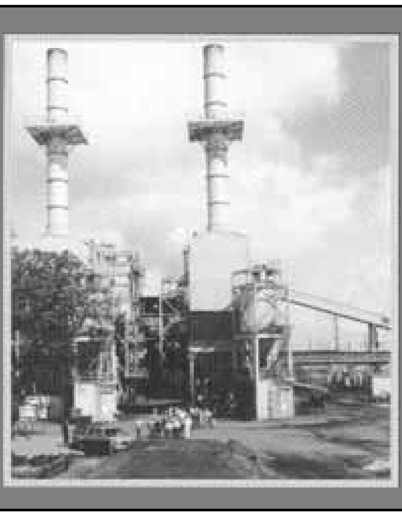


Thermal Energy, Electricity, and Transportation Fuels from Wood

by John I. Zerbe

In July of 2005, U.S. airlines were losing money. Some were in bankruptcy or on the verge of bankruptcy. The world's Number 1 auto producer, General Motors, was losing money and market share. By the end of the month sales had set records, but this was mainly because of costly sales incentives. The U.S. dollar that had been at a high point of $1.29 in exchange for the euro on January 13, 2004 was worth around 83 euro cents. Oil prices had just gone to a record level of over $60 per barrel. This does not mean that the world's Number 1 economy is headed for disaster, but it is symptomatic of a problem of too much dependency on foreign oil imports.

According to Energy Information Administration statistics (USDOE 2005), petroleum products net imports increased 16.8 percent in January 2005 compared with the level 1 year earlier. Crude oil net imports increased 5.3 percent, coal net imports increased 21.7 percent, and natural gas net imports increased 3.8 percent.

The best ways of decreasing this growth in importation of fossil fuels are to try and conserve usage (use automobiles less, and don't comfort condition entire oversized residences) and to produce more energy from domestic sources. One alternative source that is available and underused is surplus wood.

Feedstock

Certainly wood that is suitable for use in more valuable products should not be diverted to energy use that provides less income; however, other wood is unused or even burned or landfilled for disposal. Such wood is well suited for energy applications.

This wood includes small wood that should be removed from stands of timber for fire protection or in regular thinnings in accord with good forest management, "noncommercial" timber (rough trees, rotten trees, and salvageable dead trees), harvesting residues (growing and non-growing residues, uncut trees, and bark), softwood and hardwood removals (land clearing, stand improvement), insect and disease-killed trees, manufacturing residues, and construction/demolition waste.

Rough trees are live trees of commercial species that do not contain at least one 12-foot sawlog or two noncontiguous sawlogs each 8 Feet or longer, and contain defects because of roughness or poor form. Also included are live trees of noncommercial species. Timber volumes less than 5 inches in diameter at breast height and less than 4 inches in top diameter may also be considered noncommercial.

Rotten trees are those having more than 50 percent of their diameter classified as rotten.

Salvageable dead trees are standing or down dead trees that are considered merchantable.

A 1980 report (USDA 1980) estimated the unused wood available annually for energy in the United States as equivalent to 544 million metric dry tons (600 million dry tons) or 10.8 exajoules (10.2 Quads) of energy. Based on 4041 kJ/m^3 (145,000 BTUs/gal) of oil, this is 1,675 million barrels of oil. The ability to recover portions of this unused biomass economically was not proven. Nonetheless, it was assumed that technology for recovering perhaps 50 percent (272 million metric tons or 300 million dry tons) of this resource could be implemented by 1990 with a dedicated research, development, and application effort. This would have been enough biomass, added to the then current use d wood for energy, to produce 6.75 exajoules (6.4 Quads) of energy from 343 million dry metric tons (373 million dry tans of wood). The 343 million dry metric tons (378 million dry tons) statistic was derived from 272 million dry metric tons (300 million dry tons) of new production by 1990, 54 million dry metric tons (60 million dry tons) then used by industry. and 16 million dry metric tons (18 million dry tons) then used in residences and other applications.

A report by Perlack et al. (2005) estimates that forestlands in the contiguous United States can produce 334 million dry metric tons (368 million dry tons) of biomass for energy annually. This projection includes 47 million dry metric tons (52 million dry tons) of fuelwood harvested from forests, 131.5 million dry metric tons (145 million dry tons) of residues from wood-processing mills and pulp/paper mills, 42.6 million dry metric tons (47 million dry tons) of urban wood residues, including construction/demolition debris, 58 million dry metric tons (64 million dry tons) of residues from logging and site clearing operations, and 54 million dry metric tons (60 million dry tons) of biomass from fuel treatment operations to reduce fire hazards. These estimates were obtained by excluding all forestlands not currently accessible by roads, and all environmentally sensitive areas.

The 2005 estimate of 334 million dry metric tons (368 million dry tons) of forest biomass available is close to the 1980 estimate of 343 million dry metric tons (378 million dry tons). A 1976 report (USDA 1976) showed that about 907,200,000 dry metric tons (1 billion dry tons) of "noncommercial" timber existed in inventory at that time. Thus it is likely that through the use of existing inventory and expanding productivity and accessibility of forest biomass it would be possible to obtain 10 percent of our energy needs from forest biomass. Ten percent of our 2004 consumption amounts to 10.0 Quads (USDOE 2005). Wood is a very important source of renewable energy

In 1980, the contribution of energy from wood to our total energy consumption was 3.7 percent. In 1990, it was 3.1 percent, and in 2000 it was 3.2 percent (USDOE 2005). A growth to 10 percent should he possible, but commitment and effort are necessary or the figures For 2030,2020, and even 2050 could still be around 3 percent or less. For 10 percent of our energy to come from wood, measures to conserve fossil fuel use must also be implemented.

In addition to waste wood, another biomass energy resource that may assume importance in the future is cellulose energy crops (Wimberly 2005). Plants that have been proposed as cellulosic energy crops include switchgrass, but more research has been conducted on fast-growing trees such as hybrid poplars grown with short-rotation intensive culture (SRIC). The report by Perlack et al. (2005) assumes that 25 percent of the wood fiber crops are used for energy and the remainder for other. higher value conventional forest products.

Technologies

Direct Burning

The most effective way to use wood biomass for energy is to combust it efficiently. Combustion systems include boilers or other combustors, plus any emission control equipment as well as in-plant fuel preparation equipment. Different combustors can use different types of particulate or fireplace-length fuel. Research has also been applied to burn whole-tree length wood units. Wood fuel may be burned dry or with moisture contents (MCs) up to about 60 percent based on wet weight. Uniformity of fuel facilitates combustion control and overall process efficiency. However, some installations fire as-received hog fuel that varies in size and density, contains excessive moisture, and may be contaminated with sand or dirt. Residue fuel may be handled and enhanced in-plant by sizing, cleaning, drying, storing, conveying, and metering.

Net boiler efficiencies may range from 60 percent for green wood at 60 percent MC to 80 percent for ovendried wood.

In some applications, wood may be co-combusted with coal or natural gas. Co-combustion with coal that is high in sulfur content is often advantageous in order to reduce sulfur emissions to the atmosphere and problems with mercury and other heavy metals.

Pyrolysis

The dictionary definition of pyrolysis is chemical change brought about by the action of heat. However, pyrolysis is often taken to mean heating a material such as wood in the absence of oxygen or in the presence of limited amounts of oxygen that are insufficient to support complete combustion. For this discussion, we will assume the second definition. Products of pyrolysis are liquid, char. and gas. Lower pyrolytic temperatures will produce higher proportions of liquid and char and lesser amounts of gas. Higher pyrolytic temperatures will produce more gas.

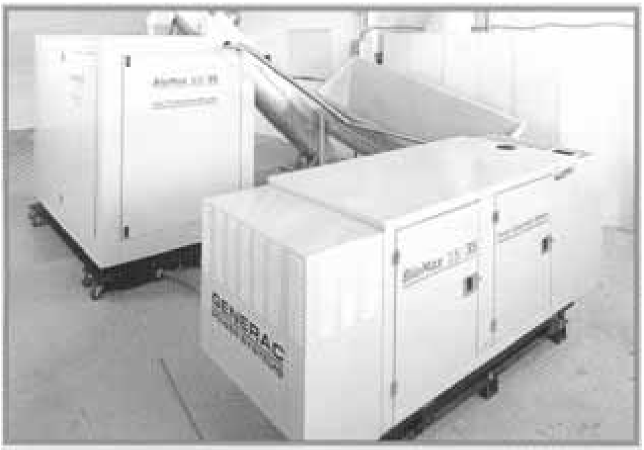
In the temperature range from400° to 600°C (752° to 1112°F), a maximum liquid yield was obtained at 500°C (932°F). The char yield decreased and the gas yield increased with temperature (van de Beld 2004).

In mid-2005, there was renewed interest in "flash pyrolysis" to produce liquid bio-oil. In this process, organic materials are heated rapidly to 450° to 600°C (822' to 1.112°F) in the absence of air. Typically 70 to 75 weight percent of the feedstock is converted into oil. The oil can be used for a variety of products. The oil is somewhat corrosive, but with appropriate treatment it could conceivably he used for diesel fuel. Another possibility is to use the oil for boiler fuel.

Charcoal

Another approach to gaining an improved fuel from a pyrolytic process is to manufacture charcoal. Charcoal is produced by heating wood in airtight ovens or retorts, in

Railroad ties and logs for fuel at Wheelabrator Shasta Energy Company, Anderson, California. The power plant is allowed to burn not mom than 25 percent railroad ties; burning plywood, particleboard, or plastic laminates is not permitted.



The BioMax 15 is a prototype combined heat and power system developed by Community Power Corporation, Littleton, Colorado. This is a state-of-the-art, transportable, fully automated, and environmentally friendly system. It can provide heat and power to small businesses, rural homes, and greenhouses.

chambers with various gases, or in kilns supplied with limited and controlled amounts of air. in all cases, heating breaks down the wood into gases, a watery tar mixture known as lignosulfonic acid, and charcoal. In the United States, charcoal is used primarily as an outdoor cooking fuel. Up until the 1960s, recovery of acetic acid and methanol from the retorts used in charcoal production stimulated growth of the industry. However, as synthetic production of these chemicals became more economical, co-production in the charcoal manufacturing or carbonizing process ceased. and now U.S. charcoal is made in kilns.

Since the 1960s, the charcoal industry in the United States has stagnated. However, manufacture of charcoal provides an improved fuel compared to wood as it is resistant to attack by insects and decay, and it is more easily transported. A serious disadvantage in the use of charcoal is that the conversion process entails a potential fuel yield that is only about 49 percent or less of the energy content of the original wood.

Gasification

Gasification of wood to produce alternative fuels flourished in some countries before and during World War II when petroleum supplies were tight. Cars run by gasfiers worked somewhat better with charcoal than with wood. Because of some operational disadvantages, the technology disappeared soon after the war. Gasification is an efficient process, even at a small scale, and can be used for mobile or decentralized energy conversion systems.

Gasification to provide energy for generating electricity may enable efficiencies of 22 to 37 percent in comparison to efficiencies of 15 to 18 percent with steam provided by combustion. Gasification could be used with internal combustion engines or gas turbines. Steam would normally be used with steam turbines. although steam engines provided some power in the past. in utilizing gas in fuel cells, high electrical efficiencies can theoretically be attained in small scale and under partial load (25% to 50%).

The current status of gasification of wood is highlighted by the development of power generating units consisting of internal combustion engines that drive generators, e.g., demonstration units produced by Community Power Corporation, Littleton, Colorado. In Scandinavian countries and Austria there are operating gasification units that produce heat for space heating. Some of these units have also been exported to the United States.

Pellets and Briquettes

Wood pellets and briquettes are more fully processed and refined than chips, sawdust, chunkwood, and other forms of particulate solid wood. Pellets and briquettes are more uniform in size, MC, and other physical properties such as ash content.

Pellets are made by hammer-milling wood into sawdust. If necessary, some drying may be done at the same time as milling. The sawdust is fed into a pelleting machine where it is subjected to high pressure and extruded through a die. Wood chips do not possess the good free-flowing characteristics of wood pellets. Wood pellets are readily combustible and well suited For use with sophisticated and automatically controllable appliances. Pellets may be bought bagged or in bulk, but bagged pellets cost more.

The higher refinement of pellets requires more energy expenditure than that for solid wood fuels. A 7.5 metric ton/hour (8.3 ton/hr). (180 metric tons per day or 198 tons per day), West Coast softwood pellet producer using primarily sawdust as a raw material, consumed 78 kWh per metric ton (71 kWh/ton) Additionally, a hardwood pellet plant in Quebec that used sawdust as a raw material had an electrical consumption of 250 kWh per metric ton (227 kWh/ton) (Samson and Duxbury 2000). No reason is stated for the discrepancy in energy consumption of the two plants. However, premium wood pellets burn at a high efficiency of 83 percent according to a Forest Products Laboratory Techline (Bergman 2004). The higher combustion efficiency for pellets makes up for some of the extra energy used in pellet manufacture.

Most North American pellet mills are producing a 6.4–mm (1/4-inch) pellet (Samson and Duxbury 2000). Briquettes are larger than pellets, and they are used mainly for boiler fuel. Fireplace logs are larger than briquettes.

Fireplace logs are of two types. Some are made solely of wood particulates. The other kind may have a combination of wood and petroleum wax.

Thermal Energy

For this article, four categories will be used to classify installations for converting wood into thermal energy for space and process applications: 1) micro scale, up to 1 MW (3.4 million BTUs/hr); 2) small scale, 1 to 5 MW (3.41 to 17.1 million BTUs/hr); 3) medium scale, 5 to 15 MW (17.1 to 551.2 million BTUs/hr); and 4) large scale, above 15 MW(51.2 million BTUs/hr).

Micro Scale

Typically, micro scale units are used for space heat in residences or institutions such as schools. For residential use, combustion furnaces or gasification units may be used to fire split lengths of firewood or particulate fuel to heat air in a plenum or water in a tank or boiler. Air, hot water, or steam is then circulated through ducts or pipes throughout a building. In a simpler arrangement, heat is accumulated From burning logs in a fireplace and distributed to the surrounding space by convection or forceful fanning.

The residential sector consumed 0.35 exajoules (332 trillion BTUs) of energy from wood in 2004 (USDOE 2005). In the commercial sector of the economy, 0.04 exajoules (41 trillion BTUs) were consumed.

Small Scale

The typical heating medium for small-scale units is hot water, not steam. High-pressure steam may require additional operator attention and maintenance that could make wood heat not economical (Bergman and Zerbe 2004). Known capacity at educational institutions in the Midwest and several other states is a total of about 120 MW (410 million BTUs/hr).

At the Lied Conference Center in Nebraska City, Nebraska, there is a facility with a rated capacity of about 3.4 MW (11.5 million BTUs/hr), where steam is generated not only for heat to be used for heating space and a swimming pool, but also for energizing an air-conditioning system.

Air-conditioning applications are another example where more wood could be used to greater advantage. Absorption chiller refrigeration units can use steam or hot water to provide energy for evaporation in the evaporation/condensation cycle. The absorbent used at the Lied Conference Center is lithium bromide. Recently, other systems that use silica gel as an adsorber have entered the market. These units can use warmer water (55° to 100°C [131° to 212°F]) For energy in the chiller units.

Other lithium bromide absorption air-conditioning units that use wood fuel are at Chadron State College, Chadron, Nebraska; University of Idaho, Moscow, Idaho; a hospital, two office buildings, and a brewery in Pfaffenhofen, Germany: and a national demonstration project in Fußach, Austria.

Medium Scale

There are a few educational institutions that have medium scale facilities, e.g., in Massachusetts, Minnesota, and Mississippi. Various types of combustors, boilers, and fuels are used. Known capacity at educational institutions is a total of about 31.2 MW (106 million BTUs/hr).

Large Scale

Large-scale facilities using wood fuel are common in forest products manufacturing plants. In the industrial economic sector, 1.528 exajoules (1.448 Quads) of energy were produced from wood in 2004 (USDOE 2005).

An educational institution in Moscow, Idaho, operates a hogged fuel burning facility with a capacity of about 25.8 MW (88 million BTUs/hr). Another institution in Rolla, Missouri, has a facility with a capacity of about 39.6 MW (135 million BTUs/hr).

Other industries, especially those located near forested areas, could also use more wood for fuel. The cement industry provides an example. If the entire cement industry were viewed as a single corporate entity, it would only rank about 120th in Fortune Magazine's top 500 companies. The cement-making process is very energy intensive and it would rank high on a scale depicting energy consumed versus dollar value of end products. Large amounts of Fuel are required to heat materials to 1400°C (2,700°F). Where coal is burned it can take about 181 kg (400 pounds) of coal to make 1 ton of cement. This results in high emissions of CO_2 to the atmosphere in addition to the high emissions of CO_2 in the calcining process that converts calcium carbonate to calcium oxide (limestone to a major cement ingredient). As a result of high CO_2 emissions, cement plants are recognized as being major generators of this greenhouse gas.

Substitution of wood for coal or other fossil fuel in cement making would mean that the CO_2 from combustion and expelled to the atmosphere would not be there permanently, as much of it would be used in new growth to replace the renewable wood resource. High sulfur coal used in cement manufacture also results in lower cement yields from the raw material input and a disposal problem, as scrubbing sulfur from the coal with calcium oxide results in nonmarketable calcium sulfate.

Wood has been used experimentally as an alternative to coal in cement manufacture in Colorado.

Electrical Generation and Cogeneration

Gasification

Engine/Generator. — Gasification of wood is an old technology, but not necessarily a mature technology. Community Power Corporation {CPC) has demonstration gasifiers paired with internal combustion engines and power generators operating in the 5-kW to 15-kW range. and it has 50-kW and 100-kW units under development. CPC has made significant improvements in tar filtration and computerized operating control in the design of its units. CPC also has provision for collection of waste heat from cooling gas before it enters the engine. Use of this heat for drying wet wood chips to 25 percent MC can improve the efficiency of the gasification process from 55 percent without heat recovery to 75 percent with heat recovery. Utilization of waste heat from the engine exhaust and cooling systems could further increase efficiency. This technology is promising for highly efficient and economical power production in the future.

Besides internal combustion engines, steam engines or Stirling engines (both external combustion types) might be operated with energy from gasification or combustion to provide mechanical force to drive generators or other machines such as compressors for air-conditioning and refrigeration units, similar to the types of air-conditioning units used in cars. Steam engines have a long history. They were operated with wood fuel almost exclusively in the early days of railroading and transportation on river steamboats.

Turbine/Generator. — Gas turbines are an efficient means of providing energy for power generation, and in a bottoming cycle gas turbine (integrated gasification combined cycle [IGCC]) waste heat can be recovered for making steam. In completing the process, the steam is used to generate additional electricity via a steam turbine.

Some attempts to use gas derived from wood in gas turbines were unsuccessful because foreign elements in the gas caused intolerable erosion of the turbine blades too rapidly. With improvements in gas filtration, the prospects for future use of this technology are better. The near-term opportunity for IGCC technology to be used with wood is in the forest products industry because a majority of the industry's power boilers will reach the end of their useful lives in the next 10 or 15 years (Bain and Overend 2002).

Steam Turbine

Most electric power from wood is produced with steam-driven turbine/generators. There are wood-fired power plants up to about 73 MW around the country. Wood-powered power plants of 10 to 20 MW are more common. The average biomass-to-electricity efficiency of the industry is 20 percent. Perhaps the nearest term low-cost option for the use of biomass in power generation is cofiring with coal in existing boilers (Bain and Overend 2002).

Cogeneration or combined heat and power (CHP) enables more efficient utilization of wood than production of electricity only. In an electricity-only process, all of the steam is condensed in the turbine cycle; in CHP operation, a portion of the steam is extracted to provide process heat. The addition of dryers and incorporation of more rigorous steam cycles is expected to raise the efficiency of direct combustion systems by about 10 percent over today's efficiency and to lower capital investment costs from the present $2,000/kW to about $1,275/kW pain and Overend 2002)

Gas Turbine

When using wood fuel in gas turbines it is necessary to use a clean and clean-burning non–corrosive gas. There are various gasification technologies to produce medium- or low-calorific gas from wood. These processes along with gas cleaning processes are improving. In IGCC systems, the steam for the bottoming turbine is produced from heat recovered from the gas turbine cycle.

Fuel Cell

Fuel cell technology is highly efficient for the production of electricity at various scales. Use of wood to provide fuel for fuel cells could involve conversion of wood to hydrogen for direct use in fuel cells, conversion of wood to methanol for direct use of methanol in fuel cells, reforming methanol or ethanol from wood to hydrogen for use in Fuel cells, or conversion of wood to low- or medium-calorific gas for use in fuel cells. Different types of fuel cells would be necessary for these different approaches. It will probably be a matter of a decade or more before these details can be worked out, and different approaches will be needed fer different applications.

Transportation Fuels

Ethanol

For a long time, ethanol has been envisioned as a liquid fuel to use as an alternative to gasoline and diesel fuels or for admixture with gasoline and diesel fuels. Ethanol produced from sugar has been popular in Brazil since the 1970s. Ethanol for admixture with gasoline in the proportion of 10 percent ethanol to 90 percent gasoline has been common in the United States since the 1980s. The source for this ethanol has mainly been corn. A small amount has come from sulfite pulp waste liquor.

> **The biggest problem in making ethanol from wood is to make it at a competitive cost. It is easier to hydrolyze starch in corn to glucose to make ethanol than it is to hydrolyze cellulose in wood to glucose.**

Ethanol is a good fuel, since it burns cleanly and efficiently in modern engines. It has a high octane rating. It is non-toxic. The disadvantages of ethanol are that it has a lower fuel density than gasoline. and it can cause starting problems in cold weather. The fuel density of ethanol is about 2348 kJ/m^3 (84,250 BTUs/gal) as compared to gasoline at about 3456 kJ/m^3 (124,000 BTUs/gal). Automobile engines do need some modifications to use fuel that has 85 percent ethanol. Some engines are modified to burn multi-fuels such as either gasoline or ethanol.

Ethanol from wood was used as a motor fuel in the United States during World War I. Some countries used ethanol from wood during World War II. A plant to manufacture ethanol from wood was built in Springfield, Oregon, during World War II. It did not come into production during the war, and it was closed after the war, since there was no longer a need. Ethanol plants operated in Russia and Bulgaria after World War II

The biggest problem in making ethanol from wood is to make it at a competitive cost. It is easier to hydrolyze starch in corn to glucose to make ethanol than it is to hydrolyze cellulose in wood to glucose. Hemicellulose in wood, particularly hardwood, can also he converted to xylose for fermentation to ethanol. Even larger yields of ethanol might be obtained if all three major components of wood (cellulose, hemicellulose, and lignin) could be gasified and converted to ethanol synthetically.

A problem in converting corn to ethanol is that corn requires much fossil fuel as it is being cultivated. harvested. transported, and processed. It has been estimated that the ratio of energy output to energy input is no more than 1.1 for corn-based ethanol in the United States, and the energy input is provided mainly by fossil fuels (Rostrup-Nielsen 2005). Harvesting, transporting, and processing wood to ethanol should require considerably less energy.

Methanol

Methanol is another liquid alcohol fuel that can be manufactured from wood and is being proposed as an alternative to gasoline and diesel or as an admixture with gasoline and diesel for transportation. As a motor fuel, it can be burned cleanly and efficiently. It is used in racing cars at the Indianapolis Speedway. However, the fuel density of methanol is about 1750 kJ/m^3 (62,800 BTUs/gal) compared to ethanol at about 2348 kJ/m^3 (84,250 BTUs/gal). Methanol is also toxic

Wood was once an important source of methanol as a by-product of charcoal manufacture, but when collection of lignosulfonic acid from charcoal manufacture ceased in the 1960s, this method of manufacture was discontinued. When methanol was made synthetically from natural gas in the 1920s, this became the most economical pathway for production. Tennessee Eastman Corporation bought a wood-ternethanol plant in 1920 and later converted it to a plant to make synthetic chemicals from coal that was first gasified. Today, making methanol from wood economically would require gasifying wood and making a synthesis gas (syngas). Commercial plants to make methanol from wood lag behind plants that use syngas technology to make methanol from coal.

The most common feedstock for making methanol is natural gas. In winter. demand for heating with natural gas rises and methanol plants have been curtailed or closed down. However, currently, the only fuel component for which methanol is the raw material is methyl tertiary butyl ether (mtbe) for octane enhancement and as an oxygenate in gasoline. When gasoline with mtbe is spilled or leaked from storage tanks, the mtbe can contaminate ground water. The market for mtbe has softened, because its use has been banned in some states, and there is reason to think that it may be completely outlawed. If the use of mtbe is decreased further, there would be more demand for ethanol, or perhaps methanol, as oxygenates.

Despite marginal success gasifying coal to make methanol and other chemicals in different parts of the world during the last 50 years, there is no existing commercial plant for making methanol solely from wood. Yet wood should be easier to gasify than some coal, because it has more volatiles, less sulfur, and less mercury and other heavy metals compared to coal. Coal does have a higher concentration of carbon for use as a feedstock. Another consideration is that coal is found in large veins, and therefore it saves transportation costs to build plants near the concentrated and abundant raw material source. Wood supplies, which are often dispersed at distances of 80.45 km (50 miles) or more from the plant, can incur high transportation costs.

in Spreewitz, Germany, a town north of Dresden, the SVZ Schwarze Pumpe company operates an IGCC facility that converts 450,000 metric tons (496,000 tons) of solid waste and 50,000 metric tons (55,000 tons) of liquid waste into electricity, steam, and methanol feedstock. The solid materials treated at Spreewitz include plastic wastes, wood from used railroad ties and telephone poles, sewage sludge, old tires, and household garbage. These materials are ground up, pelleted, mixed with coal, and sent into four fixed-bed gasifiers made by different companies.

The methanol produced at the plant is refined until it is pure enough for sale. In September 2000, SVZ installed a British Gas-Lurgi oxygen-blown gasifier, which enables the production of higher quality methanol. Some of the methanol is used to make mtbe. SVZ filed for insolvency in April 2004 and was acquired by Swiss Sustec Holding AG.

Gasoline

Gasoline could be made from wood. But, again, technology that is most promising calls for gasification of wood and conversion of producer gas to syngas first. And in the United States and other parts of the world, gasification technology gives preference to coal rather than wood as a feedstock, despite the advantages that wood could have. For more than 50 years, Sasol in South Africa has been making gasoline and diesel fuel from coal. In the United States, support for clean coal technology reinforces the competitive advantages of coal as a raw material. But in the United States, manufacture of syngas from natural gas has been cheaper than making syngas from coal. Also, improved plant energy self-sufficiency can be obtained from gas made from wood by using some of the gas in an IGCC system to generate electricity.

Another process developed by Mobil Oil Corporation involves the conversion of methanol to hydrocarbons such as gasoline over zeolite catalysts (Spath and Dayton 2003).

The most direct way of making gasoline and diesel fuels from organic feedstocks is through Fischer-Tropsch (FT) synthesis. This involves syngas generation, gas purification, FT synthesis, and product upgrading. Several laboratories around the world are at work to improve gasoline and diesel fuel manufacture from wood and other biomass, but there is no commercial plant operating.

Diesel

Laboratory work on FT synthesis with wood seems to be closer to commercialization for diesel rather than for gasoline. In Freiberg, Saxony, Germany, a research group called Choren has been working intensively since 1994 with

This 22-MW stand-alone, biomass fired power plant at Pacific Oroville Power Inc., Oroville, California, burns about 450 to 500 bone dry tons of wood chips and other fuels per day at full capacity.

Overlook from debarker to yard at the small log mill of Sierra Pacific Industries, Anderson, California. The cogeneration plant uses woodwaste from lumber and pole manufacturing to produce electricity for the mill and office and heat for the dry kiln.

wood and other biomass to produce a clean gas for production of liquid fuels as well as heat and electricity. Choren plans to co-produce heat and electricity in an IGCC gas turbine to further improve energy self-sufficiency from wood. Research partners with Choren include DaimlerChrysler and Volkswagen. Choren aims to manufacture liquid fuels that they call hiomass-to-liquid (BtL or SunDiesel). It is claimed that SunDiesel may be used in current engines without the need for any adjustments or conversion. and it provides some advantages in exhaust emissions. This is because of low aromatic hydrocarbon and sulfur emission levels and a high cetane number.

A demonstration plant to manufacture SunDiesel is being built in Freiberg (Rudloff 2005). An overall efficiency of 45 to 55 percent is to be attained at the demonstration plant. If biomass is used as the exclusive source of energy. and if the electrical energy requirements For the auxiliary units and for cryogenic air separation from the residua1 gas are covered by the process itself (basic self-sufficient scenario using IGCC), the degree of efficiency is lower than if the yield of diesel fuel is maximized. In this case, 6.6 percent of the total input energy must be obtained as electrical energy from outside sources (partially self-sufficient scenario). In addition to the self-sufficient and partially self-sufficient scenarios, a future scenario was also defined. It considers increasing yields by adding hydrogen to the process. Hydrogen would be obtained by using excess regenerative electricity.

The European Union has a goal to produce more than 20 percent of its motor fuels from renewable materials in the year 2020. Headquartered in Güssing, Austria, an organization called RENEW has as its goal to develop cost-effective fuels from biomass for conventional as well as future combustion engines. There is a biomass power plant in Güssing that will be the site of some of the research, optimization, and testing of fuels from biomass. Volkswagen will be coordinating this project for RENEW during the period January 2004 to December 2007 (Rauch 2004)

Other Liquid Fuels

Approximately 67 percent of the energy required for ethanol production is consumed in the fermentation/distillation process, of which over half is used to distill ethanol from water (Huber et al. 2005). In contrast. when alkanes are produced from aqueous solutions of carbohydrates in wood. they separate from water simultaneously. A catalytic process for the conversion of biomass-derived carbohydrates to liquid alkanes in the higher mass ranges (from C_7 to C_{15}) that can be used as sulfur-free fuel components has been proposed by University of Wisconsin researchers (Huber et al. 2005). This research has not gone beyond the laboratory stage.

Power Energy Fuels Inc., Lakewood, Colorado, suggests using a mixture of ethanol and higher alcohols that may be used as a straight 100 percent alcohol fuel or blended with gasoline (8.5% or 10% alcohol).

Hydrogen

With evolving fuel cell technology. there will undoubtedly be increasing demands for hydrogen to directly fuel at least some of the fuel cells. Hydrogen is also being considered as a fuel for combustion engines. A federal Hydrogen Initiative has been proposed that would involve spending $1.2 billion over 5 years to develop hydrogen. fuel cell, and infrastructure technologies to reduce our dependence on foreign oil. The State of California has a Hydrogen Highway goal of building a network of 150 to 200 hydrogen fueling stations throughout the state.

Possibly hydrogen will be made from wood. Alternatively, methanol or ethanol may be made from wood. and these alcohols can then be reformed to hydrogen. The biggest challenge to using wood is the low cost of making hydrogen from natural gas. Wood could be combusted or gasified to generate or cogenerate electricity to produce hydrogen through electrolysis of water; however, making hydrogen from natural gas is much cheaper than making hydrogen through electrolysis. But if the price and amount of natural gas imported continue to increase. this situation will change.

To make hydrogen through gasification of wood to producer gas (low-calorific gas). the first step is to reform hydrocarbons (methane. tars) in the gas with steam. Subsequently carbon monoxide and water (steam) are converted to hydrogen and carbon dioxide with a two-step catalytic process. Separation of hydrogen from the resulting gas mixture - essentially carbon dioxide, steam. and remnants of nitrogen - follows. through pressure swing absorption (PSA) (Stucki and Bioiliaz 2000). In a report by Stucki and Bioiliaz (2000), costs were estimated for hydrogen from wood. coal, and natural gas, and it was found that natural gas was 30 percent more favorable than wood, and coal was about 50 percent less favorable than wood. However, they were figuring a plant size of 350 MW (1194 million BTUs/hr), which would be exceptionally large for wood and could easily result in raw material supply problems.

Economics

Today in the United States we consume over 22 Quads of coal every year. Much of this use is for combustion to provide power generation and process heat. We need to continue consuming coal to reduce our drain on natural gas and petroleum resources that are more problematical fossil fuels because of higher dependence on imports for their supply. If we continue to pursue clean coal technology, we will be using more coal for synthesizing chemicals such as methanal and hydrogen.

Because of the need to improve forest stands, and because of the availability of some manufacturing residues, I believe that wood may be used more economically than coal in many applications. Thinning of stands with excessive brush is necessary to reduce conflagration hazard. For small-diameter material that cannot be used for manufacture of higher value products, use as a fuel should be preferable to open burning for disposal. Although most manufacturing residues are being used, there are some locations where they are available at a reasonable cost.

In some cases, it may be possible to grow wood with SRIC for fuel. Some researchers are assuming that 25 percent of SRIC material would best be used for energy (Perlack et. al. 2005). Closer spacing of trees and shorter rotations in SRIC plantations could produce more material at lower cost that is more suitable for energy use than for use in the manufacture of other commercial products.

With the increasing cost of natural gas, both wood and coal may become more competitive with that fuel.

In 2004, the USDA Forest Products Laboratory published a fifth edition of a fuel value calculator (FPL 2004) that compares the value of wood at various MCs and prices per ton with the equivalent cost of the following: wood pellets per ton, natural gas per 1,000 ft^3, electricity per kWh, ovendried switchgrass per ton, bituminous coal per ton, shelled corn per ton, fuel oil #2 per gallon. fuel oil #6 per gallon, and propane per gallon. Comparisons are made on the basis of high heating value (HHV) of each fuel converted to a net heating value based on corrections for MC and typical boiler efficiencies.

In 2004, the average residential price for natural gas was \$10.74 per 1,000 ft^3. To compete in heating a home, the FPL fuel value calculator indicates that when natural gas sells for \$10.66 per 1,000 ft^3 (\$13 per million BTUs), wood at 60 percent MC could sell for \$53.71 per ton, wood at 20 percent MC for \$137 per ton. and wood pellets for \$177 per ton to be competitive. Electricity could compete at \$0.043 per kWh and seasoned firewood could compete at \$200 per cord.

Price alone does not determine value or desirability. Convenience, cleanliness, and environmental impact are also important. Wood does come with storage and ash removal requirements. However, some wood gasification-type and pellet stoves do operate efficiently with minimal operator attention and control. Wood stoves may require chips, but some efficient gasifier-type stoves can burn firewood. Natural gas is not totally without problems as there have been explosions and asphyxiations with natural gas. Similar comparisons can be made with wood and other fuels for applications other than residential heating. or for residential heating and cooling if wood-fired chiller units become available.

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Environment

An emphasis on renewable energy is gaining support in the United States and it is already a high priority in many other countries. The use of more wood for energy would conform to goals for the use of more renewable fuels. Next to hydropower, wood is the most important renewable energy source, and during periods of drought and lowered snow cover on the mountains of the West, wood provides more energy than hydropower.

To maintain healthier forests, it is important to remove more material that contributes to dangerous forest fires from forest stands. Much of this wood is more valuable for use as energy than when used for other purposes. More brush removal and thinning of small-diameter trees results in more wood For disposal. It would be better to use this wood constructively than to dispose of it through open burning.

Air and water emissions from burning wood are less problematic than from burning or gasifying coal. With coal there can be problems with sulfur, mercury. and other heavy metals, which don't occur with wood. Air emissions of particulates from burning wood can be reduced with catalytic converters for combustion of unburned hydrocarbons and treatment of exhaust gases through proper individual or combined methods of filtering. scrubbing, and precipitating.

Conclusions

In the United States, we could and should be getting 10 percent of our energy consumption from wood. It is possible to grow to this level from the current supply of 3.1 percent of our energy consumption by applying good forestry practices and using more wood residues.

To gain the most beneficial impact in replacing fossil fuel usage with wood we must use wood for energy in the most efficient ways to fill market needs. We can be most effective in using wood as an alternative fuel if we consume as little fossil fuel as possible in harvesting, transporting. processing, and using wood for fuel. Combustion and gasification of wood directly are more efficient than

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conversion of wood to improved fuels, but improved fuels are needed for transportation applications.

For making improved fuels such as ethanol, wood biomass naturally gown is more effective for conservation of fossil fuels in use as feedstock for energy and chemicals than biomass grown under intensive agriculture or short-rotation intensive culture forestry.

The time is right for implementing available technology in using wood for energy in order to gain economic and environmental advantages. Expansion of infrastructure is also needed (roads, machinery for small-diameter removal, and processing plants) to improve accessibility, harvesting, and the production of wood fuel. Unless there is greater implementation of the current state of technology, research to improve technology, and infrastructure is given a boost, we cannot make more progress in the next 25 years than we have in the past 25 years.

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