Chapter 3 Products and Possibilities

3.0 Introduction

Biomass, in various forms, has been a major source of energy for thousands of years. Biomass includes everything from algae and kelp found in oceans to trees and shrubs found in forests. When processes such as combustion or decomposition break down biomass, chemical energy is released, which can be captured and used. Biomass and components of biomass can also serve as building blocks for a variety of materials and products. This chapter will introduce you to the various conversion processes used to convert woody biomass feedstocks into products such as heat, mechanical power, electricity, transportation fuels, and other products.

3.1 Conversion Processes

The most common way to capture energy from woody biomass is through direct combustion (burning biomass to produce heat). Until the mid 1800s, woody biomass was mostly used for home heating and cooking. In many parts of the world, wood is still used for these purposes. Combustion is one of many thermochemical processes used to release energy.

Figure 1: *Wood gasification has the potential to meet energy requirements by converting the wood into a syngas that can be used in high efficiency gas turbines to generate electric power.* Photo courtesy of Warren Gretz, National Renewable Energy Laboratory.

There are three primary paths to producing bioenergy and bioproducts: biochemical, chemical, and thermochemical. Scientists and engineers have developed and refined thermochemical processes such as gasification to produce combustible syngases (or synthetic gases) and biochemical processes such as fermentation to produce liquid transportation fuels.

Biochemical Conversion

Biochemical conversion involves the use of bacteria, yeasts, and enzymes to break down the carbohydrates that make up biomass. The three most common types of biochemical conversion are anaerobic digestion, aerobic digestion, and fermentation. A good example of this process is the production of ethanol through fermentation. This process changes biomass into alcohol, a combustible fuel.

Chemical Conversion

Chemical conversion differs from biochemical conversion in that the catalyst that causes biomass to break down is a chemical rather than a living organism. A good example is the process used to make biodiesel. This process, commonly referred to as transesterification, alters the molecular makeup of biomass oil with the addition of a base or acid. The oil then becomes liquid fuel similar to that of diesel. Gasoline additives are also produced in this manner. One of the most common products used for this method is vegetable cooking oil taken from restaurants and food services. Through refinement of the chemical conversion process, these oils become biodiesel.

Thermochemical Conversion

When plant matter is exposed to heat, it breaks down into various gases, liquids, and solids. This is the basic concept of producing bioproducts or energy via thermochemical conversion. Heat is sometimes applied in the presence of oxygen, sometimes not; sometimes the contents are under pressure, sometimes not. The most common thermochemical conversion processes are gasification, combustion, pyrolysis, liquefaction, and Fischer-Tropsch, a two-part process that catalyzes syngas into oil. Each method produces a different product.

Tip: If your audience would like a more in depth, visual explanation of thermochemical, biochemical, and chemical woody biomass conversion processes, interactive graphics are available at The National Learning Center for Private Forest and Range Landowners (http://forestandrange.org/Biomass/Modules/Module%206/Index.asp)

3.2 Electricity and Heat

Of all the products that can be produced from woody biomass, heat, mechanical power, and electricity have the most potential and are where the majority of woody biomass is used currently.

Electricity

Typically, when wood is used to produce electricity, it is burned in a boiler, through direct combustion. Wood is burned alone or in combination with other fuels, such as coal or solid waste. In most boiler systems, wood chips, ground wood, or wood pellets are carried into the combustion chamber, also known as a firebox, on a traveling metal grate. The heat from the burning wood boils water that makes steam, which activates turbines, generating electricity. The electricity can be used to power small industrial applications or large, municipal power plants. If the complete replacement of fossil fuel feedstocks with biomass feedstocks is not realistic due to material handling costs, transportation, or supply issues, then co-firing the feedstocks is an alternative. Co-firing is the process of burning a combination of fuels, such as woody biomass and coal.

Woody biomass can also undergo gasification to produce electricity. In this process, biomass is gasified, turned directly from a solid to a gas, such as carbon monoxide, hydrogen, or other gases, which are then burned in a gas turbine, generating electricity.

Small Heating Systems

If you have ever left a pot of water on a campfire a little too long, seen firefighters battling a blazing house-fire, or owned a woodstove, you can appreciate the heat energy released by burning wood. Heat is a form of energy created by the motion of atoms and molecules. Although heat has a number of applications, wood heat is primarily used for increasing air temperature, rotating turbines, and drying material.

Open fires are the oldest small heating method in the world, and they continue to play a large role in developing countries today. However, the efficiency of open fires for heating domestic space is relatively low. Additionally, emissions under open fire conditions are difficult to regulate, if at all, and often conflict with local and regional air quality guidelines. In developed countries, open fires are mostly chosen for aesthetic reasons.

Figure 2: *Researchers evaluate and label pellet fuels for efficiency, pollutant emissions, and ease of handling.* Photo courtesy of Scott Bauer, USDA Agricultural Research Center.

Wood-fired heating systems such as forced hot air, hydronic, combination, and outdoor boiler systems are affordable energy solutions for increasing the air temperature of buildings in areas where wood is plentiful. Wood heating units are either indoor boilers or stoves or outdoor furnaces. These furnaces come in a variety of sizes and are typically made from stainless steel. Outdoor wood furnaces can heat buildings up to 30,000 square feet; whereas, indoor heating units tend to be used for smaller areas.

Heating systems designed to burn wood pellets are becoming a popular alternative to more conventional methods of home heating (e.g., fuel oil). The low air pollution emissions and clean burning nature of these pellet burners have the potential to produce heat at efficiency levels in the 80 to 90 percent range.

Pellets are small biomass particles such as straw, sawdust, and wood chips that have been processed and converted into small, dense, uniformly shaped cylinders. Increasing density allows for easier handling and storage, and the uniformly low moisture content of pellets leads to high combustion efficiency. Pellets are typically 6 to 8 millimeters (mm) in diameter and 5 to 30 mm long, with maximum water content of 8 percent. The construction of pellet production facilities is increasing in the United States, partially in response to an increase in demand from European countries and to a lesser extent domestic demand.

Pellet stoves are designed to burn these dense cylinders of wood for heat production. They can be an alternative for residential or small-scale use, and as a result are increasing in popularity. The stoves, with a low fuel-to-air ratio, are energy efficient and burn cleaner than more conventional wood burning stoves. Pellet stoves also offer convenience. Bags of fuel pellets store easily and stack compactly; and the uniform and small shape of pellets allows them to flow easier, making the automation of fuel handling easy.

Process Heat

Heat is generated during the electricity production process. Under a typical scenario, about one third of the fuel's energy can be converted to electrical energy while the other two thirds are released as waste heat in the form of low temperature steam, hot water, and hot air. The usefulness of heat as energy depends on the temperature because heat transfer requires a temperature difference.

In commercial and industrial wood processing, wood-fired boilers produce either hot water or steam. The steam is used for drying and processing as well as powering turbines for electricity. When electricity and heat are produced and used simultaneously, the process is referred to as co-generation or combined heat and power (CHP). CHP, also known as cogeneration, represents the largest use of wood energy in the U.S. Large pulp and paper manufacturing plants use their waste wood or by-products internally in these systems instead of fossil fuels such as natural gas. However,

What's the difference between cogeneration and cofiring?

Cogeneration (or combined heat and power, CHP) is a process by which electricity and heat are produced simultaneously.

Cofiring is when two different feedstocks, such as biomass and coal, are burned simultaneously to produce electricity, heat, CHP.

many smaller facilities both inside and outside the forest products industry successfully use CHP systems as well. Large institutional facilities such as hospitals and colleges also use them, frequently combining them with district heating and cooling systems to distribute energy to several buildings. Part of the popularity of CHP systems is their high efficiency. The overall system efficiency can reach around 75 percent for CHP, whereas using wood for electricity production exclusively typically provides around 30 percent system efficiency.

3.3 Transportation Fuels

In the U.S., refining petroleum has been the preferred method of producing transportation fuels, such as gasoline and diesel. However, concerns over resource depletion, increasing prices, the environment, and energy security are leading to an increased interest in and use of alternative feedstocks such as wood biomass. Biofuels are by no means a new concept or product. In fact, Henry Ford's first model T automobile was designed to run on ethanol, an alcohol produced from biomass. Biofuels have, however, largely been overlooked because up until recently crude oil has been cheaper and easier to refine. Three common biofuels are ethanol, methanol, and biodiesel. The following sections will explore each in more detail.

Ethanol

Ethanol is a flammable, tasteless, colorless, mildly toxic alcohol with a distinct odor. It is the same alcohol found in alcoholic beverages and is used as a transportation fuel and an industrial product. Ethanol is produced chemically through the hydration of ethylene, biologically by fermenting sugars with yeast, and thermochemically by gasifying wood and running the resulting syngas through a catalyst. Cellulosic ethanol or wood-based ethanol is made from materials contained in the cell walls of plants. Turning wood into ethanol is typically more complex than the process that breaks down food-based, agricultural biomass such as corn and sugarcane. This is because the cellulose (sugar) has to be separated out from lignin, the glue-like substance that holds the cellulose fibers together and upright.

Figure 3: *Ethanol plant.* Photo courtesy of Reuters News Media Inc.

Cellulosic ethanol is not only created from a renewable resource but it also burns cleaner than both gasoline and diesel. It has low carbon, sulfur, and particulate emissions (ash and soot). The large-scale production of ethanol from cellulosic biomass, in particular, is important because it would mean less waste when producing biofuels from feedstocks such as corn and cane. However, when exploring these feedstocks, it is important to consider how the replacement of petroleum-based fuel with agriculture and forestry fuels could impact supplies and prices for food and fiber products.

Methanol

Methanol, also known as wood alcohol or wood spirit, is a simple, yet toxic alcohol originally derived from the distillation of wood. Today, however, it is created synthetically using natural gas and steam. Methanol is also burned as an automobile fuel on a limited basis and in the 1990s it became popular to add methanol to gasoline to increase octane. It has since been banned in many states because even small spills can lead to problematic groundwater pollution. However, there are more than a billion gallons produced each year in the U.S., and the associated high-octane properties of methanol make it a fuel suitable for high-compression internal combustion engines, which is why it is largely used in the automobile racing industry. It also remains an important feedstock or base for a variety of products including plastic, paints, solvents, and explosives.

Biodiesel

Biodiesel is a transportation fuel made from fatty acids found in plants. Fatty acids are typically found in the fruit or food-based portion of a plant and can make up about 10 percent of a dried plant's mass. Fatty acids make up 90 percent of biodiesel. The other 10 percent of biodiesel, which is methanol, can be made from wood. Methanol is added to biodiesel to reduce "gooeyness" so that it can flow easily through automobile engines. While methanol can be made from wood, the majority of methanol currently mixed with biodiesel is made from petroleum feedstocks. For more information about food-based agricultural feedstocks, please refer to chapter 2, "What is Woody Biomass?"

A recent technological advance developed at the University of Wisconsin shows new promise for cellulosic biodiesel, which is made from the nonfood-based portion of the plant. What makes this advance so attractive is that the 90 percent of dry biomass currently not suitable for production of biodiesel could be used. Moreover, because the process eliminates the need for distillation, it is exothermic, meaning it requires very little extra energy, and thus the process is more efficient. This is important because the largest cost in the current biofuel refining process is the energy it requires.

3.4 Bioproducts

Petroleum- and coal-based feedstocks have dominated as industrial inputs over the past century. Rising prices, a decline in reserves, and consumer demand for environmentally friendly products have resulted in numerous opportunities for biobased materials in the marketplace. As research and development continues, new innovative substitutes for traditional petroleum- and coal-based products are discovered at a rapid rate.

Figure 4: *Char.* Photo by Sarah Ashton, Southern Regional Extension Forestry.

Char

Char is the solid portion of biomass that does not fully react during a thermochemical conversion process. It is recycled to produce steam for heat and energy. It can also be used as a filtration agent when converted to activated carbon, and it can be processed to create fertilizer or charcoal briquettes for grilling.

Glass Aggregates

Glass aggregates are unstructured solids formed when the minerals found in various sludge effluents are subjected to heat and subsequently melt. So how is this a product of biomass? A common effluent used in this process is paper mill residue, and the minerals found in paper mill residue originate in the wood fiber used in the pulping process. Once the aggregates are formed, they are ground into various sizes depending on their ultimate use: ceramic tile, roof shingle granules, asphalt paving, material for cement, and sandblasting media.

Anaerobic Digestion Effluent

Anaerobic digestion effluent is a mixture of solids and liquids expelled from the anaerobic digestion process. Much of it comes from livestock and poultry operations where animals are managed in relatively confined areas and animal waste is concentrated. While not as abundant, effluent is also produced from the anaerobic digestion of woody biomass, which is 20 to 30 percent biosolids and comprised of nitrogen, potassium, and phosphorous. Effluent can be used for composting, fertilizer, and bedding.

Bedding Wood Shavings and Pellets

Figure 5: *Pellets made from woody biomass.* Photo by Sarah Ashton, Southern Regional Extension Forestry.

Bedding refers to any tangible material that goes into covering floors in animal husbandry structures such as horse stalls and poultry houses. It consists of anything from sand to wood chips and even plastics. People have used straw, wood shavings, and sawdust for ages and continue to do so in industries like equestrian sports, livestock shows, and traditional animal husbandry. These biomass products provide insulation and protection for animals as well as needs.

Another type of biomass bedding in production today is wood pellets. Wood pellets specially designed for bedding are a healthy and long-lasting alternative to shavings and straw. Using pellet bedding in horse stalls has the potential to reduce yearly labor costs and is quicker and easier to remove when cleaning the stalls compared to more traditional materials. The use of wood pellets for bedding also reduces stall waste and the breakdown of the used pellets is faster, making it more valuable as a soil amendment.

Bioplastics

Renewable biomass resources such as starches, fatty acids, and vegetable oils can serve as sources for bioplastics. Biodegradable plastics—such as starch esters, cellulose acetate blends, polylactide, and thermoplastic proteins are all derived from cellulose. Rayon, for example, is a fabric woven from fibers of spun wood cellulose (Monroe, 2007). Cellulose is also processed and purified into cellulose gum to thicken low-fat dressings, paint, and shampoo (Monroe, 2007).

Ash

Ash is a byproduct produced when woody biomass s combusted. It comes from the minerals present in the wood and soil contamination. Properties of wood ash depend on a variety of factors including the type of plant; part of the plant (bark, wood, or leaves); type of feedstock (wood, pulp, or paper residue); combination with other fuels; type of soil and climate; and conditions of conversion (e.g., combustion, gasification, pyrolysis).

Figure 6: *Ash remnants from burning woody biomass.* Photo courtesy of D. E. Wieprecht, USGS.

There are a number of uses for ash generated from wood. Wood ash stimulates microbial activities and mineralization in soil by improving the soil's physical and chemical properties. It is highly alkaline, so it is often used to raise the pH of acidic soils. In the U.S., wood ash applications are used as a source for potash production, as a liming agent, a source of nutrients, and as a tannin-neutralizing agent. It also neutralizes soil acidification caused by acid deposition and nutrient export caused when whole trees are harvested. Wood ash, because it is a direct source of phosphorous, calcium, magnesium, and potassium, is also used to correct nutrient deficiencies. Wood ash is sometimes used to reduce the total carbon and nitrogen in a soil. When wood is co-fired with other fuels, however, the resulting ash cannot be used as wood ash.

3.5 Biochemicals

Steady advances in the production technology have made biobased chemicals a competitive commodity. The use of biobased chemicals derived from biomass can alleviate our dependency on high-cost, crude oil-based chemicals by providing a renewable alternative.

Acids

Acids are a vital component of many industrial products and processes including the production of food preservatives and plastics. Increasing the feedstock for the production of acids is necessary for the U.S. to stay economically competitive in the global market. Acetic acid, fatty acid, itaconic acid, lactic acid, and succinic acid can all be recovered from forest residues.

Specialty Chemicals

Specialty chemicals also play an important role in the U.S. economy. Currently, organic chemicals are made primarily from petroleum and used for the production of paints, solvents, fibers, pharmaceuticals, and plastics. There is a growing market for specialty chemicals made from woody biomass, including ethylene, enzymes, PDO, 3-HP, biobased fuel gas, syngas, butanol, and glycerin.

Oils

Raw liquefaction oil is a free-flowing dark liquid produced by a thermochemical conversion process called liquefaction. It is easily stored and transported. Some light liquefaction oils are even used as refined biodiesel. Some chemical components of liquefaction oil are used as solvents, which can then be found in paint remover and nylon, used as additives to rubber and waxes, and used in the manufacturing of explosives and jet fuel to increase octane (the quality of fuel).

Figure 7: *Bio-oil liquid can be used in fuel applications in addition to extracting useful chemical compounds.* Photo courtesy of Warren Gretz, National Renewable Energy Laboratory.

Pyrolytic bio-oil is a complex, combustible mixture produced by pyrolysis, the breakdown of biomass at high temperatures in the absence of oxygen. Pyrolytic bio-oil or biocrude is marketed as a free-flowing, dark brown liquid that can be stored and transported easily. It has been used commercially for industrial heat since the early 1930s and is currently being tested as a fuel for diesel transportation and stationary turbine and diesel power. Extracted additives from pyrolyticbio-oil produced in a fast pyrolysis process are used to infuse ”smoked”, “roasted”, or “grilled” flavors in food.

3.6 Carbon

In addition to the tangible goods derived from woody biomass, there are also important ecological services. One such service is carbon sequestration.

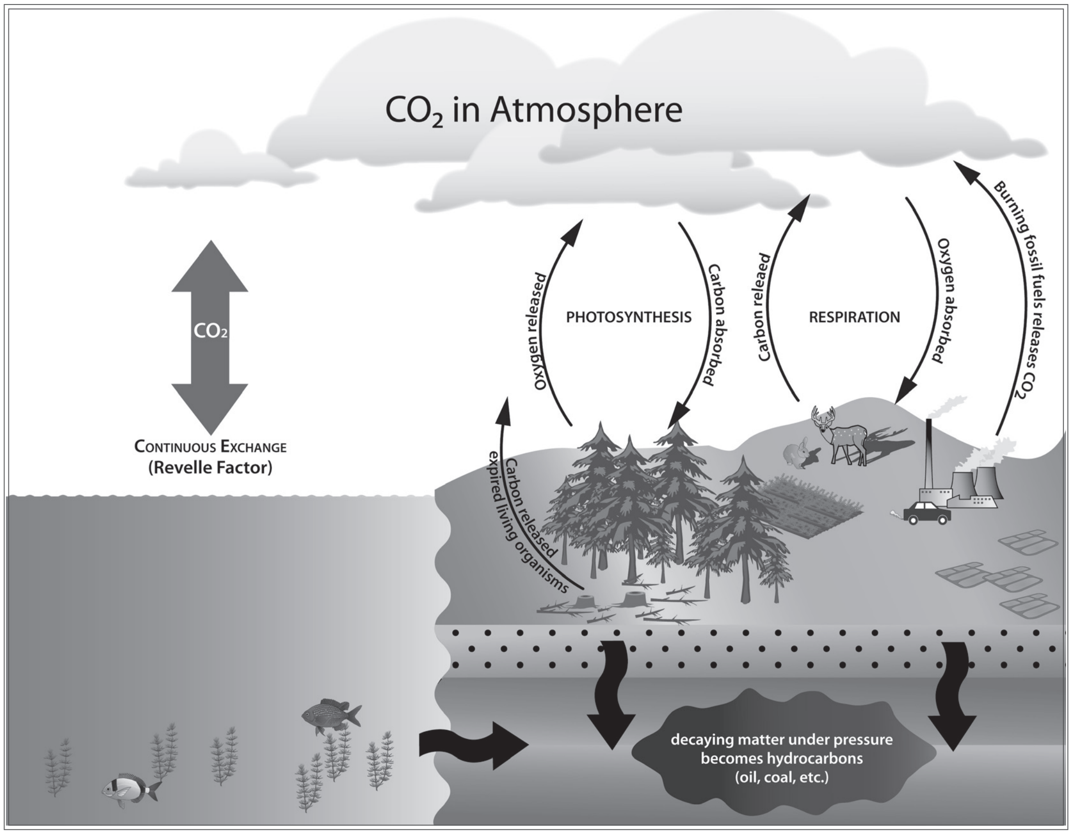
Carbon cycles continuously through all plants and animals, soils, oceans, and the atmosphere (Diagram 1). This cycle results in a natural balance of carbon dioxide levels. Carbon is a major component of all living organisms. Humans and animals get carbon from food. Green plants absorb carbon from the atmosphere during photosynthesis. As plants and animals grow, they store and release carbon. As they decompose, they also release carbon. Tree growth and wood decomposition represents a short-term carbon cycle, where growing trees convert carbon dioxide to cellulose and decomposition releases the carbon back into the atmosphere. Whether trees naturally decompose or are burned, carbon combines with oxygen and is emitted back into the atmosphere, replacing the carbon dioxide that was recently sequestered. When fossil fuels are burned, on the other hand, they release carbon that has been stored for millions of years back into the atmosphere.

Internationally, some governments, in an effort to reduce carbon emissions, have set carbon emission cap-and-trade policies, which set a total allowable carbon dioxide emission or “cap,” and thereby establish a market value or price for carbon. If an industry or utility emits more carbon than allowed, it has a choice: reduce carbon emissions or purchase carbon credits from a seller. A seller is a person or entity that, by some action, is producing fewer carbon emissions than allowed by the cap or else is sequestering carbon. Adoption of some form of carbon trading or regulation within the U.S. has been an increasing discussion by Congress and the President and his administration.

Working forests sequester a significant amount of carbon. Young stands absorb 2 to 9 tons of carbon dioxide a year as they grow; although older stands store more carbon overall, they sequester less because of reduced growth rates and higher respiratory losses (Birdsey, 1996). In all, U.S. forests sequester between 200 and 280 million metric tons (a metric ton is 2,200 lbs) of carbon each year, offsetting approximately 12 percent of U.S. greenhouse gas emissions (Birdsey and Health, 1995 and Murray et al., 1995). By owning and managing forests, landowners may qualify as carbon credit holders. Carbon credit programs and a carbon market are still in their infancy, but at some point, there may be a significant value landowners can capture.

Carbon sequestration refers to the condition of long-term storage of carbon in the terrestrial biosphere, underground, or the oceans to help slow or reduce the buildup of carbon dioxide.

Diagram 1: *Carbon cycle.* Illustration adapted by Camilla Geniatulina.



3.7 Summary and Conclusion

Research and development have created technologies to replace many petrochemically derived products with products derived from biomass. Scientists and engineers also continue to make progress in the development of processes that reduce the real cost of converting plant matter into value-added products. At the same time, environmental concerns and legislation are intensifying the interest in agricultural and forestry resources as renewable feedstocks. Sustained growth of this developing industry will depend on new market development and the cost competiveness of bioenergy and biobased industrial products.

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