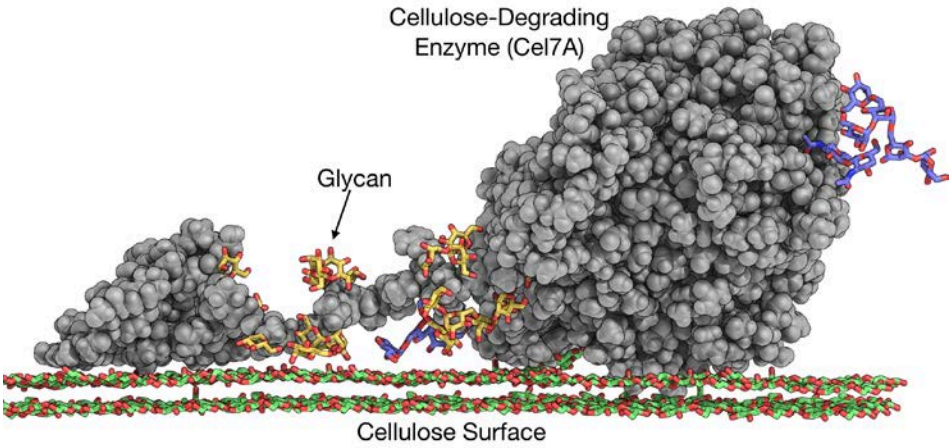
Wood stove from the 2018 Wood Stove Design Challenge. *Photo courtesy of Sam Kittner for Brookhaven National Laboratory*

Research Finds a "Sweet Spot" for Engineering Better Biofuel Enzymes

Researchers at NREL are seeking to unlock the bioenergy stored in plant cell walls by understanding the mechanisms that cellulose-degrading enzymes use to break down cellulose and identifying the means to improve their performance. Cellulose in plant cell walls is the largest reservoir of renewable carbon on Earth. However, easily accessing that cellulose is a challenge. One strategy to overcome this is to engineer cellulose-degrading enzymes for improved performance—a task that requires detailed knowledge of enzyme structure and function. Glycans—or small sugar molecules—decorate the surface of enzymes. These sugars are added to enzymes through a process known as "glycosylation," which is known to have a substantial impact on enzyme function. However, the specific ways that different glycans affect enzyme functions have been elusive until now.

NREL engineered a line of cellulase mutants that lacked various combinations of glycosylation sites and then compared the function of mutant enzymes to native enzymes. This allowed researchers to gather critical data about the relationships between each specific glycan, its function, and its location. NREL discovered that, depending on the type of glycan and where it is attached—its "sweet spot"—glycosylation can achieve a few advantages. This research suggests that fine-tuning glycosylation could provide a new avenue for improving cellulase enzyme activity—which means more efficient and cost-effective production of biofuels and bioproducts.

More info at Energy.gov



The cellulose-degrading enzyme, Cel7A (shown in gray), degrades cellulose (green and red) into soluble sugars, which can then be upgraded into valuable fuels, chemicals, and materials. NREL researchers demonstrated the impact of Cel7A's glycans (shown in yellow and blue) on the enzyme's performance, further enabling glycan control as a "knob to turn" in engineering Cel7A. *Image courtesy of Brandon Knott/NREL*

From Breakfast to Biocrude: Study Identifies Waste-to-Energy Production Potential

NREL and PNNL researchers performed detailed analyses of distinct types of organic wastes—such as cattle waste, wastewater, grease from restaurants, and food waste—for their potential as biofuel feedstocks for production across the United States. Oil researchers used the waste-to-energy technology known as hydrothermal liquefaction (HTL) to assess the feedstock's ability to be transformed into biocrude. Researchers coupled information on these organic wastes from an existing waste feedstock database with PNNL's Biomass Assessment Tool modeling framework and an HTL conversion model to estimate the amounts and geographic distribution of potential biocrude oil production.

On average, results showed as much as 5.9 billion gallons of biocrude oil production each year. Cattle waste showed the potential for 2.7 billion gallons of biocrude per year with the Midwest and Great Lakes regions having the highest resource availability. Wastewater sludge sourced from publicly owned treatment plants could produce 1.1 billion gallons of biocrude per year with a high density of sites in the eastern half of the United States. Fats, oils, and grease were found to be well distributed throughout the nation, with higher density in the eastern half of the United States and estimated to provide 1.16 gallons of biocrude oil per year. Food waste could produce 0.9 billion gallons per year with high-density populations showing high resource availability.

More info at Energy.gov

Novel Method for Producing Renewable Acrylonitrile Wins R&D 100 Award

Researchers at NREL developed a green nitrilation process, which can produce near-100% yields of cost-competitive acrylonitrile (ACN)—a building block for carbon fiber—from non-food biomass. NREL's novel approach led to a prestigious 2018 R&D 100 Award presented by R&D Magazine. The annual awards are given in recognition of exceptional new products or processes that were developed and introduced into the marketplace during the previous year. NREL's research includes two phases. In Phase 1, NREL researchers successfully produced 50 grams of bio-derived ACN by converting corn stover sugars into 3-hydroxypropionic acid (3-HP) using a genetically modified microorganism. 3-HP is then transformed into ACN in subsequent steps. Water and ethanol form

the byproducts of this bio-based nitrilation process. In Phase 2, now underway, NREL researchers and partners expect to produce 50 kilograms of ACN for conversion into renewable carbon fiber and then test to ensure product characteristics—such as tensile strength—are comparable to conventional carbon fiber composites. Partners for this research include MATRIC, Cargill, and Ford Motor Company.

More info at NREL.gov

First-of-a-Kind Algal-Based College Certificate Program Sends Off First Graduates

The Algae Technology Educational Consortium (ATEC) announced its first graduates from the algal certificate program at Santa Fe Community College in Santa Fe, New Mexico. Graduates received their Associate Applied Science Degree in Controlled Environment Agriculture with a certificate in Algae Cultivation in May 2018. ATEC recognized early on that curriculum featuring algal production can provide a sustainable source of biomass for bio-based products, feed, fuel, and foods while support of the renewable energy sector and U.S. bioeconomy.

Some of the Algae Technology Educational Consortium's first graduates celebrate receiving their algal certificates from the Santa Fe Community College, in Santa Fe, New Mexico. *Photo courtesy of Santa Fe Community College*

More info at Energy.gov and Santa Fe Community College

Multi-Lab Collaboration Assesses Algal Biofuel Potential

Argonne National Laboratory, NREL, and PNNL published a harmonized modeling study that evaluated algal biomass production and conversion processes through resource assessment, techno-economic analysis, and life cycle analysis. Building on work from BETO's *Billion-Ton Report*, the multilab study highlights key requirements to achieve techno-economic and environmental performance goals for algal biofuels. Using a targeted annual average cultivation productivity of 26 grams per square meter per day, the harmonization study models biomass production across the United States while identifying a minimum fuel selling price and assessing greenhouse gas, energy, and water use implications. The study also outlines potential for high fuel yields and high-value tailored bioproducts from algal biomass and suggests plausible pathways to achieve future cost targets and sustainability metrics at significant volumes.

More info at NREL.gov

A New Source of Renewable Plastics: Converting Ethanol to Butadiene in a Single Step

Researchers at PNNL developed a catalyst capable of converting ethanol directly into butadiene—a molecule that is the building block for major synthetic plastics and rubber, such as those used in children's toys and tires, and is typically produced from petroleum. Previous ethanol-to-butadiene catalysts were not commercially viable, so PNNL scientists created a more efficient single-step catalyst capable of converting about 70% of ethanol to butadiene in a single pass and at industrially-relevant process conditions. The catalyst uses silica as a support material, with silver nitrate powder and zirconyl nitrate as the catalytic materials. It works by removing hydrogen from the ethanol molecules, creating acetaldehyde. Carbon-to-carbon bonds form producing crotonaldehyde, which is converted to crotyl alcohol. The alcohol undergoes dehydration and creates butadiene. To get such an efficient catalyst, the team had to balance the components of the catalyst just right—especially its acidity.

PNNL's catalyst introduces the possibility of ethanol as a source of butadiene. The ethanol can be derived from renewable sources, such as corn, switchgrass, algae, and even waste gas from steel mills. If successful, the ethanol-to-butadiene catalyst could be a boon to the butadiene market and could open the door to a new renewable source of plastics.

More info at Energy.gov ■

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