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

BIOENERGY TECHNOLOGIES OFFICE

New pathways will enable energy-efficient biochemical conversion of lignocellulosic biomass into biofuels that are compatible with today's vehicles and infrastructure. *Photos (clockwise from upper left): iStock/4373820, Energetics Inc., iStock/6091090, NREL/15040*

Biochemical Conversion:
Using Enzymes, Microbes, and Catalysts to Make Fuels and Chemicals

Advanced biofuels are part of America's all-of-the-above strategy to develop domestic energy resources and win the global race in clean energy technology. The Bioenergy Technologies Office works with the emerging U.S. bioindustry to sustainably convert non-food biomass resources into cost-competitive biofuels, biopower, and bioproducts.

Cellulosic biomass—the fibrous, non-edible part of plants—is an abundant domestic resource that can potentially provide a renewable feedstock for next-generation biofuels and bioproducts. The U.S. Department of Energy's (DOE's) Bioenergy Technologies Office conducts collaborative research, development, and demonstration (RD&D) projects to improve several processing routes for the conversion of cellulosic biomass.

Biochemical conversion entails breaking down biomass to make the carbohydrates available for processing into sugars, which can then be converted into biofuels and bioproducts through the use of microorganisms and catalysts. Potential fuel blend stocks and other bioproducts include the following:

- Renewable gasoline
- Ethanol and other alcohols
- Renewable chemical products
- Renewable diesel

Key challenges for biochemical conversion include the considerable cost and difficulty involved in breaking down the tough, complex structures of the cell walls in cellulosic biomass. The Bioenergy Technologies Office is exploring more efficient and cost-effective ways to gain access to these useful sugars for conversion processing.

Another key challenge is to more efficiently convert the sugars into biofuels and purify them. The Office is exploring new pathways and separation technologies to achieve this goal.

> Renewable, home-grown fuels are a key part of our strategy for a clean-energy future.
>
> *—President Barack Obama*
> *POET Biorefinery in Macon, Missouri*

Biochemical Conversion Step by Step

Biochemical conversion uses biocatalysts, such as enzymes, in addition to heat and other chemicals, to convert the carbohydrate portion of the biomass (hemicellulose and cellulose) into an intermediate sugar stream. These sugars are intermediate building blocks that can then be fermented or chemically catalyzed into a range of advanced biofuels and value-added chemicals. The overall process can be broken into the following essential steps:

A. **Feedstock Supply:** Feedstocks for biochemical processes are selected for optimum composition, quality, and size. Feedstock handling systems tailored to biochemical processing are essential to cost-effective, high-yield operations.

B. **Pretreatment:** Biomass is heated (often combined with an acid or base) to break the tough, fibrous cell walls down and make the cellulose and hemicellulose easier to hydrolyze (see next step).

C. **Hydrolysis:** Enzymes (or other catalysts) enable the sugars within cellulose and hemicellulose in the pretreated material to be separated and released over a period of several days.

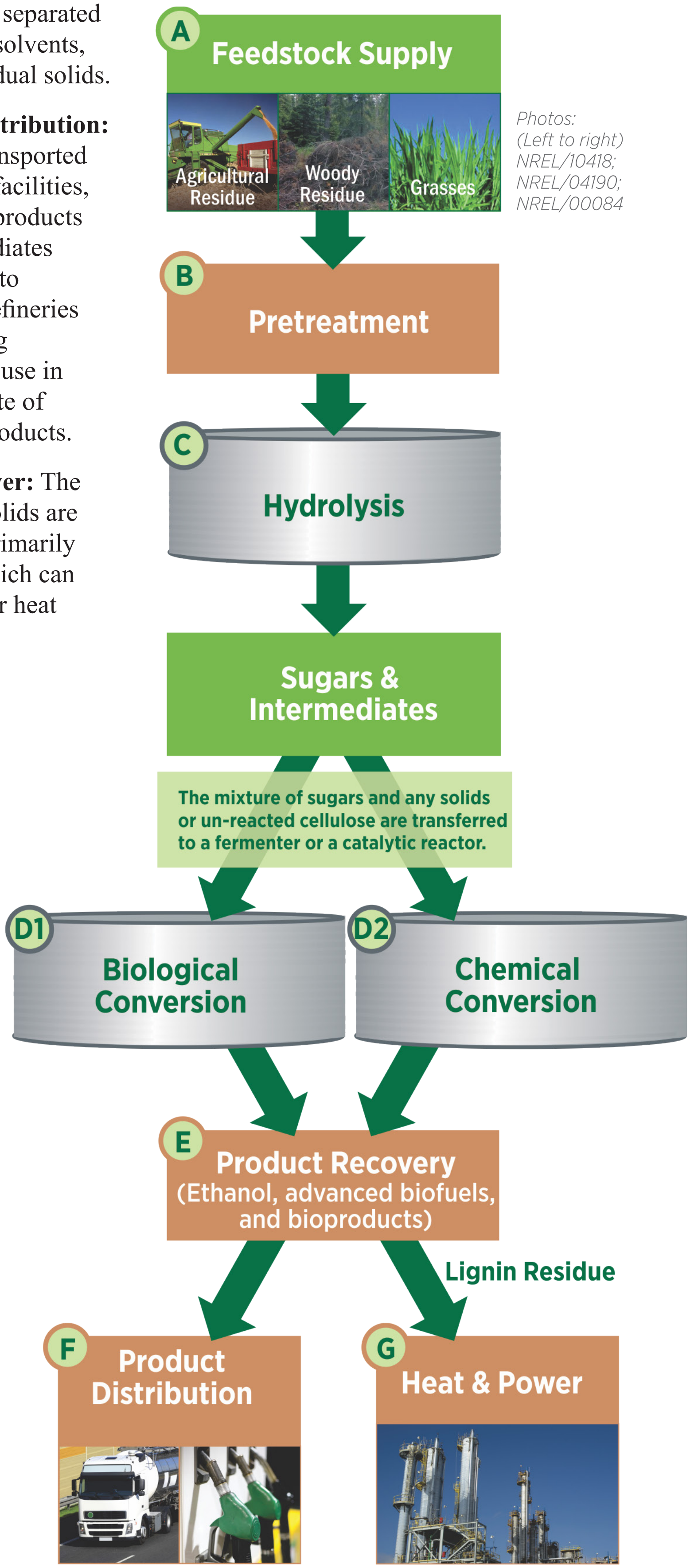
D1. **Biological Conversion:** Microorganisms are added, which then use the sugars to generate other molecules suitable for use as fuels or building-block chemicals.

D2. **Chemical Conversion:** Alternatively, the sugars can be converted to fuels or an entire suite of other useful products using chemical catalysis.

E. **Product Recovery:** Products are separated from water, solvents, and any residual solids.

F. **Product Distribution:** Fuels are transported to blending facilities, while other products and intermediates may be sent to traditional refineries or processing facilities for use in a diverse slate of consumer products.

G. **Heat & Power:** The remaining solids are composed primarily of lignin, which can be burned for heat and power.



Photos: (Left to right) NREL/10418; NREL/04190; NREL/00084

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Improving Conversion Efficiency

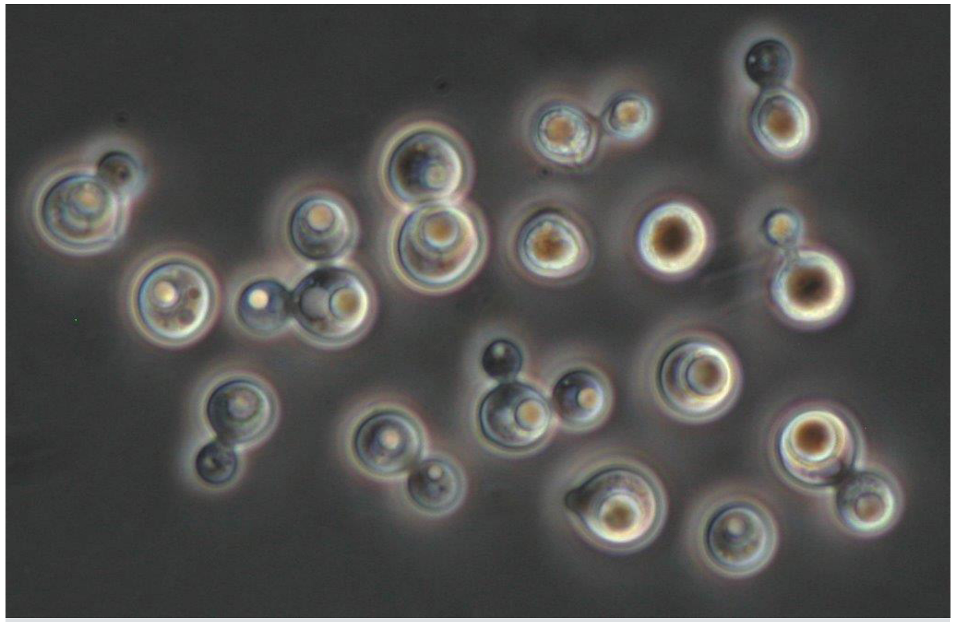
To improve the economics of biofuels production, the Bioenergy Technologies Office is exploring new pathways for integrated biorefineries to convert diverse feedstocks into cost-competitive liquid transportation fuels, bioproducts, and biopower. To optimize the role of biochemical conversion within this flexible production scenario, researchers are developing technologies needed throughout the process. A few examples are provided below.

Sample Research Areas:

- **Enzymes for Hydrolysis.** A new generation of enzymes and enzyme production technologies are needed to cost-effectively hydrolyze the cellulose and hemicellulose in biomass to free the sugars for conversion. The program is working to identify the most productive, naturally occurring enzymes and then use a variety of techniques to increase their efficiency. Research objectives also include lowering the cost of the enzyme unit operation in the sugar extraction process (saccharification).

Enzyme Primer

- Enzymes are proteins that naturally enable chemical reactions in living organisms.
- Many of these reactions break down larger molecules into smaller ones.
- Enzymes act as catalysts to dramatically increase reaction times. Reactions that might otherwise take a year may take only a few seconds in the presence of the right enzyme.



Researchers are exploring use of sugar-fed oleaginous yeasts to provide lipids for subsequent conversion into hydrocarbon blendstocks for gasoline, diesel and jet fuel. The image shows the yeast *Lipomyces starkeyi*, which can be cultured to accumulate a significant portion of its cell biomass as lipids. In this micrograph, the lipid bodies are spheres in the middle of the cells; some appear brown (false color). *Photo: PNNL*

- **Microorganisms for Conversion.** Researchers are using sophisticated metabolic engineering techniques to develop microorganisms that can more effectively ferment the variety of sugars derived from biomass. Specifically, they are developing microorganisms that can co-ferment both the five-carbon sugars (such as xylose from the hemicellulose) and the more common six-carbon sugars (such as glucose) in cellulosic biomass. Scientists in the public and private sectors are working to develop designer strains for specific feedstocks, feedstreams, and processes and to validate the performance of these strains in improving production economics. Future investments will focus on microorganisms that produce longer-chain molecules that can be used as biofuel blend stocks (or biofuel intermediates), biochemicals, or other bioproducts.
- **Advanced Catalytic Conversion.** A promising area of research is the development of chemical catalytic processes for transforming sugars into chemical intermediates that can be further processed into a range of biofuel blend stocks and chemicals.

Scientist bioprospecting for microbes at Yellowstone National Park. *Photo: INL*

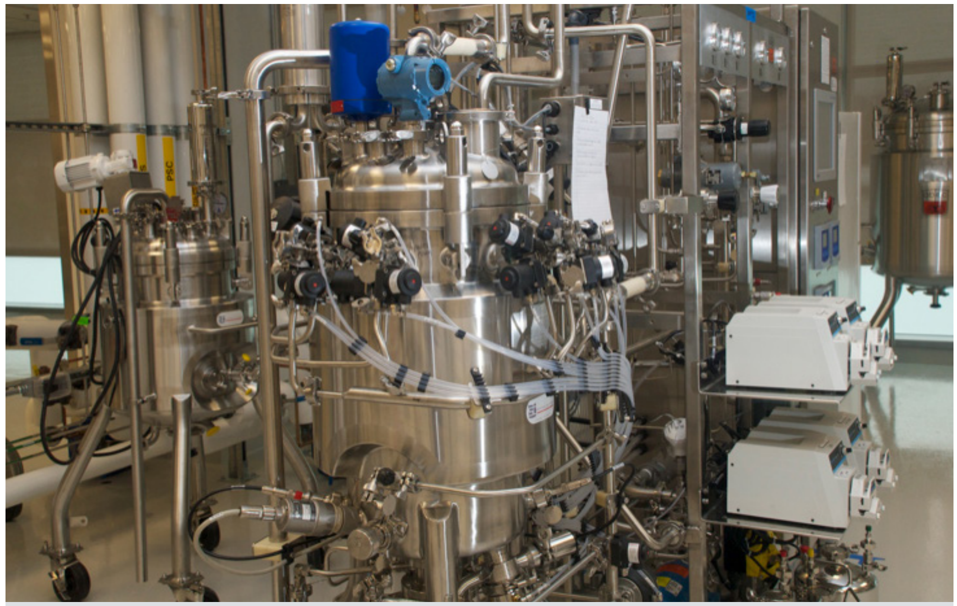
Public-Private Research Partnerships

DOE's research partners in the national laboratories, universities, and industry are actively exploring and demonstrating novel biochemical conversion processes at bench, pilot, demonstration, and commercial scales. As conversion technologies mature, higher levels of integration will become feasible. Second-generation biorefineries are likely to integrate biochemical and thermochemical processes, expanding the efficient use of a wide range of feedstocks.

Process Demonstration Units (PDUs)

DOE is expanding its capability to demonstrate and evaluate bioprocessing technologies for the production of biofuels and chemicals. The Bioenergy Technologies Office has established two such facilities for use by industry and other researchers:

- The Advanced Biofuels PDU at Lawrence Berkeley National Laboratory (LBNL) accepts diverse feedstocks to demonstrate the efficiency of novel biofuel production processes, including ionic liquids.
- The Integrated Biorefinery Research Facility at the National Renewable Energy Laboratory evaluates the efficiency and fuel yields for different feedstock blends, process designs, and conditions.



The Advanced Biofuels Process Demonstration Unit at LBNL can convert biomass into advanced biofuels in sufficient quantities for engine testing. *Photo: LBNL*

Researchers at NREL's Integrated Biorefinery Research Facility study biochemical processes for the conversion of lignocellulosic biomass. NREL can process biomass at a scale of 1 ton per day. *Photo: NREL/16330*

Learn More

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