Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

fact sheet

How Biomass Energy Works

To many people, the most familiar forms of renewable energy are the wind and the sun. But biomass (plant material and animal waste) supplies almost 15 times as much energy in the United States as wind and solar power combined—and has the potential to supply much more.[1]

There are a wide variety of biomass energy resources, including tree and grass crops and forestry, agricultural, and urban wastes. It is the oldest source of renewable energy known to humans, used since our ancestors learned the secret of fire.

Biomass is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates, complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burned, they turn back into carbon dioxide and water and release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably—with only as much used as is grown—the battery will last indefinitely.

From the time of Prometheus to the present, the most common way to capture the energy from biomass was to burn it, to make heat, steam, and electricity. But advances in recent years have shown that there are more efficient and cleaner ways to use biomass. It can be converted into liquid fuels, for example, or cooked in a process called "gasification" to produce combustible gases. And certain crops such as switchgrass and willow trees are especially suited as "energy crops," plants grown specifically for energy generation.

Types of Biomass

There are many types of plants in the world, and many ways they can be used for energy production. In general there are two approaches: growing plants specifically for energy use, and using the residues from plants that are used for other things. The best approaches vary from region to region according to climate, soils, geography, population, and so on.

Energy Crops

Energy crops, also called "power crops," could be grown on farms in potentially very large quantities, just like food crops. Trees and grasses, particularly those that are native to a region, are the best crops for energy, but other, less agriculturally sustainable crops such as corn tend to be used for energy purposes at present.

Trees

In addition to growing very fast, some trees will grow back after being cut off close to the ground, a feature called "coppicing." Coppicing allows trees to be harvested every three to eight years for 20 or 30 years before replanting. These trees, also called "short-rotation woody crops," grow as much as 40 feet high in the years between harvests. In the cooler, wetter regions of the northern United States, varieties of poplar, maple, black locust, and willow are the best choice. In the warmer Southeast, sycamore and sweetgum are best, while in the warmest parts of Florida and California, eucalyptus is likely to grow well.

Grasses

Thin-stemmed perennial grasses used to blanket the prairies of the United States before the settlers replaced them with corn and beans. Switchgrass, big bluestem, and other native varieties grow quickly in many parts of the country, and can be harvested for up to 10 years before replanting. Thick-stemmed perennials like sugar cane and elephant grass can be grown in hot and wet climates like those of Florida and Hawaii.

The Fuss About Switchgrass

In his 2006 State of the Union Address, President Bush remarked that "We're working on research—strong research to figure out cellulosic ethanol that can be made from wood chips or stalks or switchgrass." What is switchgrass, and why did it get mentioned in a major presidential address? Switchgrass is a summer perennial grass that grows throughout the Great Plains region of the United States, as well as various parts of the South. Switchgrass is a hardy species—resistant to floods, droughts, nutrient poor soils, and pests—and does not require much fertilizer to produce consistent high yields. Today, switchgrass is primarily cultivated and used by many farmers as either a feed for livestock or, due to its deep root structure, as ground cover to prevent soil erosion. However, this prairie grass was recently put in the spotlight because of its promise for energy production. Researchers believe that switchgrass can be an important feedstock for the production of ethanol, providing substantial advantages, including greater net energy savings and carbon dioxide reductions compared to corn-based ethanol production. It can also help reduce our nations' dependence on oil—a serious problem that President Bush has described as an addiction.

Other crops

A third type of grass includes annuals commonly grown for food, such as corn and sorghum. Since these must be replanted every year, they require much closer management and greater use of fertilizers, pesticides, and energy. While corn currently provides most of the liquid fuel from biomass in the United States, there are more sustainable ways to produce energy from plants.

Oil plants

Plants such as soybeans and sunflowers produce oil, which can be used to make fuels. Like corn, though, these crops require intensive management and may not be sustainable in the longer term. A rather different type of oil crop with great promise for the future is microalgae. These tiny aquatic plants have the potential to grow extremely fast in the hot, shallow, saline water found in some lakes in the desert Southwest. In 2004, Green Fuel Technologies, a Massachusetts-based company, harnessed the ability to capture and use carbon dioxide emissions from power plants as a means to stimulate algae growth.[2] The algae is then converted into a various range of fuels. This technology, known as Emissions-to-Biofuels, is demonstrating great promise and has the potential to transform the way utilities produce energy.

Biomass Residues

After plants have been used for other purposes, the leftover wastes can be used for energy. The forestry, agricultural, and manufacturing industries generate plant and animal wastes in large quantities. City waste, in the form of garbage and sewage, is also a source for biomass energy.

Forestry
Forestry wastes are the largest source of heat and electricity now, since lumber, pulp, and paper mills use them to power their factories. One large source of wood waste is tree tops and branches normally left behind in the forest after timber-harvesting operations. Some of these must be left behind to recycle necessary nutrients to the forest and to provide habitat for birds and mammals, but some could be collected for energy production. Other sources of wood waste are sawdust and bark from sawmills, shavings produced during the manufacture of furniture, and organic sludge (or "liquor") from pulp and paper mills.

Agriculture
As with the forestry industry, most crop residues are left in the field. Some should be left there to maintain cover against erosion and to recycle nutrients, but some could be collected for fuel. Animal farms produce many "wet wastes" in the form of manure. These wastes are commonly spread on fields, not just for their nutrient value, but for disposal. Runoff from overfertilization threatens rural lakes and streams and can contaminate drinking water. Processing crops into food also produces many usable wastes.

Cities
People generate biomass wastes in many forms, including "urban wood waste" (such as shipping pallets and leftover construction wood), the biodegradable portion of garbage (paper, food, leather, yard waste, etc.) and the gas given off by landfills when waste decomposes. Even our sewage can be used as energy; some sewage treatment plants capture the methane given off by sewage and burn it for heat and power, reducing air pollution and emissions of global warming gases.

Converting Biomass to Energy

The old way of converting biomass to energy, practiced for thousands of years, is simply to burn it to produce heat. This is still how most biomass is put to use, in the United States and elsewhere. The heat can be used directly, for heating, cooking, and industrial processes, or indirectly, to produce electricity. The problems with burning biomass are that much of the energy is wasted and that it can cause some pollution if it is not carefully controlled.

An approach that may increase the use of biomass energy in the short term is to burn it mixed with coal in power plants—a process known as "co-firing." Biomass feedstock can substitute up to 20 percent of the coal used in a boiler.[3] The benefits associated with biomass co-firing include lower operating costs, reductions of harmful emissions, and greater energy security. Co-firing is also one of the more economically viable ways to increase biomass power generation today. In 2000, the Chariton Valley Biomass Project, a joint effort including Alliant Energy, the U.S. Department of Energy, and local biomass groups, began testing the co-firing of switchgrass with coal at Alliant's Ottumwa Generating Station in Iowa. The project has proved so successful that in 2005, Alliant received permission to build a permanent biomass processing facility at the plant, capable of co-firing up to five percent of its energy with switchgrass.[4]

A number of noncombustion methods are available for converting biomass to energy. These processes convert raw biomass into a variety of gaseous, liquid, or solid fuels that can then be used directly in a power plant for energy generation. The carbohydrates in biomass, which are comprised of oxygen, carbon, and hydrogen, can be broken down into a variety of chemicals, some of which are useful fuels. This conversion can be done in three ways:

- ***Thermochemical.*** When plant matter is heated but not burned, it breaks down into various gases, liquids, and solids. These products can then be further processed and refined into useful fuels such as methane and alcohol. Biomass gasifiers capture methane released from the plants and burn it in a gas turbine to produce electricity. Another approach is to take these fuels and run them through fuel cells, converting the hydrogen-rich fuels into electricity and water, with few or no emissions.

- ***Biochemical.*** Bacteria, yeasts, and enzymes also break down carbohydrates. Fermentation, the process used to make wine, changes biomass liquids into alcohol, a combustible fuel. A similar process is used to turn corn into grain alcohol or ethanol, which is mixed with gasoline to make gasohol. Also, when bacteria break down biomass, methane and carbon dioxide are produced. This methane can be captured, in sewage treatment plants and landfills, for example, and burned for heat and power.

- ***Chemical.*** Biomass oils, like soybean and canola oil, can be chemically converted into a liquid fuel similar to diesel fuel, and into gasoline additives. Cooking oil from restaurants, for example, has been used as a source to make "biodiesel" for trucks. (A better way to produce biodiesel is to use algae as a source of oils.)

In 1998, the first U.S. commercial scale biomass gasification demonstration plant based on the SilvaGas process began at the McNeil Power Station in Burlington, Vermont. [5] The SilvaGas process, a particular form of biomass gasification, indirectly heats the biomass using heated sand in order to produce a medium Btu gas. The McNeil power station is capable of generating 50 MW of power from local wood waste products.

One persistent myth about biomass is that it takes more energy to produce fuels from biomass than the fuels themselves contain. In other words, that it is a net energy loser. In fact, most of the studies done over the past 10 years confirm that the production of ethanol has a positive energy balance. According to a 2002 U.S. Department of Agriculture study, technological advances in ethanol conversion and efficiency increases in farm production have caused the net energy value (NEV) of corn ethanol to increase gradually over time.[6],[7] This study states that every British thermal unit (BTU) of energy used in the production of ethanol leads to a 34 percent energy gain.[8]

Nonetheless, we could do much better. Corn is one of the most energy-intensive crops, and current corn-based ethanol production uses just the kernels from the corn plant, and not even the entire kernel. By making ethanol from energy crops, we could obtain between four and five times the energy that we put in, and by making electricity we could get perhaps 10 times or more. In the future, to make a truly sustainable biomass energy system, we would have to replace fossil fuels with biomass or other renewable fuels to plant and harvest the crops.

Another important consideration with biomass energy systems is that biomass contains less energy per pound than fossil fuels. This means that raw biomass typically can't be cost-effectively shipped more than about 50 miles before it is converted into fuel or energy. It also means that biomass energy systems are likely to be smaller than their fossil fuel counterparts, because it is hard to gather and process more than this quantity of fuel in one place. This has the advantage that local, rural communities—and perhaps even individual farms—will be able to design energy systems that are self-sufficient, sustainable, and perfectly adapted to their own needs.

Potential for Biomass

In the United States, we already get 45 billion kilowatt-hours of electricity from biomass, about 1.2 percent of our nation's total electric sales.[9] We also get nearly four billion gallons of ethanol, about two percent of the liquid fuel used in cars and trucks.[10] The contribution for heat is also substantial. But with better conversion technology and more attention paid to energy crops, we could produce much more.

Estimates of the ultimate potential for biomass energy vary, and depend on agricultural forecasts, waste reduction by industry, and paper recycling. The Department of Energy believes that we could produce four percent of our transportation fuels from biomass by 2010, and as much as 20 percent by 2030.[11] For electricity, the U.S. Department of Energy (DOE) estimates that energy crops and crop residues alone could supply as much as much as 14 percent of our power needs.

Environmental Benefits

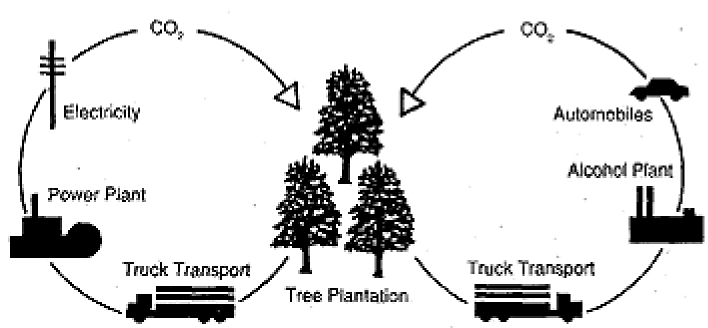
Biomass energy brings numerous environmental benefits—reducing air and water pollution, increasing soil quality and reducing erosion, and improving wildlife habitat.

Biomass reduces air pollution by being a part of the carbon cycle (see the box below), reducing carbon dioxide emissions by 90 percent compared with fossil fuels. Sulfur dioxide and other pollutants are also reduced substantially.

Water pollution is reduced because fewer fertilizers and pesticides are used to grow energy crops, and erosion is reduced. Moreover, agricultural researchers in Iowa have discovered that by planting grasses or poplar trees in buffers along waterways, runoff from corn fields is captured, making streams cleaner.

In contrast to high-yield food crops that pull nutrients from the soil, energy crops actually improve soil quality. Prairie grasses, with their deep roots, build up topsoil, putting nitrogen and other nutrients into the ground. Since they are replanted only every 10 years, there is minimal plowing that causes soil to erode.

Riding the Carbon Cycle: The carbon cycle is nature's way of moving carbon around to support life on Earth. Carbon dioxide is the most common vehicle for carbon, where one carbon atom is bound to two oxygen atoms. Plant photosynthesis breaks the carbon dioxide in two, keeping the carbon to form the carbohydrates that make up the plant, and putting the oxygen into the air. When the plant dies or is burned, it gives its carbon back to the air, which is then reabsorbed by other plants.



Fossil fuels, on the other hand, are made of plants that grew millions of years ago. The carbon they absorbed *then* is released *now* when the fossil fuels are burned. There are no extra plants to absorb that carbon, so the cycle becomes out of balance. There are two different carbon cycles in operation now: the natural one between plants and the air, which is in balance, and the human-made cycle where carbon is pulled from Earth and emitted into the atmosphere.

Finally, biomass crops can create better wildlife habitat than food crops. Since they are native plants, they attract a greater variety of birds and small mammals. They improve the habitat for fish by increasing water quality in nearby streams and ponds. And since they have a wider window of time to be harvested, energy crop harvests can be timed to avoid critical nesting or breeding seasons.

All of these benefits are described in comparison with food crops such as corn, wheat, and soybeans. Compared to undisturbed natural habitat, energy crops are not as good. But the strength of biomass is that it is much closer to the natural world than our modern industrial agriculture. The harvest of prairie grasses is not so different than the fires that periodically swept across the plains. Plantations of poplar and maple trees may not be the same as varied forests, but are certainly closer than pesticide-laden monocrops. Nonetheless, the environmental benefits of biomass hinge on whether energy crops are managed with sustainable agricultural practices. Just like food crops, they can be mishandled, with productivity increased by greater chemical inputs.

If biomass energy turns out to have unforeseen environmental effects, we must be willing to alter our methods to reduce these effects.

Conclusions

In addition to the many environmental benefits, biomass offers many economic and energy security benefits. By growing our fuels at home, we reduce the need to import oil and reduce our exposure to disruptions in that supply. Farmers and rural areas gain a valuable new outlet for their products. Biomass already supports 66,000 jobs in the United States; if the DOE's goal is realized, the industry would support three times as many jobs. [12]

Photo: Warren Gretz, NREL

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Endnotes

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