Biodiesel (Courtesy of How Stuff Works)

If you've read or watched the news lately, you've probably come across some article, snippet or sound bite related to oil and oil prices. Even in your daily routines, there's a good chance of someone mentioning it. Whether it's in automotives, economics, history, geography or politics, oil has managed to filter into almost every aspect of our daily lives. It's one of the most discussed (and controversial) commodities that consumers rely on daily.

All of this talk about oil sparks continued interest in **gasoline alternatives**. Things like electric cars and hydrogen fuel cells are being talked about as feasible alternatives to oil. As technology improves, these concepts could become reality. But what about now?

Alternative Energy Image Gallery

Photo courtesy Nebraska Soybean Board
Bus that runs on soybean biodiesel. See more pictures of alternative energy.

Lost in the mix are the **biofuels**, fuels made from biological ingredients instead of fossil fuels. These starting ingredients can range from corn to soybeans to animal fat, depending on the type of fuel being made and the production method.

In this article, we'll take a closer look at **biodiesel**, one of the major biofuels. For starters, it would be a good idea to check out How Car Engines Work and How Diesel Engines Work to get some background. After that, head back over and we'll separate biodiesel fact from fiction.

Generally speaking, biodiesel is an alternative or additive to standard diesel fuel that is made from biological ingredients instead of petroleum (or crude oil). Biodiesel is usually made from plant **oils** or animal **fat** through a series of chemical reactions. It is both **non-toxic** and **renewable**. Because biodiesel essentially comes from plants and animals, the sources can be replenished through farming and recycling.

Photo courtesy U.S. Department of Energy
Biofuels, such as ethanol made from corn and biodiesel made from soybeans, help support American agriculture.

Biodiesel is safe and can be used in diesel engines with little or no modification needed. Although biodiesel can be used in its pure form, it is usually **blended with standard diesel fuel**. Blends are indicated by the abbreviation **Bxx**, where **xx** is the percentage of biodiesel in the mixture. For example, the most common blend is **B20**, or 20 percent biodiesel to 80 percent standard. So, **B100** refers to pure biodiesel.

Biodiesel isn't just a catch-all term, however. There is also a formal, technical definition that is recognized by ASTM International (known formerly as the American Society for Testing and Materials), the organization responsible for providing industry standards. According to the National Biodiesel Board (NBB), the technical definition of biodiesel is as follows:

> a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751.

That sounds kind of rough, but it's a lot more familiar than you may think -- you encounter these fatty acids every day. We'll look at them in more detail in the next section.

Fats and Biodiesel

Part of what makes biodiesel so appealing and interesting is that it can be made from numerous natural sources. Although animal fat can be used, **plant oil** is the largest source of biodiesel. You've probably used some of these in the kitchen. Scientists and engineers can use oils from familiar crops such as soybean, rapeseed, canola, palm, cottonseed, sunflower and peanut to produce biodiesel. Biodiesel can even be made from recycled cooking grease!

Photo courtesy National Biodiesel Board
Soybeans can be made into biodiesel.

The common thread shared by all biodiesel sources is that they all contain **fat** in some form. Oils are just fats that are liquid at room temperature. These fats, or triacylglycerols (sometimes called triglycerides) are made up of carbon, hydrogen, and oxygen atoms bound together and arranged into a specific pattern. These triacylglycerols are pretty prevalent. In addition to household vegetable oils, they're also in common things like butter and lard. You may have seen a triglyceride count listed if you've been to a doctor and had some blood work done.

One way to visualize these triacylglycerols is to think of a capital "E." Forming the vertical backbone of this E is a molecule known as glycerol. Glycerol is a common ingredient used in making such things as soap, pharmaceuticals and cosmetics. Attached to this glycerol backbone and forming the horizontal elements of the E are three long chains composed of carbon, hydrogen, and oxygen. These are called fatty acids.

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So how do these triacylglycerols end up in a car, truck or boat? Biodiesel is not pure vegetable oil. Although raw vegetable oil has been used to fuel diesel engines in the past, it has usually caused problems. The raw fat or oil must first undergo a series of chemical reactions in order to become fuel. There are a few different ways to make biodiesel, but most manufacturing facilities produce industrial biodiesel through a process called **transesterification**. In this process, the fat or oil is first purified and then reacted with an alcohol, usually methanol (CH3OH) or ethanol (CH3CH2OH) in the presence of a catalyst such as potassium hydroxide (KOH) or sodium hydroxide (NaOH). When this happens, the triacylglycerol is transformed to form esters and glycerol. The esters that remain are what we then call biodiesel.

Biofuel History

Photo courtesy Bob Allan

Current U.S. biodiesel production is primarily from oil from soybeans such as these or from recycled restaurant cooking oil.

The concept of biofuels is surprisingly old. Rudolf Diesel, whose invention now bears his name, had envisioned vegetable oil as a fuel source for his engine. In fact, much of his early work revolved around the use of biofuel. In 1900, for example, at the World Exhibition in Paris, France, Diesel demonstrated his engine by running it on peanut oil. Similarly, Henry Ford expected his Model T to run on ethanol, a corn product. Eventually, in both Diesel's and Ford's cases, petroleum entered the picture and proved to be the most logical fuel source. This was based on supply, price and efficiency, among other things. Though it wasn't common practice, vegetable oils were also used for diesel fuel during the 1930s and 1940s.

It was in the 1970s and 1980s that the idea of using biofuels was revisited in the United States. One of the most important events occurred in 1970 with the passage of the Clean Air Act by the Environmental Protection Agency (EPA). This allowed the EPA to more closely regulate emissions standards for pollutants like sulfur dioxides, carbon monoxide, ozone and nitrogen oxides (NOx). This set the stage for developing cleaner-burning fuels. This also set standards for fuel additives.

Events overseas such as the 1973-1974 Arab oil embargo and the 1978-1979 Iranian Revolution, coupled with a decrease in domestic oil production, served to drive prices up. According to the U.S. Department of Energy's Energy Information Administration, U.S. crude oil imports were cut by 30% during the embargo, and "the world price of crude oil jumped from around $14 per barrel at the beginning of 1979 to more than $35 per barrel in January 1981 before stabilizing. Prices did not drop appreciably until 1983, when the world price stabilized between $28 and $29 per barrel."

With petroleum prices increasing, researchers began to look elsewhere. In August 1982, the first International Conference on Plant and Vegetable Oils was held in Fargo, N.D. This conference dealt with matters ranging from fuel cost and the effects of vegetable oil to fuel additives and extraction methods.

In 1990, the Clean Air Act was amended and included more stringent restrictions on vehicle emissions. The amendment introduced provisions for such things as increased oxygen content in gasoline (which lowers carbon monoxide emissions) and lower sulfur content in diesel fuels.

In 1992, the EPA passed the Energy Policy Act, or EPACT. This was aimed at increasing the amount of alternative fuel used by the U.S. government transportation fleets in order to reduce dependency on foreign oil. The 1998 EPACT amendment included using biodiesel fuel in existing government diesel vehicles as an acceptable alternative to purchasing alternative fuel vehicles, or AFVs, as stipulated in the original EPACT.

With all of these rules and regulations in place, it's understandable that any viable petroleum alternative would cause a clamor. But biodiesel isn't a perfect substitute for gasoline.

The Pros

Biodiesel has several key advantages:

- Biodiesel is environmentally friendly.
- It can help reduce dependency on foreign oil.
- It helps to lubricate the engine itself, decreasing engine wear.
- It can be used in almost any diesel with little or no engine modification.
- It is safer than conventional diesel.

One of the major selling points of biodiesel is that it is environmentally friendly. Biodiesel has **fewer emissions** than standard diesel, is **biodegradable**, and is a **renewable** source of energy.

Emissions control is central to the biodiesel argument, especially in legislation matters. There are a few components of emissions that are especially harmful and cause concern among scientists, lawmakers, and consumers. Sulfur and its related compounds contribute to the formation of acid rain; carbon monoxide is a widely recognized toxin; and carbon dioxide contributes to the greenhouse effect. There are also some lesser known compounds that cause concern, such as polycyclic aromatic hydrocarbons (PAHs), ring-shaped compounds that have been linked to the formation of certain types of cancer. Particulate matter (PM) has negative health effects, and unburned hydrocarbons contribute to the formation of smog and ozone.

Biodiesel does reduce hazardous emissions. Of the current biofuels, biodiesel is the only one to have successfully completed emissions testing in accordance with the Clean Air Act.

Average Biodiesel Emissions Compared to Conventional Diesel		
Emission Component	**B100**	**B20**
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NOx	+10%	+2%
Sulfates	-100%	-20%
PAH	-80%	-13%
Source: National Biodiesel Board		

In addition, B100 can reduce CO2 emissions by 78% and lower the carcinogenic properties of diesel fuel by 94% (National Biodiesel Board, U.S. DOE Office of Transportation Technologies).

Another feature of biodiesel is that it is **biodegradable**, meaning that it can decompose as the result of natural agents such as bacteria. According to the EPA, biodiesel degrades at a rate four times faster than conventional diesel fuel. This way, in the event of a spill, the cleanup would be easier and the aftermath would not be as frightening. This would also hold true for biodiesel blends.

Biodiesel could also lower U.S. dependence on imported oil and increase our energy security. Most biodiesel in the U.S. is made from **soybean oil**, which is a major domestic crop. With U.S. petroleum demands increasing and world supply decreasing, a renewable fuel such as biodiesel, if properly implemented, could alleviate some of the U.S. energy demands.

Biodiesel also contributes to an engine's lubricity, or its ease of movement. Biodiesel acts as a solvent, which helps to loosen deposits and other gunk from the insides of an engine that could potentially cause clogs. Since pure biodiesel leaves no deposits of its own, this results in **increased engine life**. It is estimated that a biodiesel blend of just 1% could increase fuel lubricity by as much as 65% (U.S. DOE Office of Transportation Technology).

Biodiesel is also safer. It is **non-toxic** (about 10 times less toxic than table salt) and has a **higher flashpoint** than conventional diesel. Because it burns at a higher temperature, it is less likely to accidentally combust. This makes movement and storage regulations easier to accommodate. Next, we'll look at the cons and the future of biodiesel.

The Cons

Of course, nothing is without penalty, and biodiesel does have its drawbacks. Some have to do with the fuel itself, and many have to do with the bigger picture.

One of the problems with the fuel itself is the **increase in NOx** in biodiesel emissions. Often, in diesel fuel manufacturing, when you decrease the amount of particulate matter in the emissions, there is a corresponding increase in nitrogen oxides, which contribute to smog formation. Though some of this can be addressed by adjusting the engine itself, that's not always feasible. There are technologies being researched to reduce NOx amounts in biodiesel emissions.

Another problem is biodiesel's behavior as a **solvent**. Though this property is helpful, it's kind of a double-edged sword. Some older diesel vehicles (such as cars made before 1992) may experience clogging with higher concentrations of biodiesel. Because of its ability to loosen deposits built up in the engine (which may be there from old diesel fuel), biodiesel can cause the fuel filter to become jammed with the newly freed deposits. Biodiesel manufacturers suggest changing the fuel pump shortly after switching to high-concentration biodiesel blends. Components within these older fuel systems may also become degraded. In addition to deposits within the fuel system, biodiesel also breaks down rubber components. Some parts in the older systems, such as fuel lines and fuel pump seals, may become broken down due to their rubber or rubber-like composition. This is usually remedied by replacing such components. Though many manufacturers have included biodiesel in their warranties, potential for problems could still exist. For more information on biodiesel and vehicle warranties, check out The Biodiesel Standard.

Also, in some engines, there can be slight **decrease in fuel economy and power**. On average, there is about a 10% reduction in power. In other words, it takes about 1.1 gallons of biodiesel to equal 1 gallon of standard diesel.

The major drawbacks to biodiesel are connected to the bigger picture, namely the market and associated logistics. Of these, the most important is **cost**. According to the EPA, pure biodiesel (B100) can cost anywhere from $1.95 to $3.00 per gallon, while B20 blends average about 30 to 40 cents more per gallon than standard diesel. This all depends on variables such as the feedstock used and market conditions.

The other, perhaps more important issue is that of **amount and availability**. Though biodiesel isn't necessarily produced in all 50 states, it can be made available in all of them. There are three major ways to get biodiesel, with each particular method better suited for certain types of customers. Biodiesel can be purchased directly from the supplier, from a petroleum distributor, or from public pumps. There are currently 19 NBB-members producing and marketing biodiesel in the United States. To find out how to get biodiesel, contact the National Biodiesel Board. Also, the Alternative Fuels Data Center has a search feature that allows you to locate refueling stations by city or state.

For information on locating biodiesel stations outside the U.S., contact your local biofuels agency.

So how much do we make? Given the number of different producers (i.e., federal, private, industrial) and crop sources, it's hard to attach a neat figure. Right now, the U.S. produces approximately 75 million gallons of biodiesel per year (National Biodiesel Board). This production is flexible and can be increased or decreased as needed.

Whether or not it grabs the spotlight occupied by flashier technologies, biodiesel will certainly be a constant work in progress.

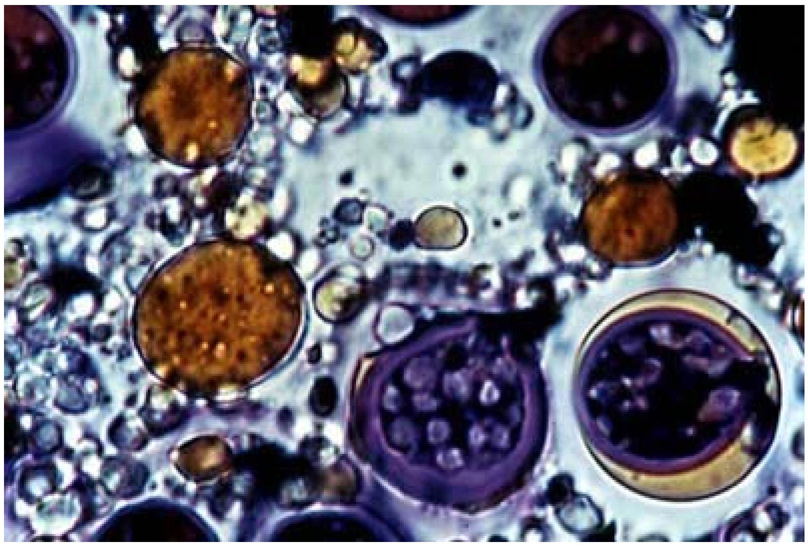

Photo courtesy Paul Roessler

Microalgae, organisms from which a diesel-like fuel can be derived: Cultured in the American southwestern deserts, NREL-developed microalgae may one day produce large amounts of lipids for conversion to biodiesel fuel.

Currently, the largest biodiesel market is fleet vehicles. According to the National Biodiesel Board, there are over 100 such fleets using biodiesel in the United States. These include federal and public organizations such as the U.S. Postal Service, the U.S. Air Force, U.S. Army, NASA, the U.S. Department of Energy, Duke Energy, and Florida Power & Light. Many public transportation services are also looking to biodiesel in order to complement petroleum usage. City buses such as Cincinnati Metro are also using biodiesel. Potential future targets include areas such as marine and agricultural applications and home heating.

As public awareness grows, biodiesel and biofuels in general could easily find their way into dinner conversations. Political support is also on the rise and, in the wake of legislation such as the 1998 EPACT amendment, alternative fuel sources will be a necessity in the not-so-distant future.

Biomass Energy Basics-NREL

Sources of Biomass

We have used biomass energy or "bioenergy"—the energy from plants and plant-derived materials—since people began burning wood to cook food and keep warm. Wood is still the largest biomass energy resource today, but other sources of biomass can also be used. These include food crops, grassy and woody plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. Even the fumes from landfills (which are methane, a natural gas) can be used as a biomass energy source.

Benefits of Using Biomass

Biomass can be used for fuels, power production, and products that would otherwise be made from fossil fuels. In such scenarios, biomass can provide an array of benefits. For example:

- The use of biomass energy has the potential to greatly reduce greenhouse gas emissions. Burning biomass releases about the same amount of carbon dioxide as burning fossil fuels. However, fossil fuels release carbon dioxide captured by photosynthesis millions of years ago—an essentially "new" greenhouse gas. Biomass, on the other hand, releases carbon dioxide that is largely balanced by the carbon dioxide captured in its own growth (depending how much energy was used to grow, harvest, and process the fuel).

- The use of biomass can reduce dependence on foreign oil because biofuels are the only renewable liquid transportation fuels available.

Other Resources
Exploring Ways to Use Biomass Energy
U.S. Department of Energy Consumer Guide

Biomass Program
U.S. Department of Energy

Alternative Fuels Data Center
U.S. Department of Energy

Biomass Feedstock Research & Analyses Program
Oak Ridge National Laboratory

Glossary of Biomass Terms
National Renewable Energy Laboratory

- Biomass energy supports U.S. agricultural and forest-product industries. The main biomass feedstocks for power are paper mill residue, lumber mill scrap, and municipal waste. For biomass fuels, the feedstocks are corn (for ethanol) and soybeans (for biodiesel), both surplus crops. In the near future—and with NREL-developed technology—agricultural residues such as corn stover (the stalks, leaves, and husks of the plant) and wheat straw will also be used. Long-term plans include growing and using dedicated energy crops, such as fast-growing trees and grasses, that can grow sustainably on land that will not support intensive food crops.

NREL's vision is to develop technology for biorefineries that will convert biomass into a range of valuable fuels, chemicals, materials, and products—much like oil refineries and petrochemical plants do. (PDF 664 KB) Download Adobe Reader.

NREL performs research to develop and advance technologies for the following biomass energy applications:

- Biofuels — Converting biomass into liquid fuels for transportation
- Biopower — Burning biomass directly, or converting it into gaseous or liquid fuels that burn more efficiently, to generate electricity
- Bioproducts — Converting biomass into chemicals for making plastics and other products that typically are made from petroleum

Biorefineries

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The Biomass Economy

The 20th century was the century of the petrochemical economy. Gasoline and diesel (made from petroleum) power almost all our vehicles. Myriad plastics made from petroleum or natural gas are used to make our clothes, carpets, food packaging, and increasingly, our car parts and building materials. Most of our chemicals and even toiletries and pharmaceuticals are petrochemically derived.

Unfortunately for the United States, most of the world's petroleum is located elsewhere, so we import more than half of what we use, creating heavy economic and security burdens. And unfortunately for the world, whenever gasoline, diesel, and other fossil fuels are burned, they release carbon dioxide that had been locked up underground for millions of years, increasing greenhouse gas levels.

In the 21st century, use of biomass—plants and plant-based materials, produced by photosynthesis within biological rather than geologic time—will offset this petrochemical dependence. Biomass can't fully replace the huge volumes of petroleum and other fossil fuels that we now use, but it can

Current ethanol production is primarily from the starch in kernels of field corn. NREL researchers are developing technology to also produce ethanol from the fibrous material (cellulose and hemicellulose) in the corn husks and stalks or in other agricultural or forestry residues.

Biomass Conversion Facilities

NREL has world-class facilities for testing technologies that would be used for biorefineries. These facilities are available to NREL researchers as well as to NREL's research partners, under a variety of agreements.

On the biological side, NREL has a one-ton-per-day-feedstock bioethanol pilot plant that can take cellulosic biomass all the way from feedstock preparation through pretreatment, hydrolysis, and fermentation to distillation of fuel ethanol. The plant is certified to handle metabolically engineered fermentation organisms such as NREL's *Zymomonas mobilis*; can use any of several pretreatment options, and includes complete process monitoring.

On the thermochemical side, the Thermochemical Users Facility simulates thermochemical processes such as gasification, combustion, and pyrolysis. The facility includes cyclonic and fluidized bed reactors for pyrolysis or gasification and can easily accommodate research partners' reactors. A variety of secondary reactor and condensation equipment is available, and conversion products can be analyzed online with molecular beam mass spectrometry, fourier transform infrared spectrometry, infrared spectrometry, or gas chromatography.

Artistic rendition of a cellulase enzyme breaking cellulose down to component sugars. NREL's understanding and conde-

2

provide fuels and chemicals comparable to those derived from petroleum. American farmers and foresters can fuel as well as feed and house America—in a sustainable fashion.

During the past 25 years, NREL researchers have developed an impressive slate of core biological, physical, chemical, and engineering skills for biomass technologies. With primary responsibility for carrying out U.S. Department of Energy Biomass Programs, NREL's National Bioenergy Center is at the forefront of efforts to develop the biological and thermochemical technologies that will allow economically and environmentally responsible production of fuels, chemicals, and power from biomass to meet modern-day needs—the biomass economy.

Six Biomass Platforms

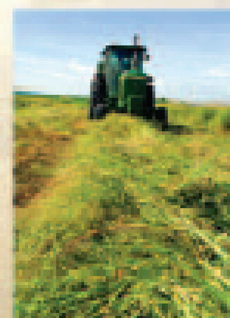
In 2000 and 2001, biomass, largely because of biomass power—combustion of materials such as timber industry scrap or municipal solid waste to generate electricity—surpassed hydroelectric power as the largest U.S. source of renewable energy. And in 2002, U.S. production of fuel ethanol, made from corn grain (starch), will surpass 2 billion gallons per year, displacing a modest but significant amount of imported oil. Also in 2002, a collaborative venture of two major companies began production of polylactic acid plastic made from biomass for clothing and packaging.

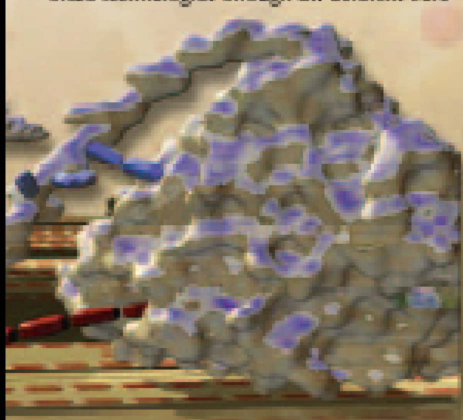
NREL researchers, who have made important contributions to each of these developments, are working to improve and greatly expand these technologies through six different core technologies or "platforms" for building the biomass economy. Just as oil refineries break down petroleum and natural gas into numerous materials that then serve as commodity or platform chemicals that the petrochemical industry can use to make a multitude of final products, these six biomass technology platforms will provide the base chemicals for making biobased fuels and products.

The Sugar-Lignin Platform. One out of eight gallons of gasoline sold in the United States already includes ethanol as an additive. Ethanol is made by fermenting sugar, most of which is derived from starch in corn kernels. In contrast, instead of starting with sugar, NREL's advanced bioethanol technology starts with cellulose and hemicellulose, two of the three main components of most plant material—vastly expanding potential feedstocks—breaking them down to sugars for fermentation. In addition to ethanol, the sugars, or intermediate breakdown products, can be fermented, polymerized, or otherwise processed into any number of products. Lignin, the third main component of biomass, can fuel the process or be used to produce a slate of different chemicals, expanding the number of products for the sugar-lignin platform biorefinery. (See sidebar "Lignocellulosic Bioethanol.")

The Syngas Platform. If biomass is heated with limited oxygen (about one-third that needed for ideal combustion), it gasifies to a "syngas" composed mostly of hydrogen and carbon monoxide. That syngas inherently burns cleaner and more efficiently than the

Switchgrass, which can be easily grown throughout much of the United States, represents a huge future resource of lignocellulosic biomass for use in biorefineries.





...ding research of the basic biochemistry underlying biorefinery processes are key to major technology advances.

Biomass Characterization Technology

One reason NREL is so effective in biomass technology research and development is because of its capabilities to analyze biomass and intermediates from its processing. Biomass gasification and pyrolysis both require precise characterization of the breakdown products being generated, so that processes can be fine-tuned to produce optimal end products.

NREL uses sophisticated molecular beam mass spectrometry and has developed a portable system that could have great value for syngas and bio-oil platform industries.

NREL's R&D 100 Award-winning Rapid Biomass Analysis system quickly and inexpensively characterizes chemical and mechanical properties of raw or processed biomass. Using near-infrared spectrometry correlated by multivariate analysis, it characterizes in minutes what would otherwise require three or four days and cost far more. Opportunities for use in the lumber and paper industries, let alone biorefineries, are almost limitless. NREL researchers are currently using this approach to analyze variations in corn stover composition and their implications for ethanol production.

raw biomass. NREL scientists are using gasification technology to improve a large innovative biomass power plant in Vermont (see sidebar "Vermont Gasifier") and to provide electricity for the first time to isolated Philippine villages with small electric generators. The syngas also can be used to produce hydrogen (see "Hydrogen Economy" on pages 10-13) which, in turn, can be used as a fuel or to make plastics, fertilizers, and a wide variety of other products. Syngas can also be converted to sulfur-free liquid transportation fuels using a catalytic process (known as the Fischer-Tropsch Process), or provide base chemicals for producing biobased products.

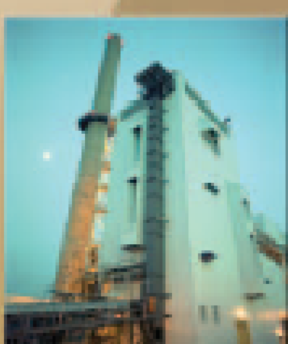
A researcher examines a beaker containing cellulase enzyme, a key element in producing ethanol from lignocellulosic biomass.

The Bio-Oil Platform. If biomass is heated to high temperatures in the total absence of oxygen, it pyrolyzes to a liquid that is oxygenated, but otherwise has similar characteristics to petroleum. This pyrolysis- or "bio-" oil can be burned to generate electricity or it can be used to provide base chemicals for biobased products. As an example, NREL researchers have extracted phenolics from bio-oil to make adhesives and plastic resins. NREL uses several thermochemical reactor systems—available for use by outside researchers—to efficiently pyrolyze and control the bio-oil components. NREL scientists have also used pyrolysis for "true recycling" of plastics such as nylon carpeting, selectively regenerating the base chemicals from which the plastics were made.

The Biogas Platform. Another way to convert "waste" biomass into useful fuels and products is to have natural consortiums of anaerobic microorganisms decompose the material in closed systems. Anaerobic microorganisms break down or "digest" organic material in the absence of oxygen and produce biogas as a waste product. Biogas produced in closed tanks, or anaerobic digesters, consists of 50% to 80% methane, 20% to 50% carbon dioxide, and trace levels of other gases such as hydrogen, carbon monoxide, oxygen, and nitrogen. NREL has developed an anaerobic digestion system that handles much higher solids loading than typical digesters. This system effectively converts cellulosic waste (such as municipal solid waste) and fatty waste (such as tuna cannery sludge) to a methane-rich biogas suitable for power generation (or as a starting material for biobased products) and usable compost material. Anaerobic digesters are currently getting considerable attention as a way to turn swine and cattle manure into useful fuel and chemicals.

The Carbon-Rich Chains Platform. Plant and animal fats and oils are long hydrocarbon chains, as are their fossil-fuel counterparts. Some are directly usable as fuels, but they can also be modified to better meet current needs. Fatty acid methyl ester—fat or oil "transesterified" by combination with methanol—substitutes directly for petroleum diesel. Known as biodiesel, it differs primarily in containing oxygen, so it burns cleaner,

The Vermont gasifier, one of the first large-scale demonstrations of biomass gasification, supplies clean, renewable fuel from biomass to the McNeil Biomass Power Generating Station in Burlington, Vermont.



Vermont Gasifier

At the McNeil Biomass Power Generating Station in Burlington, Vermont, NREL researchers helped design and install an R&D 100 Award-winning gasification system. The project is one of two major DOE projects to develop technology to dramatically improve the efficiency and air emissions quality of biomass power systems. The McNeil Station already is successfully burning up to 200 tons per day of gasified wood chips in its normal steam generator. Once the gas is hooked up to a planned gas turbine, efficiency should be double that of a combustion-boiler generation system.

either by itself or as an additive. Biodiesel use is small but growing rapidly. In the United States, it is made mostly from soybean oil and used cooking oil. Soybean meal, the coproduct of oil extraction is now used primarily as animal feed, but also could be a base for making biobased products. Glycerin, the coproduct of making biodiesel, is already used to make a variety of products, but has potential for many more. And the fatty acids are used for detergents and other products. So carbon-rich chains are already well on their way as a platform for the biorefinery.

The Plant Products Platform. Modern biotechnology not only can transform materials extracted from plants, but can transform the plants to produce more valuable materials. Selective breeding and genetic engineering can be used to improve production of chemical, as well as food, fiber, and structural products. Plants can be developed to produce high-value chemicals in greater quantity than they do naturally, or even to produce compounds they do not naturally produce. With its genetic engineering, material and economic analysis, and general biotechnology expertise, NREL could make major contributions in this exciting arena. For example, NREL researchers exploring variation in composition of stover for various strains of corn are analyzing the impact this makes on producing ethanol from stover.

Moving to Biorefineries

As exciting as these six platforms are, biorefineries will not happen overnight. The oil refineries, and the corn wet-mills and pulp and paper plants (the biorefineries of today) that they would parallel, are highly complex and very expensive. No new U.S. oil refineries have been built in the past 30 years. Corn wet-mills produce a variety of food products—as well as ethanol—from starch, but most new ethanol plants are smaller dry mills producing just ethanol and animal feed. To overcome the challenge and complexity of producing a slate of products starting with lignocellulosic material instead of oil or starch will require enhanced technology development. NREL is providing the foundation for this to occur.

Two important concepts are guiding NREL's efforts to create novel, successful biorefineries—taking maximum advantage of intermediate products and balancing high-value/low-volume products with high-volume/low-value fuels. High-value bioproducts may meet special needs and generate market excitement, but high-volume fuels are what America needs to reduce its dependence on foreign oil and to improve the environment.

Biorefineries will not eliminate the need for petrochemicals. But they will play a key role in reducing our level of dependence on imported petroleum and making the 21st century one of an increasingly sustainable, domestic, and environmentally responsible biomass economy.

Lignocellulosic Bioethanol

NREL and the corn-starch-to-fuel-ethanol industry have grown up together during the past 25 years. NREL has contributed significantly to the industry maturing to one utilizing energy-efficient technologies.

NREL researchers are focusing on the challenge of producing bioethanol from lignocellulosic biomass instead of corn starch. Toward this end, NREL researchers already have developed effective technology to thermochemically pretreat biomass; to hydrolyze hemicellulose to break it down into its component sugars and open up the cellulose to treatment; to enzymatically hydrolyze cellulose to break it down to sugars; and to ferment both five-carbon sugars from hemicellulose and six-carbon sugars from cellulose. This entire process has been integrated using an NREL-patented R&D 100 Award-winning metabolically engineered bacteria—*Zymomonas mobilis*. Using a one-ton-feedstock-per-day bioethanol pilot plant, NREL researchers are testing and improving these technologies under conditions that simulate industrial production.

Bioethanol and the biorefinery concept are closely linked. The cellulosic ethanol technology developed by NREL will open the door to making a wealth of other products. Just as cellulose and hemicellulose are polymers of sugars, new polymers can be made from those sugars. Biodegradable plastics and natural, nontoxic herbicides are just some of the possibilities NREL researchers are exploring.

NREL uses a one-ton-per-day pilot plant to test bioethanol technologies, including NREL's metabolically engineered bacteria, Zymomonas mobilis, which enables the cofermentation of cellulose and hemicellulose.

5

Biofuels (Video)

Unlike other renewable energy sources, biomass can be converted directly into liquid fuels, called "biofuels," to help meet transportation fuel needs. The two most common types of biofuels are ethanol and biodiesel.

Ethanol is an alcohol, the same as in beer and wine (although ethanol used as a fuel is modified to make it undrinkable). It is made by fermenting any biomass high in carbohydrates through a process similar to beer brewing. Today, ethanol is made from starches and sugars, but NREL scientists are developing technology to allow it to be made from cellulose and hemicellulose, the fibrous material that makes up the bulk of most plant matter. Ethanol is mostly used as blending agent with gasoline to increase octane and cut down carbon monoxide and other smog-causing emissions.

Biodiesel is made by combining alcohol (usually methanol) with vegetable oil, animal fat, or recycled cooking grease. It can be used as an additive (typically 20%) to reduce vehicle emissions or in its pure form as a renewable alternative fuel for diesel engines.

Biomass Pretreatment

NREL researchers are leaders in investigating and developing pretreatment technologies for hydrolyzing hemicellulose and solubilizing lignin in lignocellulosic biomass. This breaks the hemicellulose down into its component sugars and exposes the cellulose, so that it can be more easily broken down to its components. NREL biomass researchers have focused on a process model of dilute acid hydrolysis of hemicellulose followed by enzymatic hydrolysis of cellulose. They have, however, also investigated other pretreatment approaches and play a lead role in a research consortium effort to systematically evaluate all pretreatment technologies. For the dilute acid/enzyme model, NREL researchers have developed several innovative processing systems, greatly enhancing pretreatment effectiveness.

Cellulase Enzyme Development

NREL's research on enzyme development focuses on decreasing the cost of the enzyme unit operation in the biomass saccharification process, which has been identified as a key factor for developing cost-competitive biorefinery products. Researchers have developed great expertise in the basic science underlying enzymatic hydrolysis. They are working closely with major industrial enzyme producers to apply recombinant DNA technology to bacteria and fungi to develop improved cellulase enzymes and to determine the most efficient method for producing these enzymes.

Strain Development

NREL researchers are applying sophisticated metabolic engineering techniques to develop microorganisms that can more effectively ferment the sugars in biomass. Lignocellulosic biomass contains five carbon sugars such as xylose (from the hemicellulose) as well as the more "common" six carbon sugars such as glucose found in grains. This makes fermentation and other bioprocessing far more challenging. While some biorefinery scenarios will take advantage of the different sugar streams to produce multiple products, others will be more cost effective if all the sugars can coferment in a single set of equipment.

Researchers are developing microorganisms that can coferment all the sugars in biomass in order to improve ethanol production economics. They are applying sophisticated metabolic engineering techniques to Zymomonas mobilis that can coferment both xylose and arabinose along with glucose. With industrial partners, researchers are working to develop designer strains for specific feedstocks, feedstreams, and processes.

Bioprocess Integration, Scale-up, and Demonstration

A team of biotechnology researchers focuses on integrating all the unit operations of biomass conversion. With extensive knowledge of the individual unit operations, these researchers focus on linking unit operations together for industrial application and on demonstrating integrated processes at the mini-pilot and pilot scales. They also conduct rigorous bench-scale experimentation to improve specific unit operations within the process.

Biomass is matter usually thought of as garbage. Some of it is just stuff lying around -- dead trees, tree branches, yard clippings, left-over crops, wood chips (like in the picture to the right), and bark and sawdust from lumber mills. It can even include used tires and livestock manure.

Your trash, paper products that can't be recycled into other paper products, and other household waste are normally sent to the dump. Your trash contains some types of biomass that can be reused. Recycling biomass for fuel and other uses cuts down on the need for "landfills" to hold garbage.

Biomass Power Plant - Photo credit: U.S. Department of Energy, Energy Efficiency & Renewable Energy Network (EREN)

This stuff nobody seems to want can be used to produce electricity, eat, compost material or fuels. Composting material is decayed plant or food products mixed together in a compost pile and spread to help plants grow. California produces more than 60 million bone dry tons of biomass each year. Of this total, five million bone dry tons is now burned to make electricity. This is biomass from lumber mill wastes, urban wood waste, forest and agricultural residues and other feed stocks. If all of it was used, the 60 million tons of biomass in California **could** make close to 2,000 megawatts of electricity for California's growing population and economy. That's enough energy to make electricity for about two million homes!

How biomass works is very simple. The waste wood, tree branches and other scraps are gathered together in big trucks. The trucks bring the waste from factories and from farms to a biomass power plant. Here the biomass is dumped into huge hoppers. This is then fed into a furnace where it is burned. The heat is used to boil water in the boiler, and the energy in the steam is used to turn turbines and generators (see Chapter 8). Biomass can also be tapped right at the landfill with burning waster products. When garbage decomposes, it gives off methane gas. You'll remember in chapters 8 and 9 that natural gas is made up of methane. Pipelines are put into the landfills and the methane gas can be collected. It is then used in power plants to make electricity. This type of biomass is called landfill gas.

A similar thing can be done at animal feed lots. In places where lots of animals are raised, the animals - like cattle, cows and even chickens - produce manure. When manure decomposes, it also gives off methane gas similar to garbage. This gas can be burned right at the farm to make energy to run the farm.

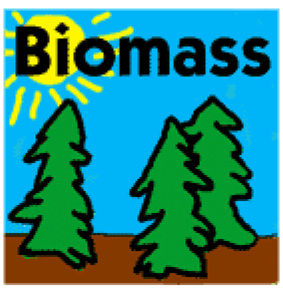
Using biomass can help reduce global warming compared to a fossil fuel-powered plant. Plants use and store carbon dioxide (CO_2) when they grow. CO_2 stored in the plant is released when the plant material is burned or decays. By replanting the crops, the new plants can use the CO_2 produced by the burned plants. So using biomass and replanting helps close the carbon dioxide cycle. However, if the crops are not replanted, then biomass can emit carbon dioxide that will contribute toward global warming.

So, the use of biomass can be environmentally friendly because the biomass is reduced, recycled and then reused. It is also a renewable resource because plants to make biomass can be grown over and over.

Today, new ways of using biomass are still being discovered. One way is to produce ethanol, a liquid alcohol fuel. Ethanol can be used in special types of cars that are made for using alcohol fuel instead of gasoline. The alcohol can also be combined with gasoline. This reduces our dependence on oil - a non-renewable fossil fuel.

DID YOU KNOW THAT
ELEPHANTS CAN MAKE ENERGY!
CLICK THE PICTURE TO FIND OUT MORE....

Mali, an 8-year-old Asian elephant, is a potential power source for the Rosamond Gifford Zoo



CLICK HERE TO SEE A FLASH MOVIE
OF HOW BIOMASS POWER WORKS...

This file is VERY large. DO NOT click on this is you're using a regular modem. You need a FAST Internet connection like DSL, cable modem or LAN!

Resources

- American Biomass Association (www.biomass.org/fact_sheet_1.htm)
- Biomass - the growing energy resource - Australian Academy of Science (www.science.org.au/nova/039/039key.htm)
- Biopower - U.S. Dept of Energy (www.eren.doe.gov/biopower/)
- California Biomass Energy Alliance (www.calbiomass.org/)
- National Renewable Energy Laboratory (www.nrel.gov/lab/pao/biomass_energy.html)
- U.S. Dept. of Energy Biofuels (for transportation) (www.ott.doe.gov/biofuels/students.html)