Primer on Wood Biomass for Energy

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Introduction

This paper explains and describes 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, terminology associated with this field is explained so individuals can develop a basic understanding of and familiarity with technical terms common to bioenergy. 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

Wood combustion produces little net (~5%) carbon dioxide (CO_2), the major greenhouse gas, because the CO_2 generated during combustion of wood equals CO_2 consumed during the lifecycle of the tree. Transporting wood using petroleum generates some excess CO_2.

Minimal Metals and Sulfur

Wood fuel contains minimal heavy metals and extremely low levels of sulfur; therefore, combusting wood fuel will not create acid rain pollution through sulfur emissions. However, burning wood in the forest does emit significant amounts of nitrous oxide, a greenhouse gas, if either by wildfire or broadcast burning for stand improvement.

Minimal Ash

Particulate emissions from wood are controllable through standard emission control devices such as bag houses, cyclone separators, fly-ash injectors, 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. But today, most manufacturing wood-plant residues are being used internally as fuel or sold externally as a higher valued product. 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 are needed to have a dependable and consistent supply of wood fuel (~1,360 green kg (~1.5 green tons) per hour per megawatt of power generated for a 27% overall power plant efficiency). 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 plant operation while foresters focus on wood-fuel procurement.

Typically, the average cost of fuel wood for small-scale combustors is similar to the reported prices of pulpwood for a given location. Pulpwood is one of the lower valued forest products, ranking between industrial boiler fuel and the lowest quality saw logs, pallet logs, and stud wood. According to regional data from the first quarter of 2007 (International Woodfiber Report, May 2007, Vol. 13, No. 5), weighted average price in dollars per green short ton delivered to mill was $29 for softwood and $30 for hardwood for roundwood pulpwood across all U.S. regions. The Southern Pine pulpwood stumpage price average reported across the U.S. South in the 1st quarter 2007 Timber Mart-South (Vol. 12, No. 1) was $7.89 per green short ton, whereas the southern hardwood pulpwood stumpage price average was $6.51 per green short ton. These numbers are derived from average prices of the previous year ($1 for pine and $2 for hardwood). Considering small-scale

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operations, likely delivered costs of chips would be upwards of \$33/1000 green kg (\$30/ton), resulting in estimated average fuel costs of \$3.34/GJ (\$3.53/million Btu) assuming roughly \$16.5 to \$22 per 1,000 green kg (\$15 to \$20/ton) transportation costs.

In comparison, the 2007 price of residential No. 2 distillate oil was \$2.22 per gallon, excluding taxes (\$15.17/GJ) (\$16.01 million Btu), and the average price of residential natural gas was \$12.53 per 1000 ft^3 (\$11.55/GJ (\$12.18/million Btu)). However, the prices of oil and natural gas were less at commercial and industrial plants and significantly less at utility plants. In January 2005, coal prices at utility plants were \$1.45 per million Btu (\$1.37/GJ). One dollar per million Btu equals \$20.2 per ton of coal used at electrical utilities. According to a published report by the Energy Information Administration, (May 2007 Receipts, Average Cost and Quality of Fossil Fuels), coal prices have increased in the last two years mostly because of high demand by China and India. On May 2007, the price for utility coal was \$1.79 per million Btu (\$1.69/GJ), an increase of roughly 20%. At the wood-burning McNeil Power Station (Burlington, Vermont), the price per green ton was almost \$30 (\$33/1,000 green kg) or \$60 per dry ton, or \$3.53 per million Btu (\$3.34/GJ) in 2006.

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, 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 benefit of purchasing 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 ($\times 10^6$ Btu), add approximately 50% to the wood price to account for higher capital and operating and maintenance costs (O&M) of burning wood. Because of technology advances, however, O&M costs are becoming less of a factor.

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 and 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 of thermal energy and are used for residential or small institutions (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 (I 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 hot 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. Charcoal is another possibility for use to attain better control.

In 2006 in the United States, about 0.64 exajoules (0.61 quad) of energy from wood were used in the residential and commercial sectors. This is equivalent to about 32,600 million ovendried kg (35.9 million ovendried 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 1,630 million ovendried kg (1.8 million tons at thinning prescriptions of 10 green tons/acre).

Electricity

At the micro-scale level, small gasifiers coupled to internal combustion engines and generators can produce up to 100 kW, (341,000 Btu/h) of electricity for decentralized use. In the future, improvements should lead to more efficient arrangements with turbine generators or fuel cells as the producer (wood) gas cleaning technology improves.

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 for combined heat and power.

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

Small Scale

Space 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. Low- and high-pressure steam systems may require additional operator attention and maintenance that could make wood heat uneconomical.

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 ovendried kg (600 tons) of wood per day or 200 million ovendried kg (220,000 tons) per year. Here, a potential 5% increase supplied from forest residues amounts to 10 million ovendried 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 ovendried kg (1,500 tons) of wood per day or 500 million ovendried kg (550,000 tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 25 million ovendried kg (27,500 tons).

Medium Scale

Space 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 ovendried kg (150 tons) of wood per day or 50 million ovendried kg (55,000 tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 2.5 million ovendried 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, 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 sawmill installation at Vilppula in central Finland demonstrates this application. The new unit has a thermal capacity of 13.5 MW (46.1 million Btu/h) and produces heat for a district-heating network in addition to providing energy for a 9.0 MW_{th} heat boiler. This plant with an electrical output of 2.9 MW_e (9.9 million Btu/h) also produced over 70% of the electricity needed internally.

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). Based on high heating value, this is the equivalent of about 5 million kg (5,500 tons) of ovendried wood per day or 1,830 million ovendried kg (2 million tons) per year. Here, a 5% increase that might be supplied from forest residues amounts to 90.9 million ovendried 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 Corporation 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 104 million ovendried kg (115,000 tons) of wood per year. A 5% increase in demand would amount to 5.21 million ovendried kg (5,800 tons).

Electricity

Biomass-fueled utility 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 can exceed 50 MW_e (171 million Btu/h).

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 $22.05 to $33.07 per 1,000 green kg ($20 to $30/ton) in September 2004. A rule of thumb is that harvesting (cutting and skidding) costs are about $7.72 to $11.02 per 1,000 green kg ($7 to $ 10/green ton), stumpage costs about $1.10 per 1,000 green kg ($1/ton), and chipping about $4.41 per 1,000 green kg ($4/ton). Trucking is in addition to these amounts.

Transportation is the highest variable cost because of the distances that 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 80.4-km (50-mile) radius of the plant. Therefore, location of a new plant requires much foresight to ensure the plant would have a continuous chip supply available for the years of plant operation. Providing the necessary tonnage requires appropriate estimations. Total tonnage on a 0.40-hectare (1-acre) area could vary from 55,100 to 110,200 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 $11.02 to $16.53 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 (171 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.

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. Demonstration of integrated gasification combined cycle (IGCC) power plants (also called gasification combined-cycle plants or bottoming-cycle gasification plants) is under way. Gas turbines are extremely sensitive to particulates that easily erode turbine blades, so with solid fuels that tend toward more contamination in the gases they produce, progress in solid fuel use has been slow. Nonetheless, several large-capacity coal IGCC plants and a few smaller biomass (mainly wood) IGCC plants are operational. Nuon Power in Buggenum, Netherlands, uses a hard coal and biomass blend feedstock in a 253-MW (863-million-Btu/h) plant. At Cascina, Italy (near Pisa), Bioelettrica SpA has a 16 MW_e (55 million Btu/h) and 41 MW_{th} (140 million B/h) IGCC plant. These plants use agricultural residues, sawdust, short-rotation coppice, and wood chips as feedstock.

The Värnamo, Sweden, wood-using IGCC plant produced 6 MW_e (20 million Btu/h) and 9 MW_{th} (30 million Btu/h), which was 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 plant was shut down in 2000 and reopened for research in December 2003.

The installed capacity of power plants burning timber residues in the United States was about 7,497 MW (25,600 million Btu/h) as of 2002. Some of these plants are operable, but are not currently operating. If the 7,497-MW (25,600 million Btu/h) installed capacity is converted to wood requirements based on 5.5 MW per 1,000 ovendried kg (17 million Btu/ton), the requirement would be 32.7 million ovendried kg (36,000 tons) per day or 11,900 million ovendried kg (13.2 million ovendried tons) per year. This number is not adjusted to account for efficiency, (electrical power generation is roughly 25% efficient). However, because 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 600 million ovendried kg (660,000 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 many houses have wood-heating and wood-pellet furnaces. Some heating units burn wood chips, and wood sawdust fuel has been successfully used. 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 possibilities for using biomass energy. Many schools in Michigan, Minnesota, Vermont, Wisconsin, Arkansas, Georgia, Ken-

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tucky, Missouri, Tennessee, Pennsylvania, and Maine heat with wood.

A number of colleges have central heating systems, and at least 10 of them use wood. Fredericton, New Brunswick, has a wood-energy heating system for the university and town. At the university 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. A hospital in Michigan, a prison in New York, and a forestry laboratory and greenhouse in Nova Scotia all heat with wood. The Oujé-Bougoumou community in northern Quebec uses sawmill waste, including sawdust, for central heating of all buildings. In 2002, a wood combustion system was 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 11.3-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 ft^2 of space at the college's Gardner campus. Electricity savings are estimated to be 3,382,518 kW (12,180,000 MJ or 1.55 billion Btu) annually.

In central or district heating for municipalities, using wood may reduce coal consumption. Chilled water for central cooling in summer can also be produced. Charlottetown, Prince Edward Island, Canada, has 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/hour) and 2.3 MW (8 million Btu/h or 230 boiler horsepower or 8,000 lb of steam/hour). At an installed cost of about $375,000, the plant in winter provides steam to generate hot water for space heating, bathrooms, a laundry, and a large swimming pool. Water is chilled through a refrigeration cycle in which water vapor from an evaporator is absorbed by a lithium bromide (LiBr) solution. The diluted LiBr solution gives up its refrigerant water again when energy in the form of heat is added to vaporize the water. Thus, water performs the function of other refrigerants such as freon.

In New Hampshire, a resort hotel produces space heat, hot water, and process 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 MW (85 million Btu/h) 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% of the annual energy requirement in downtown St. Paul.

In Nederland, Colorado, a town 20 miles west of Boulder, a community biomass project set out to prove the viability of using forest waste to provide heat and power. The community center with 20,000 ft^2 of conditioned space was used to conduct pilot studies. The system used a 100-horsepower boiler (3.3 million Btu/h or 3,450 lb of steam/hour). The total cost of the project, including purchase of a used boiler, was $443,000, and the saving in fuel cost was estimated at $8,150 per year.

Beyond saving on fuel costs, the environmental and social benefits include reduction of air emissions (as compared with prescribed burns), use of a rapidly renewing fuel source, improvement of forest health, reduction of losses from wildfires, economic development, and public relations value.

Industrial

Brick and lime kilns are effective users of wood and wood charcoal in large quantities in foreign countries such as Brazil. Such applications also exist in North America, with potential for greater use of wood in brick kilns. The potential also appears logical for expanded use of fuel derived from wood 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

Utilities are firing more wood fuel in response to the Public Utilities Regulatory Power act of 1978 (PURPA) and Renewable Fuel Standards by States in the last few years. Companies are also choosing to co-fire biomass with coal to save fuel costs and earn emissions credits. As a result of such regulatory requirements and consumer demand, an increasing number of power marketers are starting to offer environmentally friendly electricity from wood and other sources.

Besides co-firing are direct fired and gasification systems. Most of today's biomass power plants are direct-fired systems that are similar to most fossil-fuel fired power plants.

Whereas steam generation technology is very dependable and proven, its efficiency is limited. Biomass power boilers are typically in the 20 to 50 MW range, compared with coal-fired plants in the 100 to 1500 MW range. The small-capacity plants tend to be lower in efficiency. Because of economic trade-offs, efficiency-enhancing equipment cannot pay for itself in small plants. When wood plants replace coal, they reduce sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2) to the air. Wood gasifiers can be more efficient than direct burning, and usually the gas may require cleaning to remove problem chemical compounds.

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. Institutional and commercial heating systems primarily use direct-burn and two-stage combustors.

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. The firebox may also be surrounded by a water jacket containing a large volume of water for use as hydronic heating for residences or small wood-product operations.

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 bum 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. Even some military tanks were operated with gasifiers. 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-Btu energy gas.

Today, a new generation of low energy, gas-producing gasifiers with better systems for cleaning and control are 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.

In July 2007, the state of Georgia awarded a development company a construction permit to build a 100-million-gallon-per-year cellulosic ethanol plant. This is the first plant to use synthesis gas from wood to produce transportation fuel.

Circulating Fluidized Bed Units

Air-blown circulating fluidized bed appliances 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 of circulating fluidized bed gasifiers for use with gas turbines is under way.

Combined Cycle Gas Turbines

The new low energy-producing gasifiers gain improved performance in power generation through the use of integrated gasification combined cycles (IGCC) 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.

A circulating fluidized bed gasifier is proposed for use with gas turbines at the Vienna University of Technology (TU Vienna, Austria).

Fuel Cells

Woody biomass gasification is promising to generate a product suitable for use with the rapidly developing fuel cell technology. A major advantage of wood for producing fuel-cell fuels 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 often 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 to produce electricity costing approximately $2 per kW of total capacity for capital investments on a power plant burning 10% wood ($200 kW per biomass kW). For example, a 500-MW_e coal plant burning 10% wood would pay $1 U.S. million for retrofitting their system to handle woody biomass. According to the U.S. Department of Energy Biomass Power Program (May 1999 Biomass Cofiring: A Renewable Alternative for Utilities and Their Customers), seven utilities burning at least 7% wood reduced their NOx emissions by 15% compared to burning 100% coal. Extensive demonstrations and trials have shown that effective substitutions of biomass energy can be made up 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 emissions of sulfur dioxide, nitrogen oxides, and non-renewable carbon dioxide.

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 engine combination 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 over-sizing 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. Over-sizing the system results in additional capital and operating 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. Biomass ethanol is mostly produced through fermentation with potential production through gasification. In the United States, ethanol is made mostly from corn grain with an annual production of 4.86 billion gallons in 2006 in an Energy Information Agency report (December 2007 Petroleum Supply Monthly, Appendix D). Also, Brazil exported 434 million gallons of ethanol produced from cane sugar to the United States in 2006 (66% of total ethanol imported into the United States). In Germany, sources being considered are beet sugar, starches from grains such as wheat and rye, and potatoes. Germany is also considering lignocellulosic sources that include fast-growing poplars, willows, miscanthus, and Jerusalem artichokes. In the United States, 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, can be burned more efficiently in high-compression engines than gasoline. Other aspects of using ethanol and preventing 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 non-attainment 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, partially because of the MTBE ban in 21 states. Legislation has also been introduced to ban MTBE nationwide, but this is not proposed to take effect until 2012. Probably most states would already have banned it by then. As of January 2007, present total existing biomass ethanol capacity is 5635.6 million gallons per year with total under new construction or expansion plans increasing to 6.123 billion gallons per year.

Methanol

Methanol is another potential liquid fuel that can be manufactured from wood. Methanol is known as wood alcohol, as 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, some methanol is made from wood and coal through gasification, forming synthesis gas (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 and bark; but ethanol is only made from cellulose and hemicelluloses with currently available hydrolysis and fermentation technologies.

Bio-oil

Pyrolysis oil (bio-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, pyrolysis oil 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. Pyrolysis oil can be used directly at the point of production. Pyrolysis oil is also transportable, opening potential for small power-generation plants to service installations such as hospitals, schools, universities, hotels, and other commercial and industrial facilities.

The produced oil is acidic with a pH of 1.5 to 3.8 and has an elevated water content 8% to 20% by weight. This leads to corrosion problems, especially at higher temperatures. The oxygen content is 40% to 50%, mostly from the water content. The lower heating value is approximately 16–21 MJ/kg (6,900–9,000 Btu/lb). The pyrolysis oil is not auto-igniting in a diesel engine. The cetane number is only – 10. The viscosity increases to a maximum in 12 months because of polymerization. The pyrolysis oil is not stable reacting with air and degasing. Pyrolysis oil cannot be blended with diesel.

A new plant in Guelph, Ontario, Canada, used approximately 40 m^3 (1,400 ft^3) of wood waste to produce an intermediate grade bio-oil. The first run was at the equivalent daily rate of 50 tonnes (55 tons) of feedstock processed and the second at a rate of 100 tonnes (110 tons).

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 five fuel types based on representative average residential unit costs that DOE is required to maintain. These costs for the five fuels were published in the Federal Register on March 16, 2007 to take effect on April 20, 2007. The reported costs are shown with assumed costs for wood fuel types including pellets and chips. 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 weighted-average efficiency of wood and other competing fuels

Fuel	Power plants (%)	Other uses (%)
Coal	35	45–60
Gas	45	80–95
Wood	22–25	65–80
Nuclear	34–37	NA
Oil	38	80
Propane	NA	80

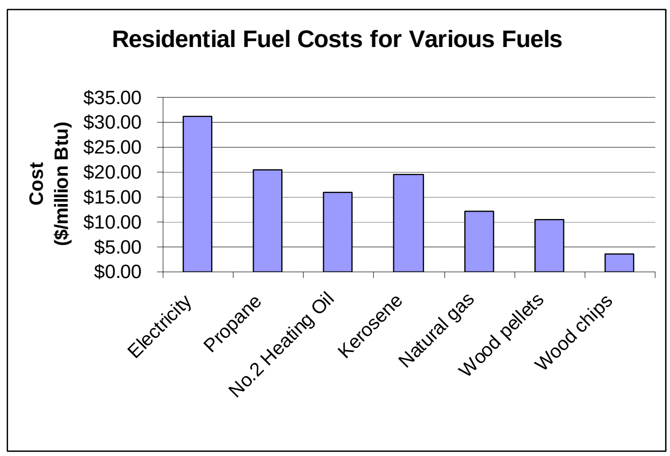

Figure 1. Representative average costs per million Btu of five fuels as published in the Federal Register by the U.S. Department of Energy on March 16, 2007. These fuels are compared with wood pellets selling at $150 per ton and wood chips selling at a minimum of $30 per green ton.

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. Bridging is 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—The provision of long-term carbon storage 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, whereas trailers 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 or cooling needs or both 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 that uses an electrochemical reverse electrolysis process to directly convert the chemical energy of a fuel (gas, propane) into electricity, heat, and water.

Gasifier—Any device that changes solid biomass into a gaseous fuel.

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

Kilowatt—A standard unit for expressing the rate of electrical power and useful heat output. The symbols 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 reduction 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—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 or used to produce chemicals in various ways.