Primer on Wood Biomass for Energy

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Introduction

The purpose of this paper is to explain and describe the concepts of wood energy on a residential, commercial, and industrial scale in the United States so that the Forest Service can help meet the demands of communities involved in the forest products industry. In addition, the terminology associated with this field is for individuals to develop a basic understanding and familiarity with the technical terms that are common to bioenergy technology. Definitions specific to wood energy are given at the end of this report.

Advantages of Wood Biomass

Environmental

Renewable

Wood fuel has several environmental advantages compared with fossil fuels. Wood can be continually replenished, which leads to a sustainable and dependable supply. However, proper forest management must be practiced to ensure that growing conditions are not degraded during biomass production.

Low Carbon Emission

There is little net production (~5%) of carbon dioxide (CO_2), the major greenhouse gas, from wood combustion, because the CO_2 generated during combustion of wood equals the CO_2 consumed during the lifecycle of the tree. Transporting the material using petroleum generates excess CO_2.

Minimal Metals and Sulfur

Wood fuel contains minimal heavy metals and extremely low levels of sulfur; wood fuel is no threat to acid rain pollution.

Minimal Ash

Particulate emissions from wood are controllable through standard emission control devices such as bag houses, cyclone separators, and electronic precipitators. Bottom ash is minimal. Usually, wood ash is less than 1% of the weight of the wood, and sometimes ash may be used as a fertilizer.

Economic

Low Fuel Cost

The principle economic advantage of wood-burning systems is that wood fuel is usually less expensive than competing fossil fuels.

However, the price of wood for use as fuel can be extremely variable. Sometimes when surplus supplies of wood residues are available at nearby forest products manufacturing plants or municipal solid-waste handling facilities, the cost can be very low or even negative. Transportation for delivering from the supply site to the wood combustion or wood-processing unit is the primary expense of wood fuel.

At other times, mostly dependent on location of the wood power facility, the cost of wood fuel can be quite high because large volumes of fuel are needed to have a dependable and consistent supply of wood fuel (~1,360 green kg (~1.5 tons) per hour per megawatt of power generated)). However, wood power plants can find and do maintain a fairly low price and consistent fuel supply when adequate quantities are available. Staff foresters allow plant personnel to focus on operation while foresters focus on wood fuel procurement issues.

Typically, the average cost of fuel wood, for small-scale combustors, equals the cost of pulpwood for a given location. Pulpwood is one of the lower valued forest products, ranking between industrial boiler fuel and the lowest quality sawlogs—pallet logs and studwood. (Weighted average price in dollars per green ton delivered to mill for roundwood pulpwood across all U.S. regions in the 1st quarter of 2004, according to regional data published in International Woodfiber Report is $27 for softwood, $29 for hardwood). Stumpage price ranges reported across Florida in the 4th quarter 2003 Timber Mart-South (TMS) report were $6.6-$13.2/1000 green kg ($6-$12/ton) for pine pulpwood. Hardwood pulpwood prices ranged from $5.5-$13.2/1000 green kg ($5-$12/ton), which was up slightly from those of the previous quarter. Considering small-scale operations, an average delivered costs of chips would be $33/1000 green kg ($30/ton) or the equivalent of $1.95/GJ ($2.05/million Btu) assuming roughly $16.5-$22/1000 green kg ($15-$20 per ton) transportation costs.

A more complete summary of 4th quarter 2003 stumpage prices is available at your County Extension office. See www.forest2market.com for weekly, South-wide, per-ton price updates for the major pine and hardwood timber products. In comparison, the price of residential No. 2 distillate oil was $1.42 per gallon, excluding taxes ($9.70/GJ ($10.2/million Btu)) in 2003, and the price of residential natural gas was $9.35 per 1000 ft^3 ($9.00/GJ ($9.50/million Btu)). However, the prices of oil and natural gas were less at commercial and industrial plants and significantly less at utility plants, although natural gas price has increased 35% since the first 8 months of 2000. From January through November 2003, the average price of fossil fuels and natural gas at utility plants was $2.13/GJ ($2.25/million Btu) and $5.31/GJ ($5.60/million Btu), respectively. Coal prices at utility plants have maintained a fairly steady price for almost 25 years at $1.27/million Btu ($1.20/GJ). At the McNeil Power Station that burns wood, the range of prices is $11-$25.3/1000 green kg ($10 to $23 per ton) delivered (~$20-46/dry ton, or ~$1.20-2.70/ million Btu).

Least-Costly Option

Because the market for wood biomass energy may be uncertain or uncommon in a particular area, potential wood biomass users may want to do a brief, informal feasibility study before undertaking a rigorous economic analysis.

A full life-cycle cost analysis can be used to compare the costs of a biomass combustion system (BCS) with a fossil fuel system. When incorporating initial costs, the analysis should be determined on an annual basis over the entire expected life of the project, typically 20 years for a BCS. It is necessary to consider the full lifetime costs of a project, because initial costs of a BCS are generally greater, approximately 50 to 200%, than a fossil fuel system. The reasons for the high initial costs are the fuel-handling and storage systems required. Therefore, comparing only initial costs of energy systems would suggest the purchase of a fossil fuel system.

A full life-cycle analysis considers annual costs for an extended period of operation, and because of relatively high fossil fuel costs, the BCS might be the least-costly option. In general, to find the equivalent price of wood compared with oil or gas on a cost per GJ (million Btu), add approximately 50% to the wood price to account for the higher capital and operating and maintenance costs (O&M) of burning wood, although O&M costs are becoming less of a factor due to technology advances.

In general, wood combustion system costs are $50,000 to $150,000 for a 0.6 MW (2 million Btu/h) system, $100,000 to $350,000 for a 0.6 to 1.5 MW (2 to 5 million Btu/h) system, and $250,000 to $500,000 for a 1.5 to 3 MW (5 to 10 million Btu/h) system. Cost of installation is extremely variable because of the different types and capacities of equipment as well as whether equipment is new, used, or in-place and can be converted to burn wood.

Scales of Operation

Micro Scale

Space Heat

Numerous wood-burning facilities use less than 1 MW (3.4 million Btu/h) of electrical energy and 1 MW (3.4 million Btu/h) of thermal energy and are used for residential or small institutions, e.g., schools in Vermont. Steam turbines that generate electricity can be rated based on the thermal (th) energy inputted or electrical (e) energy outputted at full power. (1 kW = 3,413 Btu/h; 1 MW = 3,413,000 Btu/h or 3.413 million Btu/h).

For residential use of wood for fuel, common types of furnaces use split lengths of firewood to heat air in a plenum. This air is then circulated through a duct system to various points in the building. In an even simpler arrangement, heat is accumulated from burning logs in a fireplace and fan blown to the surrounding space.

Split fuel wood can be fed to the fire from a magazine, and some automated controls of the burning and heat distribution rate can be applied. However, a greater degree of automation can be obtained through use of wood chips or wood pellets as fuel in specialized combustion units.

Each year in the United States, about 1.05 exajoules (1 quad) of energy are used for residential and small institutional space heating. This is equivalent to about 52,700 million ovendry kg (58 million tons) of wood. It is reasonable to assume that wood from small-diameter trees could provide additional fuel for this market, up to a 5% increase or 2,640 million ovendry kg (2.9 million tons at thinning prescriptions of 10 green tons per acre).

Electricity

At the micro-scale level, small gasifiers coupled to internal combustion engines and generators can produce up to 20 kW$_e$ (68,300 Btu/h) of electricity for decentralized use. In the future, improvements should lead to more efficient arrangements with turbine generators or fuel cells.

Cogeneration

Micro-scale cogeneration is sometimes used for village power applications in developing countries. In the Philippines, two units were installed that provided electrical energy to a coconut processing plant and thermal energy for copra processing. In the future, micro-scale cogeneration should be capable of operating at electrical power levels as low as 2 kW$_e$ (6,830 Btu/h) and could be used in domestic/household applications.

One small generating plant might use 454 ovendry kg (0.5 ton) of wood fuel per day or 0.164 million ovendry kg (180 tons) per year. In the short term, 20 of these plants might consume 3.27 million ovendry kg (3,600 tons) of wood from small-diameter trees per year.

Small Scale

Space and/or Process Heat

Many U.S. schools use wood combustion to produce space heat in the range of 1 to 5 MW (3.41 to 17.1 million Btu/h). Types of fuel used are whole tree and mill chips, pellets, and briquettes. The typical heating medium is hot water instead of steam. High-pressure steam may require additional operator attention and maintenance that could make wood heat not economical.

Known capacity at educational institutions in the Midwest and several other states is a total of about 120 MW (410 million Btu/h). This is the equivalent of about 0.548 million ovendry kg (600 tons) of wood per day or 2,00 million ovendry kg (220,000 tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 10 million ovendry kg (11,000 tons).

Electricity

Small-scale electrical generation with wood fuel is in place in many locations in the United States; often these facilities are at forest products manufacturing plants. Frequently, excess capacity or generation of electricity during times of low load demand results in power that can be sold back to the local power grid.

Cogeneration

A few Vermont schools use boilers with close-coupled gasifiers at the 1- to 3-MW_{th} (3.41- to 10.2-million Btu/h) level to generate hot water for space heating. If configured to produce both heat and electricity, these units could produce between 500 kW_e and 1.5 MW_e (1.71 and 5.12 million Btu/h).

Total power-generating capacity in the 1- to 5-MW range from wood in the United States is about 310 MW (1,075 million Btu/h). This is the equivalent of about 1.36 million ovendry kg (1,500 tons) of wood per day or 500 million ovendry kg (550,000 tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 25 million ovendry kg (27,500 tons).

Medium Scale

Space and/or Process Heat

A few educational facilities in the United States (e.g., Massachusetts, Minnesota, Mississippi) use wood for space heating in this category. Various types of combustors, boilers, and fuels are used.

Known capacity at educational institutions is a total of about 31.2 MW (106 million Btu/h). This is the equivalent of about 136,000 ovendry kg (150 tons) of wood per day or 50 million ovendry kg (55,000 tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 2.5 million ovendry kg (2,750 tons).

Electricity

Forest products manufacturing plants also have medium-scale generating facilities. Sometimes separate companies located close to the manufacturing plant site will buy plant residues for fuel to generate and sell electricity back to the manufacturing facility and the grid. With such arrangements, the forest products company does not finance the cost of the generating plant. California has medium-sized power-generating plants in Mount Lassen Power, Rio Bravo, and Hayfork.

Cogeneration

Medium-scale cogeneration plants would be suitable for producing electricity and processing steam for dry kilns at a lumber manufacturing plant. A new installation at a sawmill in Finland demonstrates this application. It complements a previously existing 3.5-MW (11.9-million Btu/h) boiler. The new unit has a thermal capacity of 6 MW (20.5 million Btu/h) and will produce heat for a district-heating network in addition to providing drying energy. It will also produce 900 kW (3.07 million Btu/h) of electricity for the sawmill.

Total power-generating capacity in the 5- to 15-MW (17.1- to 51.2-million Btu/h) range from wood in the United States is about 1,160 MW (3,960 million Btu/h). This is the equivalent of about 5.0 million ovendry kg (5,500 tons) of wood per day or 1,830 million ovendry kg (2 million tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 90.9 million ovendry kg (100,000 tons).

Large Scale

Space and/or Process Heat

Large-scale plants using wood fuel are common in forest products manufacturing plants. At Fort James Corp. in Green Bay, Wisconsin, a combustor boiler produces 27.8 MW (95 million Btu/h) of electricity using fuel from the paper mill and deinking sludge. Other combustors made by the same company operate on fuels such as medium-density fiberboard waste, sander dust, board trim, and hog fuel.

An educational institution in Moscow, Idaho, operates a hogged wood fuel burning facility with a capacity of about 25.8 MW (88 million Btu/h). Another institution in Rolla, Missouri, has a facility with a capacity of about 39.6 MW (135 million Btu/h) that burns coal and wood. If these two facilities operated totally on wood at maximum capacity, there would be a demand for 155 million ovendry kg

(170,000 tons) of wood per year. A 5% increase in demand would amount to 7.75 million ovendry kg (8,500 tons).

Electricity

Biomass-fueled power plants are located in California, New England, and other areas of the United States. The average size of these plants is 20 MW_e (68.3 million Btu/h). Larger plants are up to 50 MW_e (171 million Btu/h) and more.

In Vermont, two power plants (Burlington and Ryegate) use whole-tree chips as their primary fuel source, although mill chips and pellets are combusted as well. Large utility systems are designed with fuel storage and handling systems and combustion systems that can use virtually any wood fuel. The most viable source is whole-tree chips that cost \$12.66 to \$21.10 per 1,000 green kg (\$12 to \$20 per ton). This price has remained relatively stable for the past 15 years, depending on harvest prescription and other variables. A rule of thumb is that harvesting (cutting and skidding) costs are about \$7.38 to \$10.55 per 1,000 green kg (\$7 to \$10 per ton), stumpage costs about \$1.10 per 1,000 green kg (\$1 per ton), and chipping about \$4.22 per 1,000 green kg (\$4 per ton). Trucking is in addition to these amounts.

Transportation is the highest variable cost due to the distances that the chips travel to the plant (i.e., the closer the chip source, the less expensive the chips). Typically, the majority of wood chips are transported within an 86.6-km (50-mile) radius of the plant. Therefore, location of a new plant requires much foresight to ensure the plant would have a continuous supply available for the years of plant operation. Providing the necessary tonnage requires appropriate estimations. Total tonnage on a 0.40 hectare (1.0 acre) could vary from 47,400 to 94,800 green kg (50 to 100 tons), depending on species, stocking, and past harvest practices. Harvested tonnage could be a third to half those amounts or more.

Chip texture is the main quality control issue for plants, and consistent, uniform size is the main reason that mill chips are used in small-scale wood systems. In general, mill chips are high quality and cost \$10.55 to \$15.82 per 1,000 green kg (\$10 to \$15 per ton) more than whole-tree chips. Maximum daily wood consumption and energy production of the steam turbines for the two plants are 1.66 million green kg (1,825 tons) and 50 MW_e (170 million Btu/h) for the Burlington plant and 0.636 million green kg (700 tons) and 20 MW_e (70 million Btu/h) for the Ryegate plant.

Both Burlington and Ryegate are operating at approximately 25% efficiency. Until September 2001, a full-scale 10 MW_e (34.1 million Btu/h) wood gasifier located at the Burlington plant site was in the development stage and would have increased the efficiency for a wood-fired system 40% to 43% by producing a medium energy gas if it was successful. The plan was to use the filtered syn gas from the circulating fluidized bed process just like natural gas in a gas turbine. At present, the heat and power have been turned off and the gasifier operating staff has been reassigned elsewhere.

Also, a large biomass district energy system in Burlington has been proposed in conjunction with the power plant that would increase community economy by \$12 million and create 264 jobs in the state economy.

Cogeneration

With a backpressure steam turbine, combined generation of thermal energy and power results in relatively low power output, compared with thermal load output. Recent economic studies of large units have not been favorable. Instead of using steam turbines, gas turbines have a greater overall efficiency. There are three demonstration integrated gasification combined cycle (IGCC) power plants (also called gasification combined cycle plants or bottoming cycle gasification plants) in Europe that operate with biomass. The ARBRE project has completed construction and is in commissioning, while construction has started on the Bioelettrica SpA Energy Farm, and the Värnamo, Foster Wheeler pressurized CFB technology demonstration is essentially completed.

The Värnamo IGCC plant produces 6 MW_e and 9 MW_{th}, which is channeled into the district heating system of the city during the heating season. The Värnamo plant is the world's first biomass-fueled IGCC plant and was developed by Sydkraft AB and Foster Wheeler International. The Värnamo, Finland, plant produces 6 MW_e (20.5 million Btu/h) and 9 MW_{th} (30.7 million Btu/h). This is the only plant in operation in Finland. It has been used for development and demonstration activities since 1996.

The installed capacity of wood power plants capable of generating more than 15 MW (51.2 million Btu/h) in the United States was about 6,310 MW (21,500 million Btu/h) as of October 1999. Some of these plants are operable, but are not currently operating. In May 1998, all operating biomass power plants, including those generating less than 15 MW (51.2 million Btu/h), represented about 7,231 MW (24,680 million Btu/h) of capacity. If the 6,300-MW (21,500-million Btu/h) installed capacity for plants greater than 15 MW (51.2 million Btu/h) is converted to wood requirements based on 5.5 MW per 1,000 ovendry kg (17 million Btu/ ton), the requirement would be 27.6 million ovendry kg (30,400 tons) per day or 10,500 million ovendry kg (11.1 million tons) per year. This number is not adjusted to account for efficiency, and power generation is only 25% efficient. However, since some plants are not operating and all plants do not operate at full capacity for 24 hours day in and day out, the calculated wood requirement based on total capacity without adjustment for efficiency should be reasonable. If 5% of the market could be served by increased harvests of small-diameter timber through added capacity, greater use of existing capacity, or substitution of wood from harvests of small-diameter material for existing wood fuel supplies, this would amount to 525 million ovendry kg (554,000 tons) per year.

Thermal and Electric Power

Residential

Housing represents the largest share of wood fuel use in the United States. A large volume of wood is burned in fireplaces for ambience, and several houses have wood heating and wood pellet furnaces. Some heating units burn wood chips, and there has been successful use of wood sawdust fuel. At a Vermont Public Housing Authority project, an efficient wood burner provided heat at only $26 per apartment per month for the entire apartment complex for 9 years.

Commercial

Public institutions, including schools, hospitals, prisons, and municipality-owned district heating projects, are prime targets for using biomass energy. Many schools in Michigan, Minnesota, Vermont, Wisconsin, Arkansas, Georgia, Kentucky, Missouri, Tennessee, Pennsylvania, and Maine heat with wood.

Several colleges have central heating systems and at least 10 of them use wood. In Fredericton, New Brunswick, there is a wood energy heating system for the university and town. At the campus of New Brunswick, campus buildings including laboratories, a greenhouse, and a large hospital with high steam requirements are heated with wood. At the State House in Montpelier, Vermont, a wood-fired steam plant serves the campus of state government buildings. There is also a hospital application in Michigan. In the state of New York, a prison uses wood fuel for heat. A forestry laboratory and greenhouse in Nova Scotia heat with wood. At a community in northern Quebec, a modern new Indian village uses sawmill waste, including sawdust, for central heating of all buildings. One of the newest wood combustion systems has been installed at Mount Wachusett Community College in Gardner, Massachusetts. The 8 million Btu/h (2.4 MW) wood-fired hydronic heating plant, which uses wood chips for fuel in a direct combustion process, replaces the college's costly electric 11.2 million Btu/h (3.3 MW) heating system. The system will use 1,000 tons of wood chips during one heating season to heat the 427,387 square foot of space at the college's Gardner campus.

In central or district heating for municipalities, using wood may reduce coal consumption. Chilled water for central cooling in summer can also be produced. In Charlottetown, Prince Edward Island, there are two wood-fired district heating systems.

Several conference centers and other privately owned buildings use wood heating and cooling effectively. A good example of a modern wood-burning system is the demonstration plant at the Lied Conference Center (Nebraska City, Nebraska). The plant consists of a bin and an auguring and metering system for wood chip fuel, two fire tube boilers, and a computerized control system. The boilers are rated at 1.2 MW (4 million Btu/h or 115 boiler horsepower or 4,000 lb of steam per hour) and 2.3 MW (8 million Btu/h or 230 boiler horsepower or 8,000 lb of steam per hour). At an installed cost of about $375,000, the plant, in the winter, provides steam to generate hot water for space heating, bathrooms, a laundry, and a large swimming pool. Water is chilled through absorption of heat from the water through an evaporative process, so that no refrigerant gas, such as freon, is needed.

In New Hampshire, a resort hotel produces heat, hot water, and processes heat for manufacturing from wood fuel. At least one motel in Vermont is heated with wood.

Municipality

St. Paul, Minnesota, is now drawing on wood waste to heat and cool most of its downtown buildings while also generating electricity. The new combined heat and power (CHP) plant was projected to burn 280,000 tons of wood waste each year, feeding 25 megawatts (MW) of power into the Minnesota power grid. The heat from the plant that incorporates a unique combination of renewable energy, CHP, and district heating technologies meets 80 percent of the annual energy in downtown St. Paul.

The City of Nederland has the first biomass plant in Colorado. The 30,000 square foot community center in Nederland is completely heated by steam from the boiler using biomass energy. Also, there are plans to generate power using biomass for the site. The wood chips come from surrounding forests being thinned by private landowners, the U.S. Forest Service, utility companies and others. At full power, the Nederland facility is expected to consume about a ton of wood chips a day. The project's total design and construction cost is expected to be $750,000.

Industrial

Brick and lime kilns are effective users of wood in large quantities in foreign countries such as Brazil. There are also such applications in North America, and there is potential for greater use of wood in brick kilns. The potential also appears logical for expanded use in lime kilns in the Kraft pulp industry.

The potential seems even greater in the cement industry where the primary raw material for cement manufacture is calcium carbonate or limestone. Depending on the type of process, cement manufacturers can require large amounts of fuel to heat materials to 1,500°C (2,700°F). It takes about 180 kg (400 lb) of coal to make about 900 kg (1 ton) of cement. Cement production results in emitting high levels of CO_2 into the atmosphere from the calcining process, the conversion of calcium carbonate (limestone) to calcium oxide (lime) through a burning process. As a result of the high CO_2 emission levels, cement plants are recognized as being major generators of this greenhouse gas. High amounts of sulfur in coal used in cement manufacture also result in lower cement yields from limestone. The calcium sulfate produced in removing sulfur with limestone becomes a disposal problem.

Utility

As of the end of August 1995, 15 biomass power plants (500 megawatts) in California had been closed through sales or buyout of their Standard Offer #4 agreements, primarily as a cost reduction strategy by the local utilities required to buy the power, which had sometimes risen to more than 10 cents per kilowatthour, depending on the contract.

Wood System Design

The most important factors in performance of biomass combustion systems are solid engineering design and effective controls—regardless of the type of combustion system used. There are two principle combustion designs: direct-burn combustor and two-stage combustor.

In a direct-burn system, the combustor is a single combustion chamber with a large volume that allows combustion gases to rise directly to the opening of the heat exchange passages at the top of the boiler. Relative simplicity and low costs are features of direct-burn systems.

For the two-chamber systems, a separate refractory-lined combustor, the primary chamber, sits next to the boiler connected by a short opening that is also refractory-lined (a blast tube). The primary chamber houses the grates, the fuel, and the air-fed components, just like the direct-burn system. Hot gases from the combustor pass through the blast tube or directly into the combustion chamber of the boiler, the secondary chamber. The two-chamber system can burn both high and low moisture biomass fuels. A variation of the two-chamber system is the close-coupled gasifier that restricts the combustion of air so that wood gases produced are not allowed to burn in the primary chamber, but in the secondary chamber.

New and Existing Technology

Gasification

Low Energy Gas

Gasification of wood and charcoal flourished around the world during World War II. Gas with low energy content could be produced to run internal combustion engines for over-the-road transportation as well as marine transport. These gasifiers were downdraft and air blown, but updraft and side-draft gasifiers were also used as a source of direct heating energy. Sometimes gasifiers were oxygen blown; oxygen instead of air results in a medium energy gas.

Today, a new generation of low energy, gas-producing gasifiers with better systems for filtering gas is being developed. Not only are these new gasifiers more reliable for conventional applications, such as driving internal combustion engines, but they also may find suitability for use with Stirling engines, micro-turbines, and fuel cells.

Circulating Fluidized Bed Units

Air-blown circulating fluidized combustors for use with biomass that provide hot fuel gas for lime kilns and boilers have been in use since the 1980s. Size and moisture content of the fuel can vary in this type of combustion bed. Circulating fluidized beds are now being demonstrated with coal and natural gas-fired utility boilers, and development for use with gas turbines is underway. In Finland, the Lahti Kymijärvihas plant completed 3 years of reliable operation using residues, paper and textiles, wood, and peat for fuel.

Circulating fluidized bed units are proposed for use with gas turbines at the Vienna Technical University and the University of Iowa.

Combined Cycle Gas Turbines

The new low energy-producing gasifiers gain improved performance in power generation through the use of integrated gasification combined cycles in turbine operation. In these systems, gas undergoes combustion in the turbine and the heat recovered from gas-turbine exhaust (flue gas) can be used to generate power and heat in a steam turbine. The environment is the primary beneficiary of the combined cycle technology because more energy can be produced per pound of CO_2 emitted than in simple-cycle technology.

Fuel Cells

Woody biomass gasification is promising, generating a product suitable for use with the rapidly developing fuel cell technology. A major advantage is low sulfur content, because fuel cells are very sensitive to this contaminant.

Additional advantages are high volatility and reactivity. Thus, biomass gasifier fuel for fuel cells could lead to lower operating temperatures and pressures than would be possible with coal gasifiers.

Cofiring

Cofiring refers to the practice of introducing biomass as a supplementary energy source in coal plants. It is a near-term, low-cost option for using woody residue, costing approximately \$0.02 per kWh while reducing pollutants. According to the U.S. Department of Energy, 20 electric utilities are cofiring biomass with coal. Extensive demonstrations and trials have shown that effective substitutions of biomass energy can be made from 10% to 15% of the total energy input. Investments are expected to be $100 to $700 per kW of biomass capacity, with the average ranging from $180 to $200 per kW. Cofiring results in a net reduction in greenhouse gases and lower emissions of sulfur dioxide and nitrogen oxides. Extensive demonstrations and trials have shown that effective substitutions of biomass energy can be made in the range of 10% to 15% of the total energy input. One preliminary test reached 40% of the shared energy from biomass.

Cogeneration

Cogeneration is the simultaneous production of heat and electricity, commonly called combined heat and power (CHP), from a single fuel. Traditionally, a steam turbine is used to produce electricity; although a wood gasification/ internal combustion unit can also be a cogeneration unit. Several factors affect the economic feasibility of a CHP unit including wood waste disposal problems, high electricity costs, and year-round steam use.

Two common mistakes when installing a CHP system are buying a steam boiler that is designed for less than 100 lb-force/in^2 (689 kPa) or oversizing the system. Buying a steam boiler that is designed for less than 100 lb-force /in^2 (psig) results in a quality of steam that is not adequate for turbine operation. Oversizing the system results in additional capital costs, not better quality steam.

More electricity and heat are generated for a lesser amount of fuel by a CHP unit than by a separate heat and power (SHP) unit. Common challenges for all wood-fired systems are ensuring adequate fuel procurement and solving the complex fuel handling and storage issues.

Liquefaction

Ethanol

As a Motor Fuel**—**Although different types of liquid fuels, including gasoline and diesel, could be made from wood, ethanol is most commonly produced from biomass. In the United States, ethanol is made mostly from corn, and in Brazil, it is made from sugar cane. However, wood residues could be an economical and environmentally desirable raw material. For ethanol from wood to be economically viable, availability of the raw material, efficient manufacturing, well-managed product marketing, and Federal and State subsidies are important factors.

Ethanol burns cleaner than gasoline and diesel, and its octane rating is greater than that of regular gasoline. Ethanol has a lower energy density than regular gasoline, but because of its higher octane rating, it can be burned more efficiently in high compression engines than gasoline. Other aspects of using ethanol to prevent some previous problems, such as eliminating coatings on interiors of fuel lines and facilitating cold weather starting, are readily attainable.

As a Fuel Additive**—**In some cities and surrounding areas, known as nonattainment areas, ethanol may be used as an oxygenate in gasoline during summer months. Its use is mandated in some cases, where other agents, mainly methyl tertiary butyl ether (MTBE), are banned. Production of ethanol from corn in the Midwest has increased dramatically in the last several years because of the MTBE ban in numerous states including California, New York and Connecticut. As of April 2004, present total existing capacity is 3,210.8 million gallons per year with total under construction/expansions of 538.0 million gallons per year.

Methanol

Methanol is another potential liquid fuel that can be manufactured from wood. Methanol is known as wood alcohol, since it was most commonly made from wood during the 1920s. However, methanol was a byproduct of charcoal manufacture through destructive distillation. When it began to be synthesized from natural gas, methanol from wood could no longer compete. Today, methanol is made from wood and coal through gasification, forming syngas, and converting syngas to methanol, much in the way natural gas is reformed to syngas and converted to methanol. However, making methanol from wood is more complex than making it from natural gas.

Methanol has a lower energy density than ethanol, and methanol is a toxic substance. However, methanol can be made from wood at higher yields than ethanol. Making methanol from wood uses all wood components, including lignin; but ethanol is only made from cellulose and hemicelluloses with currently available hydrolysis and fermentation technologies.

BioOil

BioOil (pyrolysis oil) is a liquid fuel with medium heating value that can be used to generate electricity and heat at industrial locations such as saw mills, pulp and paper mills, wood processors, agricultural facilities and recycling facilities. Because it is derived from biomass, BioOil is deemed to be greenhouse gas neutral. It has virtually no sulfur, low nitrous oxide emissions and very low particulates (significantly lower than diesel) when combusted. BioOil can be used directly at the point of production. BioOil is transportable, opening potential for small power generation plants to service installations such as hospitals, schools, universities, hotels, and other commercial and industrial facilities.

On April 14, 2004, ground was broken in Vancouver, BC, Canada, on the construction site of what will be, when completed in the summer of 2004, the world's largest pyrolysis plant and the first pyrolysis oil fuelled power co-generation facility. It will demonstrate the commercial potential in improving the efficiency of energy recovery from conversion of biomass waste to generate electric power from less fuel than traditional methods that use solid biomass combustion.

The plant is expected to process 100 tons per day of biomass and to produce 70 tons of BioOil, 20 tons of char and 10 tons of non-condensable gases. Fifty tons of BioOil per day will be utilized to fuel a gas turbine developed by Orenda to produce up to 2.5 MWE of electricity -- enough to serve 2,500 households -- to meet the power requirements of the Erie Flooring plant and also enough to export electricity to Ontario's energy grid. Surplus heat generated by the turbine will produce up to 12,000 pounds of steam per hour to provide heat for Erie Flooring's industrial operations. The remaining BioOil and char from the plant will be sold to commercial users and used for research purposes. Non-condensable gases will be used to provide heat to the process.

Pellets and Briquettes

As wood is refined into other forms, its value as a fuel increases. Benefits of refining include facilitation of handling, transportation, and storage; improved durability; burning with increased efficiency; lower variability; and higher energy density.

Manufacture of pellets and briquettes provides most of these advantages, with the exception of higher energy density. These fuels are dry and better energy carriers than wet wood. Also, in the case of fireplace log briquettes that are usually made with the addition of petroleum-derived wax, they have a higher energy density than wood. Pellets are easily manufactured and provide an excellent fuel for automated controlled burning in pellet stoves and pellet boilers.

Charcoal

Throughout history, charcoal manufacture has been used to improve fuel characteristics of wood. It is a simple, but cumbersome, process that characteristically requires much attention to details to prevent air pollution. Charcoal manufacture in the United States is limited primarily to briquettes for residential and recreational use and, to a lesser degree, to manufacture activated carbon for industry. In some countries, charcoal is commonly used for cooking and manufacturing steel.

Prices

Figure 1 shows the cost of fuel types based on local prices in Wisconsin. No allowance has been made for conversion efficiency. Because market prices for fuels vary, this comparison should be considered as a general guideline only.

Efficiency is an important determination of how well a fuel is utilized through existing technology. In Table 1, note that, for wood, the greater the moisture content, the lower the overall efficiency.

Table 1. Overall efficiency of wood and other competing fuels

Fuel	Power plants (%)	Other uses (%)
Coal	33–35	45–60
Gas	40–50	85
Wood	22–25	65–80
Nuclear	32	NA
Oil	NA[a]	80
Propane	NA	80

[a] Not applicable.

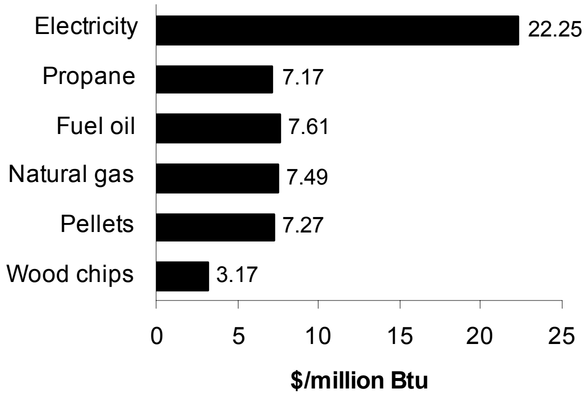

Figure 1. Cost comparisons of fuel types in Wisconsin for large volumes. (1 MW = 3.413 million Btu/h).
Source: Mike Metcalf, Madison Gas & Electric, Madison, WI. May 2004.

Glossary

Ash. The noncombustible components of fuel.

Ash fusion temperature. The temperature at which ash melts.

Biogas. A gas produced from biomass, usually combustible.

Biomass. Organic matter available on a renewable basis. Biomass includes forest and mill residues, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes.

Bottom ash. Ash that collects under the grates of a combustion furnace.

Boiler horsepower (BHP). The equivalent of heat required to change 15.6 kg (34.5 lb) per hour of water at 212°F 100°C) to steam at 212°F (100°C). One BHP equals 9.81 kW (33,479 Btu/h).

Bridging. Wood fuel in a storage bin, hopper, or conveying system that supports itself although the fuel beneath has moved. One of the most common problems associated with wood-handling systems.

British thermal unit (Btu). A standard unit of energy equal to the heat required to increase the temperature of 1 lb (0.45 kg) of water 1°F (0.56°C).

Carbon cycle. The process of transporting and transforming carbon throughout the natural life cycle of a tree from the removal of CO_2 from the atmosphere to the accumulation of carbon in the tree as it grows, and the release of CO_2 back into the atmosphere when the tree naturally decays or is burned.

Carbon sequestration. Refers to the provision of long-term storage of carbon in the terrestrial biosphere, underground, or oceans, so that the buildup of carbon dioxide (principal greenhouse gas) concentration in the atmosphere reduces or slows.

Char. Carbon-rich combustible solids that result from pyrolysis of wood in the early stages of combustion. Char can be converted to combustible gases under certain conditions or burned directly on the grate.

Clinker. A slag-like material formed in the combustion process when the temperature of combustion exceeds the ash fusion temperature of the fuel.

Chipper. A large device that reduces logs, whole trees, slab wood, or lumber to chips of more or less uniform size. Stationary chippers are used in sawmills, while trailer-mounted whole-tree chippers are used in the woods.

Cofiring. Utilization of bioenergy feedstocks as a supplementary energy source in high efficiency boilers.

Cogeneration. Combined heat and power (CHP).

Combined heat and power (CHP). The simultaneous production of heat and mechanical work or electricity from a single fuel.

Combustion air. Air that is used for the burning of a fuel.

Combustion efficiency. The efficiency of converting available chemical energy in the fuel to heat. It measures only the completeness of fuel combustion that occurs in the combustion chamber.

Combustor. The primary combustion unit, usually located next to the boiler or heat exchanger.

Cyclone separator. A flue gas particulate removal device that creates a vortex to separate solid particles from the hot gas stream.

Densified biomass fuel. Biomass material that has been dried and compressed to increase its density (e.g., pellets).

District energy system. A system using central energy plants to meet the heating and/or cooling needs of residential, institutional, commercial, and industrial buildings.

Excess air. The amount of combustion air supplied to the fire that exceeds the theoretical air requirement to give complete combustion.

Flue gas. All gases and products of combustion exhausted through the flue or chimney.

Fly ash. Ash transported through the combustion chamber by the exhaust gases and generally deposited in the boiler heat exchanger.

Fuel cell. A cell similar to a battery; it uses an electrochemical reverse electrolysis process to directly convert the chemical energy of a fuel (gas, propane) into electricity, heat, and water.

Gasifier. A combustion device that produces biogas from solid biomass.

Hog fuel. Biomass generated by grinding wood and wood waste for use in a combustor.

Kilowatt. A standard unit for expressing the rate of electrical power output—(e) and (th) stand for electrical and thermal, respectively.

Live-bottom trailer. A self-unloading tractor-trailer with a hydraulically operated moving floor used to remove biomass fuel.

Metering bin. A bin in the fuel feed stream that allows a precise feed rate of the fuel to the fire.

Mill chips. Wood chips produced in a sawmill.

On/off fuel feed. A fuel feed system that transports fuel to the grates on an intermittent basis in response to boiler water temperature and load variations.

Over-fire air. Combustion air supplied above the grates and fuel bed.

Particulates. Minute, solid, airborne particles that result from biomass combustion.

Pyrolysis. A process of combustion at oxygen-starved conditions, involving the physical and chemical decomposition of solid organic matter by the action of heat into liquids, gases, and a carbon char residue.

Residence time. The length of time the fuel remains in a combustion zone.

Seasonal efficiency. Represents the ratio between the total useful energy delivered to the thermal load over the full operating season and the total potential energy within the fuel burned over the period.

Steady-state efficiency. Ratio of output to input energy when combustion system is operating under design conditions.

Turndown ratio. A ratio found by dividing the maximum energy output by the minimum output at which efficient, smoke-free combustion can be sustained.

Under-fire air. Combustion air added under the grates.

Whole-tree chips. Wood chips produced in the woods by feeding whole trees or tree stems into a mobile chipper that discharges directly into a tractor-trailer.

Wood gasification. The process of heating wood in an oxygen-starved chamber until volatile pyrolysis gases (e.g., CO, H_2, O_2) are released from the wood. The gases emitted are low- or medium-energy-content gases that can be combusted in various ways.