Energy Industries—Bioenergy

Derived from natural resources, bioenergy is a prominent renewable energy source throughout the world. Most simplistically, it is wood used for cooking and heating; more complex examples include thermochemical conversions that produce biofuels. Although relevant technologies exist (and continue to be developed), many are not yet cost-effective, and questions remain about the industry's long-term environmental impact.

Bioenergy is any energy, or fuel used to produce energy, that is derived from either biomass or plant matter. According to the U.S. Energy Information Administration (2009), the United States consumed more bioenergy in 2008 than wind, solar, and geothermal energies combined. Despite its widespread use around the world, the term is often mistakenly equated with liquid biofuels such as ethanol and biodiesel. Biofuels—solid, liquid, or gaseous—are virtually the only liquid fuel alternative to oil for transportation purposes; they can be used not only for fueling vehicles but also for heating, cooling, and electrical power generation.

In many parts of the world, bioenergy remains the dominant energy source for heating and cooking, but bioenergy is much more than wood used in the home or liquid biofuels like ethanol. Bioenergy production includes biogas and electricity generation from such sources as food-processing wastes and the anaerobic digestion of cow manure. (Anaerobic bacteria digest matter in the absence of oxygen, yielding a biogas rich in methane and carbon dioxide.) Bioenergy is being used in district heating systems; for example in St. Paul, Minnesota, water heated from waste wood heats the central business district of the city.

Interest in bioenergy is growing for several reasons. Economic developers and rural communities see it as a growth industry that can create jobs and revive local economies. Proponents of agriculture and forestry see it as a tool to protect productive working landscapes and provide new markets for these volatile industries. Environmentalists see bioenergy as a means to reduce greenhouse gas emissions associated with fossil fuel use. Against this backdrop, policy makers are looking for ways to guarantee that rural communities capture the full benefits of sustainable bioenergy production (Radloff and Turnquist 2009).

Bioenergy as a Renewable Resource

Energy derived from biomass is considered renewable because bioenergy is simply stored solar energy from the sun. It can be produced from a wide range of biomass types including plants, animals, and animal wastes. Biomass includes conventional crops such as corn and soybeans, vegetable oils, agricultural residues like corn stover and rice straw, wood and forest residues, and mill residues. Other types of biomass, also referred to as feedstock, include construction waste, perennial grasses like switch grass, and short rotation woody crops (including willow and hybrid poplar). Animal renderings and animal manures are additional examples of biomass (Biomass Research and Development Board 2008).

Because bioenergy is not classified in a consistent manner, this article identifies three broad "types" of bioenergy based on *how* the energy derived from biomass is used: bioheating/biocooling, biopower, and biofuels.

Bioheating/Biocooling

Bioheating/biocooling is the most prevalent use of biomass worldwide, especially in parts of the developing world where it is the primary energy source for cooking. In countries like Nepal, Sudan, and Tanzania, about 80–90 percent of all energy comes from biomass (Rosillo-Calle et al. 2007). In the United States, the residential home heating market is the largest user of wood fuel. Other bioheating/biocooling examples include schools and commercial buildings that heat and cool with wood, as well as district heating systems that provide heating and cooling to multiple buildings through a system of connected pipes carrying hot water or steam.

Biopower

Biopower is electricity produced from biomass, and it is often generated through cofiring of biomass with coal. Heat from the combustion process drives a steam turbine that generates power. Alternative methods of generating biopower include gasification, a technology that converts biomass under high temperatures into a gas called "syngas." The syngas can then be converted to electricity using a more efficient technology than a conventional steam turbine. Several additional biopower technologies exist. Combined heat and power (CHP) technology increases energy efficiency by generating electricity and capturing and using any excess heat produced in the process.

Biofuels

The third category of bioenergy is biofuels, which include liquids as well as solid. Conventional liquid biofuels (like ethanol) come from existing food crops. More advanced liquid biofuels may come from cellulosic sources such as wood and perennial grasses. Solid biofuels (including wood pellets) are currently derived from wood waste and mill residues. As the demand for bioenergy grows, more solid biofuels may be manufactured from additional sources including perennial grasses, construction waste, and other waste streams.

Bioenergy is unlike other renewable energy resources in two key aspects. First, bioenergy is not an intermittent source of energy. Unlike wind and solar, which depend on windy and sunny days respectively to generate power, bioenergy is an on-demand source of renewable energy that can be dispatched where needed. As long as the feedstock supply is adequate, bioenergy represents a dependable, constant source of energy that can be generated at any time of the day as needed—independent of daily weather patterns.

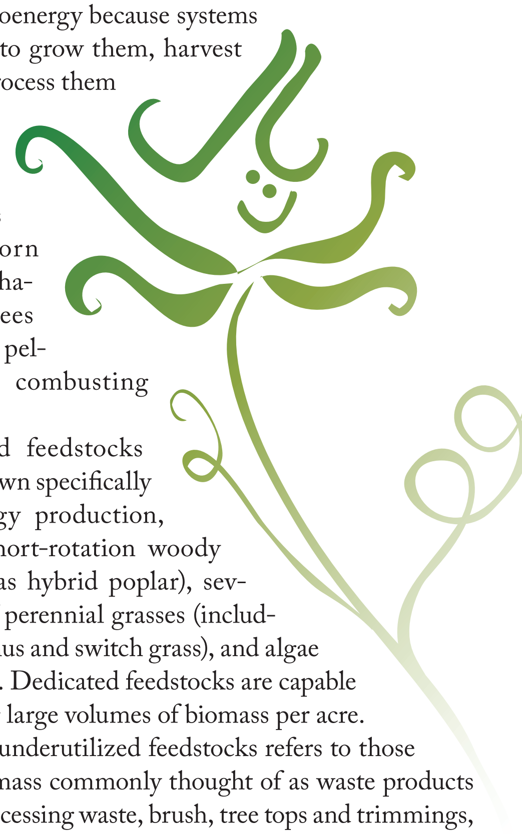
Second, biomass as an energy source is a complex system of interdependent components. According to the U.S. Environmental Protection Agency (US EPA 2007), economically and technically feasible bioenergy projects require an adequate feedstock supply, effective conversion technologies, dependable markets, and viable distribution systems. The challenge of ensuring an adequate feedstock supply is particularly challenging.

Converting biomass into energy may be a complex process, but it can be broken down into three major phases: growing and transporting feedstocks, converting feedstocks into bioenergy, and marketing bioenergy.

The Biomass Supply Chain

Growing and transporting feedstocks is known as the biomass supply chain. The first step in the process is the growing and/or harvesting of available biomass and nonagricultural waste. Biomass feedstocks can be lumped into three general categories: conventional feedstocks, dedicated feedstocks, and waste or underutilized feedstocks.

Conventional feedstocks include wood waste, grains, and other common forms of biomass. These types are easy to convert to bioenergy because systems are in place to grow them, harvest them, and process them using existing technologies. Examples include corn grain (for ethanol) and trees (for making pellets or for combusting directly).



Dedicated feedstocks are crops grown specifically for bioenergy production, including short-rotation woody trees (such as hybrid poplar), several types of perennial grasses (including miscanthus and switch grass), and algae and jatropha. Dedicated feedstocks are capable of producing large volumes of biomass per acre.

Waste or underutilized feedstocks refers to those types of biomass commonly thought of as waste products like food-processing waste, brush, tree tops and trimmings, construction and demolition debris, leaves and yard waste, animal renderings, and manure. As some of these feedstocks become increasingly valuable, it's clear they are not really "wastes" at all; rather they are historically underutilized waste products that in many cases make good bioenergy feedstocks. The second step in the biomass supply chain is to process the available biomass into a feedstock. For example, slash from a recent timber harvest may need to be bundled prior to transport. The feedstock is then aggregated and delivered to some type of biorefinery for processing.

Converting Biomass Feedstocks into Energy

The next step in the process of bioenergy production is the conversion of the feedstock into intermediate products such as combustible gases, carbon dioxide, oils, tars, and liquids. These intermediate products are then converted into final, usable energy products such as electricity, heat, and solid and liquid fuels using one of five basic conversion technologies, ranging from simple to more complex.

1. **Physical conversion.** This is the simplest way to convert biomass into a usable energy form. Making wood pellets is one example, and straight vegetable oil (SVO) production is another. With SVO production, oil is simply extracted through a seed-pressing process. Pressed vegetable oil can be used as a transportation fuel in tractors and in diesel engines. In both the wood pellet and vegetable oil examples, the biomass feedstock is physically altered through force, producing a fuel that can be used for transportation or converted into another energy product through one of the other conversion technologies discussed below.
2. **Combustion.** Combustion technologies convert biomass into hot air, hot water, and steam. They range from smaller household technologies like wood stoves to large commercial and industrial technologies including fixed bed combustion and fluidized bed combustion systems. Larger commercial and industrial combustion systems rely on wood chips, corn stover, bark, and other less processed feedstock, while smaller household-size technologies require higher quality fuels.
3. **Chemical conversion.** Through chemical conversion, feedstocks are decomposed into liquid biofuels (US EPA 2007). An example of chemical conversion is transesterification, the process used to make biodiesel in which oils, fats, used cooking greases, and other fatty wastes are combined with a catalyst such as methanol. The final products are biodiesel and glycerin, which is often used in soaps.
4. **Biochemical conversion.** Through biochemical conversion, enzymes and bacteria break down feedstocks like cow manure and perennial grasses into intermediate products such as biogas. Biogas is similar to natural gas and contains impurities including sulfur, carbon dioxide, nitrogen, and hydrogen, but biogas can be cleaned up and used in a similar fashion as natural gas. It can be combusted to generate electricity or compressed for other uses, including transportation. Examples of biochemical conversion technologies include simple composting, bioreactors at landfills, and anaerobic digesters on farms and at wastewater treatment facilities.
5. **Thermochemical conversion.** The thermochemical conversion method is similar to the biochemical conversion method in that it produces intermediate products that are then further refined into useful end products. With thermochemical conversion, however, the biomass feedstock is decomposed through the use of heat instead of with enzymes and bacteria. Intermediate products resulting from thermochemical conversion of biomass include combustible gases, liquids, tars, and charcoal. These products can be further refined into many different final products: ethanol, diesel, gasoline, hydrogen, and bio-oil. Examples of thermochemical technologies include gasification and pyrolysis (the chemical decomposition of organic matter using heat).

Bioenergy Opportunities

Making bioenergy is relatively easy; making a profitable business out of bioenergy production is not. In order for the bioenergy industry to thrive, it needs a reliable market. Bioenergy can either be used on-site, in the local community, or exported to another region. Using bioenergy on-site is an attractive option for many energy producers, because on-site use can directly substitute for off-site energy purchased at retail prices. Selling bioenergy locally is another attractive option because it cuts down on transportation costs.

There are several social, economic, environmental, and technical opportunities associated with greater bioenergy use. In rural communities, increased use of bioenergy may stimulate the economy and create cooperative and local ownership opportunities related to the growing, transporting, refining, and marketing of biomass. Enhanced bioenergy use could also make biomass-rich communities more energy independent and less susceptible to fluctuating energy prices. While expanding social and economic opportunities, bioenergy could also help the environment. Bioenergy can be produced from feedstocks such as perennial grasses, which sequester carbon underground through their vast root networks. It can also be produced using animal manures that otherwise have the potential to negatively impact water resources. In order to maximize the benefits of increased bioenergy use, there are several technical opportunities which must be taken advantage of as well.

Cellulosic Ethanol

Substantially increasing liquid biofuel production to meet transportation needs will require technical advancements in cellulosic ethanol, which is produced from nonedible plant parts such as leaves and stalks. Cellulosic ethanol currently requires too much heat, enzymes, and bacteria to be cost-effective. In the meantime, if conventional ethanol is to expand, new technologies or combinations of technologies will need to be put in place to make the process more efficient. Besides ethanol, there are significant opportunities to expand liquid biofuel production with advances in technologies like pyrolysis, direct catalytic conversion, and advanced gasification. Besides improving conversion technologies, advances must also occur in the area of feedstock development.

Algae

Algae are often touted as a potential feedstock for biodiesel production. As with cellulosic ethanol, it is possible to generate biofuels in this manner, but it is not yet cost-effective. In order to successfully develop algae as a biofuel feedstock, research and development need to occur. There are thousands of types of algae, for example, and some of them are better suited for biofuel production than others.

Bioenergy Challenges and the Future

The potential advantages of increased bioenergy use are numerous, but there are several hurdles to expanding bioenergy production and consumption as well. The biggest challenge facing expanded use of bioenergy is the question of sustainability. Despite being one of the largest renewable energy resources in the world, there is little good data on supply and demand of biomass in many countries. This lack of good baseline data makes it very difficult to derive sustainable bioenergy policies to guide the industry (Rosillo-Calle et al. 2007). Effective policies will need to be crafted at many levels in order to ensure the sustainability of biomass resources over the long haul. These policies will need to address soil and water health, air emissions, and the sustainability of the biomass sources themselves. Concerns about the net energy balance and greenhouse gas emissions of various types of bioenergy, especially liquid biofuels, will also need to be addressed.

Transporting and storing biomass is another very significant challenge facing the industry. Biomass has a relatively low energy density and often a high moisture content. These characteristics make moving and storing biomass a challenge—both from a technical and economical standpoint. Because of this, many observers believe that bioenergy production will happen on a distributed basis, with many small biorefineries generating energy and other bio-products across the rural landscape. This scenario presents the land use challenge of siting multiple facilities across rural communities.

Finally, bioenergy must be able to compete economically with fossil fuels and with other forms of renewable energy. If, as was the case in 2009, conventional energy prices drop, the bioenergy industry stagnates or goes into decline. Making bioenergy competitive with fossil fuels will likely require price supports, such as the monetized value of carbon reductions, in addition to higher-priced fossil fuels.

As recent volatility in ethanol prices and debates over the environmental sustainability of corn-derived ethanol have demonstrated, bioenergy is not without its challenges. Biomass is plant matter grown on a variety of soils; if biomass is not sustainably grown and harvested, the soil resources will be depleted over time. Sustainability concerns have also arisen as biomass is diverted from the food chain into the energy chain. Critics claim that this diversion contributes to increasing food prices, which negatively impacts the world's poor. These same voices contend that bioenergy development puts indirect pressure on developing countries to clear more native forests and grasslands to grow food crops, thereby accelerating deforestation and negatively impacting the environment.

Other challenges facing the bioenergy industry include the development of successful, local biomass supply chains. Developing a bioenergy industry is dependent upon the development of a biomass supply chain that can effectively and efficiently deliver an adequate supply of biomass at a reasonable price to the biorefinery. This process will require the formation of new business models and arrangements among those that grow, harvest, store, deliver, refine, and market biomass into bioenergy.

Despite the considerable challenges facing the bioenergy industry, there are a number of significant opportunities as well. New dedicated crops like miscanthus and switch grass, and short rotation woody crops like poplar and willow promise to provide environmental benefits such as carbon sequestration in addition to being excellent feedstocks. Emerging technologies like cellulosic ethanol promise to radically increase the efficiency of converting biomass to ethanol and to expand the range of potential feedstocks for bioenergy production. If these types of opportunities can be harnessed, bioenergy will continue to make a significant contribution to the expansion of renewable energy worldwide.

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See also Agriculture; Automobile Industry; Biotechnology Industry; Development, Rural—Developed World; Development, Rural—Developing World; Energy Efficiency; Energy Industries—Overview of Renewables; Facilities Management; Investment, CleanTech; Supply Chain Management

Further Reading

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