Bioenergy Conversion Technologies

There are four types of conversion technologies currently available, each appropriate for specific biomass types and resulting in specific energy products:

1. **Thermal conversion** is the use of heat, with or without the presence of oxygen, to convert biomass materials or feedstocks into other forms of energy. Thermal conversion technologies include direct combustion, pyrolysis, and torrefaction.

2. **Thermochemical conversion** is the application of heat and chemical processes in the production of energy products from biomass. A key thermochemical conversion process is gasification.

3. **Biochemical conversion** involves use of enzymes, bacteria or other microorganisms to break down biomass into liquid fuels, and includes anaerobic digestion, and fermentation.

4. **Chemical conversion** involves use of chemical agents to convert biomass into liquid fuels.

Thermal conversion

As the term implies, thermal conversion involves the use of heat as the primary mechanism for converting biomass into another form. Combustion, pyrolysis, torrefaction, and gasification are the basic thermal conversion technologies either in use today or being developed for the future.

Combustion

Direct combustion is the burning of biomass in the presence of oxygen. Furnaces and boilers are used typically to produce steam for use in district heating/cooling systems or to drive turbines to produce electricity. In a furnace, biomass burns in a combustion chamber converting the biomass into heat. The heat is distributed in the form of hot air or water. In a boiler, the heat of combustion is converted into steam. Steam can be used to produce electricity, mechanical energy, or heating and cooling. A boiler's steam contains 60-85% of the energy in biomass fuel.

Co-firing is a practice which has permitted biomass feedstocks to be used early on in the renewable energy transformation. Co-firing is the combustion of a fossil-fuel (such as coal or natural gas) with a biomass feedstock. Co-firing has a number of advantages, particularly when electricity is an output. If the conversion facility is situated near an agro-industrial or forestry product processing plant, large quantities of low cost biomass residues are available to be burnt with a fossil-fuel feedstock. It is now widely accepted that fossil-fuel power plants are usually highly polluting in terms of sulfur, CO_2 and other GHGs. Use of existing equipment, with modifications, to co-fire biomass may be a cost-effective means for meeting more stringent emissions targets. Biomass fuel's comparatively low sulfur content allows biomass to potentially offset the higher sulfur content of fossil fuel.

Biomass can also be used in co-generation, also called combined heat and power (CHP) which is the simultaneous production of heat and electricity. All power plants produce heat as a by-product of electricity production, and this heat is typically released to the environment through cooling towers (which release heat to the atmosphere) or discharge into near-by bodies of water. However, in CHP processes, some of the "waste heat" is recovered for use in district heating. Co-generation coverts about 85% of biomass' potential energy into useful energy.

Pyrolysis and torrefaction

These processes do not necessarily produce useful energy directly, but under controlled temperature and oxygen conditions are used to convert biomass feedstocks into gas, oil or forms of charcoal. These energy products are more energy dense than the original biomass, and therefore reduce transport costs, or have more predictable and convenient combustion characteristics allowing them to be used in internal combustion engines and gas turbines.

Pyrolysis is a processes of subjecting a biomass feedstock to high temperatures (greater than 430 °C) under pressurized environments and at low oxygen levels. In the process, biomass undergoes partial combustion. Processes of pyrolysis result in liquid fuels and a solid residue called char, or biochar. Biochar is like charcoal and rich in carbon. Liquid phase products result from temperatures which are too low to destroy all of the carbon molecules in the biomass so the result is production of tars, oils, methanol, acetone, etc.

Torrefaction, like pyrolysis, is the conversion of biomass with the application of heat in the absence of oxygen, but at lower temperatures than those typically used in pyrolysis. In torrefaction temperatures typically range between 200-320 °C. In the torrefaction process water is removed and cellulose[?], hemicellulose and lignins are partially decomposed. The final product is an energy dense solid fuel frequently referred to as “bio-coal”.

Thermochemical conversion

Thermochemical technologies are used for converting biomass into fuel gases and chemicals. The thermochemical process involves multiple stages. The first stage involves converting solid biomass into gases. In the second stage the gases are condensed into oils. In the third and final stage the oils are conditioned and synthesized to produce syngas. Syngas contains carbon and hydrogen and can be used to produce ammonia, lubricants, and through the Fischer-Tropsch process can be used to produce biodiesel.

Gasification

Gasification is the use of high temperatures and a controlled environment that leads to nearly all of the biomass being converted into gas. This takes place in two stages: partial combustion to form producer gas and charcoal, followed by chemical reduction. These stages are spatially separated in the gasifier, with gasifier design very much dependant on the feedstock characteristics. Gasification requires temperatures of about 800°C. Gasification technology has existed since the turn of the century when coal was extensively gasified in the UK and elsewhere for use in power generation and in houses for cooking and lighting. A major future role is envisaged for electricity production from biomass plantations and agricultural residues using large scale[?] gasifiers with direct coupling to gas turbines.

Biochemical conversion

The use of micro-organisms for the production of ethanol is an ancient art. However, in more recent times such organisms have become regarded as biochemical "factories" for the treatment and conversion of biological materials. Fermentation technologies, with the assistance of biological engineering, are leading to breakthrough processes for creating fuels and fertilizer, and other products useful in agriculture. Anaerobic digestion and fermentation are key biochemical conversion technologies.

Anaerobic digestion

Anaerobic digestion is the use of microorganisms in oxygen-free environments to break down organic material. Anaerobic digestion is widely used for the production of methane- and carbon-rich biogas from crop residues, food scraps, and manure (human and animal). Anaerobic digestion is frequently used in the treatment of wastewater and to reduce emissions from landfills.

Anaerobic digestion involves a multi-stage process. First, bacteria are used in hydrolysis to break down carbohydrates, for example, into forms digestible by other bacteria. The second set of bacteria convert the resulting sugars and amino acids into carbon dioxide, hydrogen, ammonia and organic acids. Finally, still other bacterias convert these products into methane and carbon dioxide. Mixed bacterial cultures are characterized by optimal temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide temperature range, for example, above 0° C and up to 60° C. When functioning well, the bacteria convert about 90% of the biomass feedstock into biogas (containing about 55% methane), which is a readily useable energy source.

Solid remnants of the original biomass input are left over after the digestion process. This by-product, or digestate, has many potential uses. Potential uses include fertilizer (although it should be chemically assessed for toxicity and growth-inhibiting factors first), animal bedding and low-grade building products like fiberboard.

Fermentation

At its most basic, fermentation is the use of yeasts to convert carbohydrates into alcohol – most notably ethanol, also called bioethanol. The total process involves several stages. In the first stage crop materials are pulverized or ground and combined with water to form a slurry. Heat and enzymes are then applied to break down the ground materials into a finer slurry. Other enzymes are added to convert starches into glucose sugar. The sugary slurry is then pumped into a fermentation chamber to which yeasts are added. After about 48-50 hours, the fermented liquid is distilled to divide the alcohol from the solid materials left over.

In the U.S., corn grain is the primary feedstock in ethanol production. About 2.8 gallons of ethanol is produced from one bushel of corn. A by-product of the corn-to-ethanol process is spent grains. These spent grains are dried and can be used as feed for livestock – termed Distillers Dried Grains, or DDGs.

Cellulosic ethanol production by fermentation is more complex than conversion of starch or sugar components of plants. Cellulosic ethanol production involves use of wood, grasses and the stems, leaves and stalks of non-grass plants. Lignocellulose, the structural material of plants, must first be broken down into sugars before being fermented into ethanol. Molecules of cellulose, hemicellulose and lignin – the components of lignocellulose, have strong chemical bonds and are difficult to separate. Mechanical pre-treatment and enzymatic are necessary to breakdown lignocellulose. As a result, at present, conversion of lignocellulosic materials into ethanol is less cost-effective than conversion of starch and sugar crops to ethanol.

Reducing the cost and improving the efficiency of separating and converting cellulosic materials into fermentable sugars is one of the keys to a viable industry. Research and development efforts are focusing on the development of cost-effective biochemical hydrolysis and pretreatment processes to overcome this barrier. Hydrolysis is a chemical process in which molecules are split into parts with the addition of water and a salt or weak acid. Another form of hydrolysis involves use of enzymes. Such technological advances promise substantially lower processing costs.

Chemical conversion

Chemical conversion of biomass involves use of chemical interactions to transform biomass into other forms of useable energy. Transesterification is the most common form of chemical-based conversion. Transesterification is a chemical reaction through which fatty acids from oils, fats and greases are bonded to alcohol. This process reduces the viscosity of the fatty acids and makes them combustible. Biodiesel is a common end-product of transesterification, as are glycerin and soaps. Almost any bio-oil (such as soybean oil), animal fat or tallow, or tree oil can be converted to biodiesel.