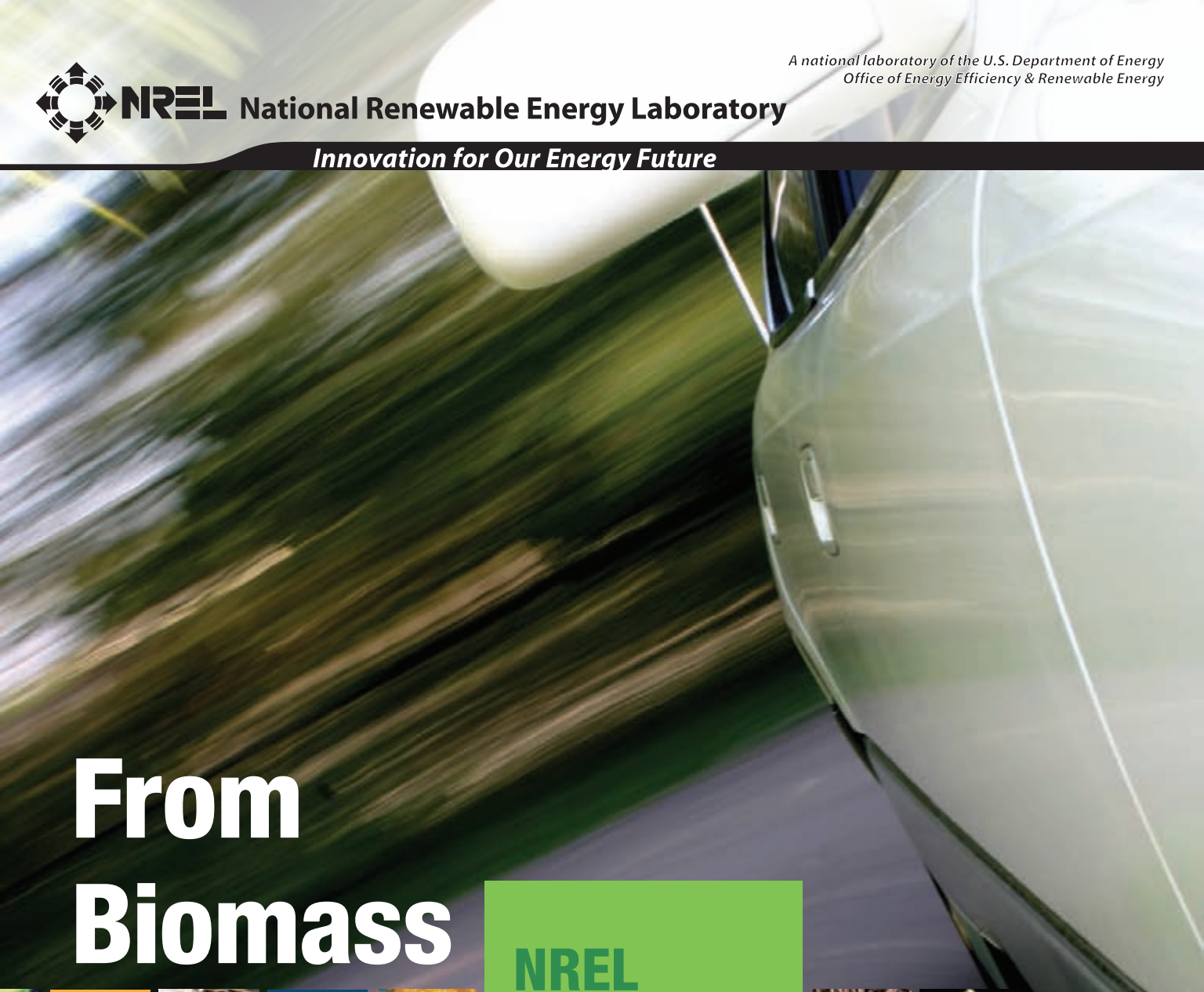
A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future



From Biomass to Biofuels

NREL Leads the Way

The Wide World of Biofuels

Fuel	Source	Benefits	Maturity
Grain/Sugar Ethanol	Corn, sorghum, and sugarcane	• Produces a high-octane fuel for gasoline blends • Made from a widely available renewable resource	Commercially proven fuel technology
Biodiesel	Vegetable oils, fats, and greases	• Reduces emissions • Increases diesel fuel lubricity	Commercially proven fuel technology
Green Diesel and Gasoline	Oils and fats, blended with crude oil	• Offer a superior feedstock for refineries • Are low-sulfur fuels	Commercial trials under way in Europe and Brazil for fuel
Cellulosic Ethanol	Grasses, wood chips, and agricultural residues	• Produces a high-octane fuel for gasoline blends • Is the only viable scenario to replace 30% of U.S. petroleum use	DOE program is focused on commercial demonstration by 2012
Butanol	Corn, sorghum, wheat, and sugarcane	• Offers a low-volatility, high energy-density, water-tolerant alternate fuel	BP and DuPont plan to introduce butanol fuel in 2007
Pyrolysis Liquids	Any lignocellulosic biomass	• Offer refinery feedstocks, fuel oils, and a future source of aromatics or phenols	Several commercial facilities produce energy and chemicals
Syngas Liquids	Various biomass as well as fossil fuel sources	• Can integrate biomass sources with fossil fuel sources • Produce high-quality diesel or gasoline	Demonstrated on a large scale with fossil feedstocks, commercial biomass projects under consideration
Diesel/Jet Fuel From Algae	Microalgae grown in aquaculture systems	• Offer a high yield per acre and an aquaculture source of biofuels • Could be employed for CO_2 capture and reuse	Demonstrated at pilot scale in 1990s
Hydrocarbons From Biomass	Biomass carbohydrates	• Could generate synthetic gasoline, diesel fuel, and other petroleum products	Laboratory-scale research in academic laboratories

Most Mature

Least Mature

How Biofuels Are Produced

Biomass resources run the gamut from corn kernels to corn stalks, from soybean and canola oils to animal fats, from prairie grasses to hardwoods, and even include algae.

In the long run, we will need diverse technologies to make use of these different energy sources. Some technologies are already developed; others will be. Today, the most common technologies involve biochemical, chemical, and thermochemical conversion processes.

Ethanol, today's largest volume biofuel, is produced through a *biochemical conversion process*. In this process, yeasts ferment sugar from starch and sugar crops into ethanol. Most of today's ethanol is produced from cornstarch or sugarcane. But biochemical conversion techniques can also make use of more abundant "cellulosic" biomass sources such as grasses, trees, and agricultural residues.

NREL's researchers develop processes that use heat, pressure, chemicals, and enzymes to unlock the sugars in cellulosic biomass. The sugars are then fermented to ethanol, typically by using genetically engineered microorganisms. Because cellulosic ethanol is the leading candidate for replacing a large portion of U.S. petroleum use, it is the focus of DOE's Biomass Program.

A much simpler *chemical process* is used to produce biodiesel. Today's biodiesel facilities start with vegetable oils, seed oils, or animal fats and react them with methanol or ethanol in the presence of a catalyst. In addition, NREL's genetic engineering work has produced algae with a high lipid content that can be used as another source of biodiesel.

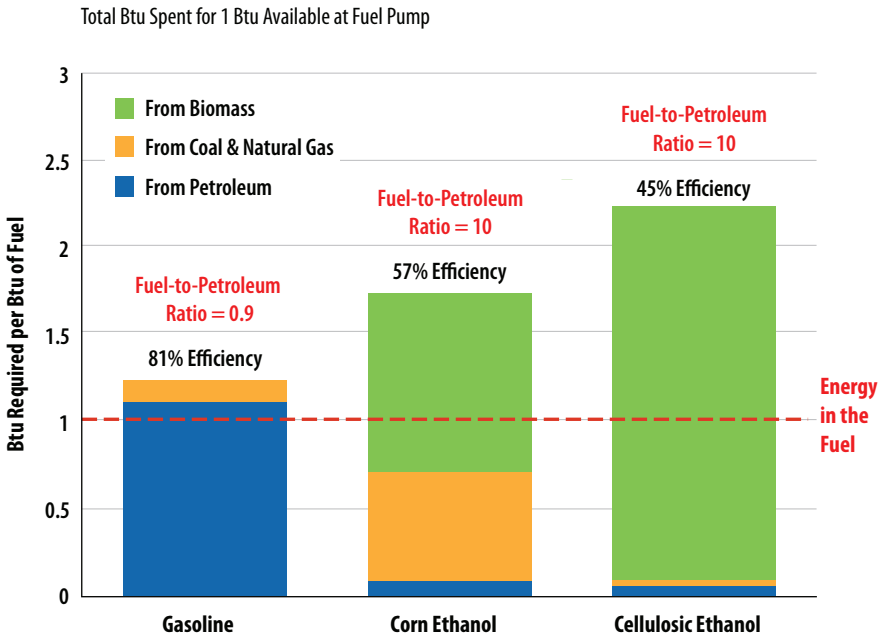
Algae are a form of biomass which could substantially increase our nation's ability to produce domestic biofuels. Algae and plants can serve as a natural source of oil, which conventional petroleum refineries can convert into jet fuel or diesel fuel—a product known as "green diesel."

NREL researchers also explore and develop *thermochemical processes* for converting biomass to liquid fuels. One such process is pyrolysis, which decomposes biomass by heating it in the absence of air. This produces an oil-like liquid that can be burned like fuel oil or refined into chemicals and fuels, such as "green gasoline." Thermochemical processes can also be used to pretreat biomass for conversion to biofuels.

Another thermochemical process employed at NREL is gasification. In this process, heat and a limited amount of oxygen are used to convert biomass into a hot synthesis gas. This "syngas" can be combusted and used to produce electricity in a gas turbine or converted to hydrocarbons, alcohols, ethers, or chemical products. In this process, biomass gasifiers can work side by side with fossil fuel gasifiers for greater flexibility and lower net greenhouse gas emissions.

In the future, biomass-derived components such as carbohydrates, lignins, and triglycerides might also be converted to hydrocarbon fuels. Such fuels can be used in heavy-duty vehicles, jet engines, and other applications that need fuels with higher energy densities than those of ethanol or biodiesel.

Energy Required to Produce Fuels



Based on "Well to Wheels Analysis of Advanced Fuel/Vehicle Systems" by Wang et al. (2005)




The U.S. Potential for Biofuels

The United States now consumes about 7 billion barrels of oil each year, and we produce more than 100 million barrels of ethanol each year from corn grain. But corn is only a small fraction of the biomass resource available. If we draw on a variety of biomass resources, biofuels can meet a significant portion of our need for liquid transportation fuels.

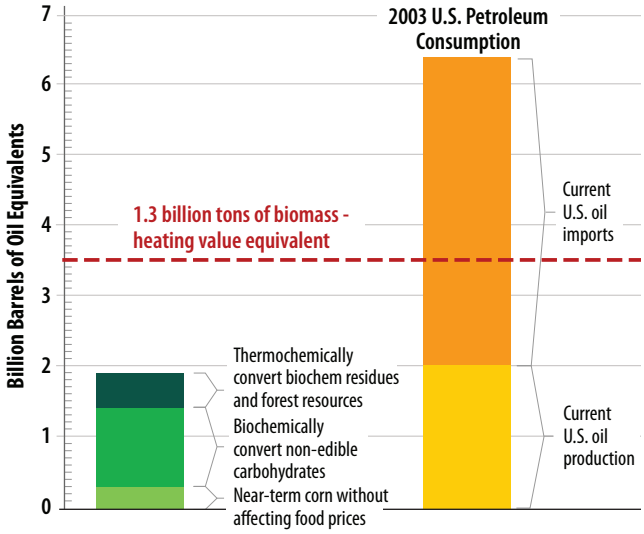
DOE and the U.S. Department of Agriculture recently demonstrated how 1.3 billion tons of biomass could be produced exclusively for energy production in the United States each year with only modest changes in terrestrial crop practices. With today's best available conversion technology, this quantity of biomass can replace about 30% of the petroleum our nation currently consumes. As conversion processes improve and we draw on a wider range of biomass resources, including aquatic forms of biomass, we should find that the potential for biofuels is even greater.

Some people believe that more fossil energy is required to produce ethanol than it provides as fuel. But in fact, a recent study by DOE's Argonne National Laboratory and General Motors Corp. concluded that today's corn growers and ethanol plants consume only about 7 British thermal units (Btu) of fossil-fuel energy for every 10 Btu of fuel they produce. In other words, it takes less energy to produce ethanol than is supplied by ethanol fuel, so the fuel provides a net energy benefit.

The benefits are even greater in terms of replacing petroleum. Because most of the fossil-fuel energy is supplied by coal and natural gas, only about 1 Btu of petroleum is consumed for every 10 Btu of ethanol fuel produced. That means that every gallon of ethanol fuel produced significantly reduces our use of petroleum.

The energy balance is even better for the production of cellulosic ethanol. Because the process residues will be used to produce heat and power for the conversion facility, biomass will provide 95% of the energy needed to make the fuel, with the remaining energy coming from petroleum. Because the process is only about 45% efficient, the net result is the same as that for corn ethanol: 1 Btu of petroleum is burned for every 10 Btu of ethanol fuel produced. However, the process uses

The 1.3-Billion-Ton Biomass Scenario



less fossil fuel overall and thus produces fewer greenhouse gas emissions. Gains in processing efficiencies and economies of scale should boost the petroleum replacement and greenhouse gas benefits of cellulosic ethanol significantly.

NREL's Approach to Efficient, Affordable Biofuels

The long-term vision for biofuels at DOE involves integrating a number of conversion technologies into a biomass-based refinery, or "biorefinery." Biorefineries could draw on a variety of biomass feedstocks and employ several conversion technologies to produce fuels, chemicals, and other products. NREL's approach is to help industry incorporate these technologies into today's agricultural, forestry, aquaculture, and petroleum industries to help the nation reap the many benefits of tomorrow's biorefineries.

NREL's research focuses on cellulosic ethanol, but we also work to increase the efficiency and reduce the cost of a wide range of biofuels. By working with industry on applied R&D, we aim to increase the yield of today's processes, such as corn ethanol production. By leading the R&D of new biofuels technologies, we are advancing not only cellulosic ethanol but also pyrolysis and gasification. And by exploring revolutionary biofuels concepts, we are opening the door for future fuels, such as the production of hydrocarbons from carbohydrates or algae.





Fueling The Future

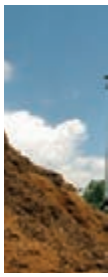
We rely on transportation fuels to keep the engines humming in our cars and trucks and trains and planes. And that reliance is expected to grow. Energy experts predict a 25% increase in U.S. petroleum consumption and a 35% increase in worldwide petroleum demand by 2025.

Where will all that fuel come from? We know from experience that all kinds of unexpected events—from hurricanes in the Gulf Coast to turmoil in the Middle East—can disrupt oil supplies and ramp up the prices of crude oil and commercial fuels. As a result, there is a pressing need for alternative, domestic sources of fuel.

Biofuels are ready to meet that need. Biofuels are one way to ensure adequate fuel supplies at a time when yields from existing oil fields are declining and new fields are not yet up and running. Biofuels can do much to help fill the gap between limited fuel supplies and increasing worldwide demand—a gap that is almost sure to widen in the coming years.

Can we produce enough biofuels to fill the gap? At the National Renewable Energy Laboratory (NREL), we think the answer is "yes." NREL, a U.S. Department of Energy (DOE) research facility, is the leading federal laboratory for biofuels research and development. Our expertise extends to a range of biofuels derived from a variety of agricultural, forest, and other feedstocks. Our researchers have achieved breakthroughs in the development and demonstration of biofuel processes, and they continue to lead the R&D community in the development of clean, inexpensive fuels from a virtually inexhaustible source of energy.

Biofuels are sure to be an exciting part of our energy future. Through our partnerships with industry, NREL is helping lead the way. You can be an important part of that future by joining with NREL today to enhance and develop tomorrow's biofuels.



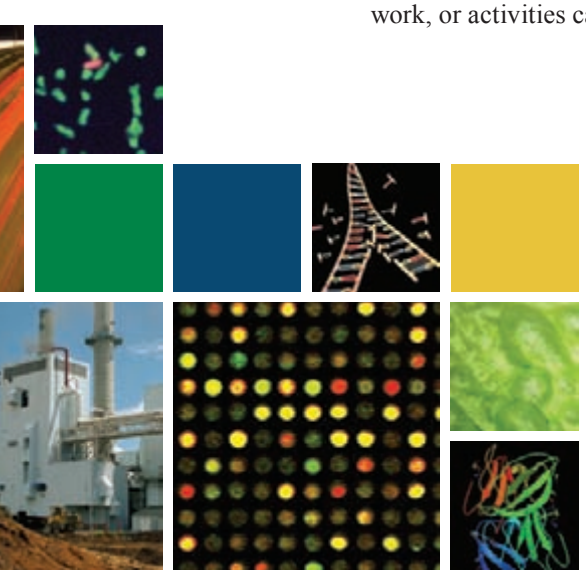
Partnering With NREL

There is no better time to get involved in biofuels research. Collaborations of experts from national laboratories, research organizations, and industry are key to moving biofuels production technologies into the marketplace.

NREL is ready to help you achieve your business goals. You can take advantage of NREL's biomass research capabilities and expertise in any of these ways:

- Your technical team can work collaboratively with NREL through a Cooperative Research and Development Agreement (CRADA). This is the most widely used means of industrial collaboration.
- You can stipulate specific research tasks at NREL through a Technology Partnership Agreement or Sponsored Research agreement. These are effective ways to take advantage of NREL's expertise and unique research facilities, such as our one-ton-per-day production capability.
- You can request simpler tasks through technical or analytical service agreements.

In addition, all of NREL's patented biomass technologies are available for licensing, and NREL's world-class biomass user facilities are available to industry, university, and government researchers. NREL may provide trained staff to conduct or direct the work, or activities can be performed by staff from the participating organization.



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Please see the following Web sites:

NREL's R&D "Working With Us" Web page: http://www.nrel.gov/biomass/workingwithus.html
NREL's Biomass Research Web site: http://www.nrel.gov/biomass/
DOE Biomass Program Web site: http://www.eere.energy.gov/biomass/

The National Bioenergy Center is headquartered at NREL:

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