House Committee on Science, Space, and Technology
Energy Subcommittee

Bioenergy Research and Development for the Fuels and Chemicals of Tomorrow
Wednesday, March 16, 2022
10:30AM ET

The purpose of this hearing is to examine the status of bioenergy research, development, and demonstration (RD&D) activities carried out by the U.S. Department of Energy. The hearing will also consider advancements in bioenergy research and the potential role of this resource in a cleaner energy transition. Lastly, the hearing will help inform future legislation to support and guide the U.S.'s bioenergy RD&D enterprise.

Witnesses

- Dr. Jonathan Male, Chief Scientist for Energy Processes and Materials, Pacific Northwest National Laboratory (PNNL)
- Dr. Andrew Leakey, Director of the Center for Advanced Bioenergy and Bioproducts Innovation at the University of Illinois Urbana-Champaign
- Dr. Laurel Harmon, Vice President of Government Affairs, LanzaTech
- Dr. Eric Hegg, Professor, Biochemistry and Molecular Biology, Michigan State University

Background

Previous societies have used biomass energy—energy from living organic materials—since the earliest humans made wood fires for cooking and heating. Centuries later, the first commercially used biomass gasifier was built in France in 1840, and in 1880, Henry Ford used ethanol to fuel his first automobiles, the quadricycle.[1] Today, through the advancement of biomass technologies, biomass is used to produce transportation fuels, heat, electricity, and products.[2] In the United States, 4.7% of energy consumed currently comes from this resource, making biomass the second largest source of clean energy in the nation, after nuclear energy, as well as the largest source of renewable energy.[3]

Recent Intergovernmental Panel on Climate Change (IPCC) reports conclude that bioenergy has significant potential to mitigate GHGs if resources are sustainably developed, and efficient technologies are applied.[4] The IPCC adds that through improvements of existing technologies and the development of new technologies, biomass could meet its potential as a major resource of clean energy production and thus deliver significant GHG mitigation performance at approximate 80 to 90% reduction compared to current fossil energy products. To achieve this level of mitigation performance, additional RD&D of conversion technologies and current

[1] https://www.energy.gov/eere/bioenergy/bioenergizeme-virtual-science-fair-biomass-history-timeline
[2] https://www.energy.gov/eere/bioenergy/bioenergy-basics#:~:text=Bioenergy%20is%20one%20of%20many,heat%2C%20electricity%2C%20and%20products.
[3] https://www.eia.gov/energyexplained/renewable-sources/
[4] https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-2-Bioenergy-1.pdf

feedstock systems is needed, as well as future feedstock options including perennial crops, forest products, and biomass residues and wastes.

Bioenergy may have an important role to play in enabling the clean energy transformation of hard-to-abate sectors such as cement, chemicals, aviation, and shipping. This is because biomass covers a large range of biomaterial with diverse chemical composition and properties, thus making it a highly versatile resource suitable for many applications that can be stored under multiple forms, including gaseous, liquid, or other molecules via conversion processes.[5]

Types of Biofuels

Ethanol

Ethanol is an alcohol used as a blending agent with gasoline to increase octane. The most common blend of ethanol is E10 (10% ethanol, 90% gasoline) and is approved for use in most conventional gasoline-powered vehicles up to E15 (15% ethanol, 85% gasoline). Some vehicles, called flexible fuel vehicles, are designed to run on E85 (a gasoline-ethanol blend containing 51%–83% ethanol, depending on geography and season), an alternative fuel with much higher ethanol content than regular gasoline. Approximately 97% of gasoline in the United States contains ethanol.[6]

Most ethanol is made from corn starch in the United States, but scientists are continuing to develop technologies that would allow for the use of cellulose and hemicellulose, the non-edible fibrous material that constitutes the bulk of plant matter.[7]

Biodiesel

Biodiesel is a liquid fuel produced from renewable sources, such as new and used vegetable oils and animal fats and is a cleaner-burning replacement for petroleum-based diesel fuel. Like petroleum-derived diesel, biodiesel is used to fuel compression-ignition (diesel) engines. Biodiesel can be blended with petroleum diesel in any percentage, including B100 (pure biodiesel) and, the most common blend, B20 (a blend containing 20% biodiesel and 80% petroleum diesel).[8]

Renewable Hydrocarbon "Drop-In" Fuels

Petroleum fuels, such as gasoline, diesel, and jet fuel, contain a complex mixture of hydrocarbons (molecules of hydrogen and carbon), which are burned to produce energy. Hydrocarbons are also produced from biomass sources through a variety of biological and thermochemical processes. Biomass-based renewable hydrocarbon fuels, also known as green or

[5] https://www.energy-transition-institute.com/insights/biomass-to-energy
[6] https://afdc.energy.gov/fuels/ethanol.html
[7] https://energy.wisc.edu/education/for-educators/educational-materials/why-it-so-difficult-create-cellulosic-ethanol
[8] https://afdc.energy.gov/fuels/biodiesel.html

drop-in biofuels, are nearly identical to the petroleum-based fuels they are designed to replace—thus making them compatible with today's engines, pumps, and other infrastructure.

Renewable hydrocarbon fuels are produced from non-food biomass, such as perennial grass. The processes to make these fuels are more complex and less well developed than those for first-generation biofuels (conventional ethanol and biodiesel), and often involve converting fibrous non-edible material called "cellulose" into fuel.

Types of renewable hydrocarbon biofuels include:

- Renewable diesel (differs from conventional biodiesel)
- Green Gasoline
- Sustainable Aviation Fuels

Sustainable Aviation Fuels

One area of significant promise for biofuels is within the aviation sector. Data from 2019 showed that taking a long-haul flight generates more carbon emissions than the average person in dozens of countries around the world produces in an entire year[9], and a large aircraft, such as a Boeing-747, consumes about 4 liters of aviation fuel per second.[10]

The environmental impact of continued dependence on fossil fuel-derived jet fuel has spurred international efforts in the aviation sector toward alternative solutions, most recently culminating in a pledge of the global air transportation industry to achieve net-zero emissions by 2050. The International Air Transport Association estimates that to meet this emissions reduction goal, the industry must abate a cumulative total of 21.2 gigatons of carbon between now and 2050.[11]

Given the limited options for decarbonization, sustainable aviation fuels (SAF) are viewed as one of the nearest term options for the hard-to-abate sector. SAF possesses similar properties to conventional jet fuel and, depending on the feedstock and technologies used to produce SAF, the fuel can significantly reduce lifecycle GHG emissions as compared to conventional jet fuel. Some emerging SAF pathways are even targeting a net-negative GHG footprint.[12]

SAF Pathways

There are seven SAF "pathways" or fuel categories that have been approved under the American Society for Testing and Materials (ASTM) standards. The SAF volumes of each pathway must be blended with conventional aviation turbine fuel before they are certified as being equivalent and subsequently used in aircrafts.[13]

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[9] https://www.theguardian.com/environment/ng-interactive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-many-people-do-in-a-year
[10] https://simpleflying.com/jet-aircraft-fuel-consumption/
[11] https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/
[12] https://www.nrel.gov/news/program/2021/from-wet-waste-to-flight-scientists-announce-fast-track-solution-for-net-zero-carbon-sustainable-aviation-fuel.html
[13] https://afdc.energy.gov/fuels/emerging_hydrocarbon.html

One noted barrier to greater SAF adoption is cost. SAF currently costs four times as much as conventional jet fuel and makes up less than one percent of fuel available in the market. Increasing its cost-competitiveness with petroleum-based fuels is seen as essential since fuel makes up about 30% of the operating cost of an airline.[14]

In response to the barriers to greater SAF adoption, DOE, DOT, and USDA created the Federal SAF Grand Challenge, a government-wide Memorandum of Understanding (MOU) that will attempt to reduce the cost, enhance the sustainability, and expand the production and use of SAF. The MOU also strives to achieve a minimum of a 50% reduction in life cycle GHG emissions compared to conventional jet fuel; and meet a goal of supplying sufficient SAF to meet 100% of aviation fuel demand by 2050.[15]

Bioproducts

In addition to fuels, biomass can be used to create valuable chemicals and materials, known as "bioproducts." Approximately 16% of U.S. crude oil consumption is used to make petrochemicals and products, such as plastics for industrial and consumer goods, fertilizers, and lubricants. According to the IEA, 2018 CO_2 emissions from the chemical sector were 1.5 gigatons or 18% of industrial CO_2 emissions.[16]

Common biobased products include:

- Household cleaners
- Paints and stains
- Personal care items
- Plastic bottles & containers
- Packaging materials
- Soaps & detergents
- Lubricants
- Clothing
- Building materials

The production of bioproducts relies on much of the same feedstocks, infrastructure, feedstock commoditization, and technologies that are central to biofuels production. Therefore, according to the Department of Energy, once technologies are proven for bioproduct applications, they could be readily transferred and greatly improve biofuel production.[17]

DOE Bioenergy R&D Programs

Bioenergy Technologies Office

[14] https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf
[15] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge
[16] https://www.iea.org/reports/the-future-of-hydrogen
[17] https://www.energy.gov/eere/bioenergy/bioproduct-production

The U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO) supports research, development, and demonstration of technologies to enable the sustainable use of domestic biomass and waste resources to produce biofuels and bioproducts.[18]

The five BETO program areas are:

- **Advanced Algal Systems** - supports research and development to lower the costs of producing algal biofuels and bioproducts.[19]
- **Conversion Technologies** - supports research and development in technologies for converting biomass feedstocks into finished liquid transportation fuels, co-products or chemical intermediates, and biopower.[20]
- **Data, Modeling, and Analysis** - supports research, analysis, and tool development to address the economic and environmental dimensions of bioenergy and bioproducts. [21]
- **Feedstock Technologies** - focuses on technologies and processes that transform renewable carbon sources into conversion-ready feedstocks.[22]
- **Systems Development and Integration program** - focuses on lowering the risk of bioenergy production technologies through verified proof of performance at the pre-pilot, pilot, and demonstration-scales. [23]

Biological Systems Science

Bioenergy research is now a principal focus in the DOE Office of Science's Biological and Environmental Research (BER) program. BER's Biological Systems Science Division's (BSSD) research focuses on integrating discovery and hypothesis-driven sciences with technology development to study plant and microbial systems relevant energy production and storage. BSSD defines systems biology as the "multidisciplinary study of complex interactions specifying the function of entire biological systems—from single cells to multicellular organisms—rather than the study of individual isolated components."[24] Research areas within the division include genome sequencing, proteomics, metabolomics, structural biology, computational models, and high-resolution imaging and characterization.

BSSD supports the Genomic Science program, considered a leading program in systems biology research, which uses genome sequences as the blueprint for understanding the common principles that govern living systems. The program supports single-investigator and team projects in research areas related to bioenergy, environmental microbiome science, and computational biology;[25] and also supports four distinct Bioenergy Research Centers to accelerate research pathways to improve and scale advanced biofuel and bioproduct production processes.

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[18] https://www.energy.gov/eere/bioenergy/beto-accomplishments
[19] https://www.energy.gov/eere/bioenergy/advanced-algal-systems
[20] https://www.energy.gov/eere/bioenergy/conversion-technologies
[21] https://www.energy.gov/eere/bioenergy/data-modeling-and-analysis
[22] https://www.energy.gov/eere/bioenergy/feedstock-technologies
[23] https://www.energy.gov/eere/bioenergy/systems-development-and-integration
[24] https://science.osti.gov/ber/Research/bssd
[25] https://science.osti.gov/ber/Research/bssd/Genomic-Science

Bioenergy Research Centers

In an effort to focus the most advanced biotechnology-based resources on the challenges of biofuel production, DOE has established four Bioenergy Research Centers (BRCs). Each center pursues research underlying a range of biological solutions for bioenergy applications to address three major challenges – the development of next-generation bioenergy crops; the discovery and design of enzymes and microbes with novel biomass-degrading capabilities; and the discovery and design of microbes that create fuels directly from biomass.[26] Advances resulting from the BRCs are providing the knowledge needed to develop new biobased products, methods, and tools that will benefit the emerging advanced biofuel industry.

- **Center for Advanced Bioenergy and Bioproducts Innovation (CABBI)**, led by the University of Illinois at Urbana-Champaign. CABBI integrates recent advances in agronomics, genomics, biosystems design, and computational biology to increase the value of energy crops, using a "plants as factories" approach to grow fuels and chemicals in plant stems and an automated foundry to convert biomass into valuable chemicals that are ecologically and economically sustainable.[27]
- **Center for Bioenergy Innovation (CBI)**, led by DOE's Oak Ridge National Laboratory. CBI conducts research to accelerate the domestication of bioenergy-relevant plants and microbes to enable high-impact, value-added coproduct development at multiple points in the bioenergy supply chain.[28]
- **Great Lakes Bioenergy Research Center (GLBRC)**, led by the University of Wisconsin-Madison in partnership with Michigan State University. GLBRC is developing scientific and technological advances to ensure sustainability at each step in the process of creating biofuels and bioproducts from lignocellulose.[29]
- **Joint BioEnergy Institute (JBEI)**, led by DOE's Lawrence Berkeley National Laboratory. JBEI utilizes advanced tools in molecular biology, chemical engineering, and computational and robotics technologies to transform biomass into biofuels and bioproducts.[30]

Joint Genome Institute

The BSSD subprogram also supports the Joint Genome Institute (JGI), established in 1997 to connect expertise and resources in genome mapping, DNA sequencing, technology development, and information sciences. JGI serves as the central source for genome sequence production capabilities for plants, microbes, and microbial communities. JGI's capabilities are instrumental

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[26] https://www.osti.gov/servlets/purl/985252
[27] https://cabbi.bio/
[28] https://cbi.ornl.gov/
[29] https://www.glbrc.org/
[30] https://www.jbei.org/

to several BER programs, such as the BRCs, and the Institute's resources are available to the larger research community. JGI is currently engaged in enhancing its expertise to further support microbiome research, and production of complex plant, fungal, and microbial genomes supporting systems biology research within the BRCs and the BER portfolio.[31]

[31] https://jgi.doe.gov/about-us/