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Situation Analysis

Biopower (biomass-to-electricity power generation) is a proven electricity-generating option in the United States. With about 10 GW of installed capacity, biopower is the single largest source of non-hydro renewable electricity. This installed capacity consists of about 7 GW derived from forest-product-industry and agricultural-industry residues, about 2.5 GW of municipal solid waste (MSW) generating capacity, and 0.5 GW of other capacity such as landfill gas-based production. The electricity production from biomass is being used, and is expected to continue to be used, as base load power in the existing electric-power system.

In the U.S., biopower experienced dramatic growth after the Public Utilities Regulatory Policy Act (PURPA) of 1978 guaranteed small electricity producers (less than 80 MW) that utilities would purchase their surplus electricity at a price equal to the utilities' avoided-cost of producing electricity. From less than 200 MW in 1979, biopower capacity grew to 6 GW in 1989 and to today's capacity of 7 GW. In 1989 alone, 1.84 GW of capacity was added. The present low buyback rates from utilities, combined with uncertainties about industry restructuring, have slowed industry growth and led to the closure of a number of facilities in recent years.

The 7 GW of traditional biomass capacity represents about 1% of total electricity generating capacity and about 8% of all non-utility generating capacity. More than 500 facilities around the country are currently using wood or wood waste to generate electricity. Fewer than 20 facilities are owned and operated by investor-owned or publicly-owned electric utilities. The majority of the capacity is produced in Combined Heat and Power (CHP) facilities in the industrial sector, primarily in pulp and paper mills and paperboard manufacturers. Some of these CHP facilities have buyback agreements with local utilities to purchase net excess generation. Additionally, a moderate percentage of biomass power facilities are owned and operated by non-utility generators, such as independent power producers, that have power purchase agreements with local utilities. The number of such facilities is decreasing somewhat as utilities buy back existing contracts. To generate electricity, the stand-alone power production facilities largely use non-captive residues, including wood waste purchased from forest products industries and urban wood waste streams, used wood pallets, some waste wood from construction and demolition, and some agricultural residues from pruning, harvesting, and processing. In most instances, the generation of biomass power by these facilities also reduces local and regional waste streams.

All of today's capacity is based on mature, direct-combustion boiler/steam turbine technology. The average size of existing biopower plants is 20 MW (the largest approaches 75 MW) and the average biomass-to-electricity efficiency of the industry is 20%. These small plant sizes lead to higher capital cost per kilowatt of installed capacity and to high operating costs as fewer kilowatt-hours are produced per employee. These factors, combined with low efficiencies which increase sensitivity to fluctuations in feedstock price, have led to electricity costs in the 8-12¢/kWh range.

The next generation of stand-alone biopower production will substantially reduce the high costs and efficiency disadvantages of today's industry. The industry is expected to dramatically improve process efficiency through the use of co-firing of biomass in existing coal-fired power stations, through the introduction of high-efficiency gasification-combined-cycle systems, and through efficiency improvements in direct-combustion systems made possible by the addition of fuel drying and higher performance steam cycles at larger scales of operation. Technologies presently at the research and development stage, such as Whole Tree Energy™ integrated gasification fuel cell systems, and modular systems, are expected to be competitive in the future.

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Technology Alternatives

The nearest term low-cost option for the use of biomass is co-firing with coal in existing boilers. Co-firing refers to the practice of introducing biomass as a supplementary energy source in high efficiency boilers. Co-firing has been practiced, tested, or evaluated for a variety of boiler technologies, including pulverized coal boilers of both wall-fired and tangentially-fired designs, coal-fired cyclone boilers, fluidized-bed boilers, and spreader stokers. The current coal-fired power generating system presents an opportunity for carbon mitigation by substituting biomass-based renewable carbon for fossil carbon. Extensive demonstrations and trials have shown that effective substitutions of biomass energy can be made in the range of 10-15% of the total energy input with little more than burner and feed intake system modifications to existing stations. One preliminary test reached 40% of the energy from biomass. Within the current 310 GW of installed coal capacity, plant sizes range from 100 MW to 1.3 GW. Therefore, the biomass potential in a single boiler ranges from 15 MW to 130 MW. Preparation of biomass for co-firing involves well known and commercial technologies. After "tuning" the boiler's combustion output, there is very little loss in total efficiency. Since biomass in general has much less sulfur than coal, there is an SO_2 benefit, and early test results suggest that there is also a NO_x reduction potential of up to 30% with woody biomass co-fired in the 10-15% range. Investment levels are very site-specific and are affected by the available space for yarding and storing biomass, installation of size reduction and drying facilities, and the nature of the boiler burner modifications. Investments are expected to be $100-700/kW of biomass capacity, with a median in the $180-200/kW range. Note that these values are per kW of biomass, so, at 10% co-fire, $100/kW adds $10/kW to the total, coal plus biomass, capacity costs.

Another potentially attractive biopower option is gasification. Gasification for power production involves the devolatilization and conversion of biomass in an atmosphere of steam or air to produce a medium-or low-calorific gas. This "biogas" is then used as fuel in a combined cycle power generation plant that includes a gas turbine topping cycle and a steam turbine bottoming cycle. A large number of variables influence gasifier design, including gasification medium (oxygen or no oxygen), gasifier operating pressure, and gasifier type. Advanced biomass power systems based on gasification benefit from the substantial investments made in coal-based gasification combined cycle (GCC) systems in the areas of hot gas particulate removal and synthesis gas combustion. They also leverage investments made in the Clean Coal Technology Program (commercial demonstration cleanup and utilization technologies) and in those made as part of DOE's Advanced Turbine Systems (ATS) Program. Biomass gasification systems will also be appropriate to provide fuel to fuel cell and hybrid fuel-cell/gas-turbine systems, particularly in developing or rural areas without cheap fossil fuels or having a problematic transmission infrastructure. The first generation of biomass GCC systems would have efficiencies nearly double that of direct-combustion systems (e.g., 37% vs. 20%). In cogeneration applications, total plant efficiencies could exceed 80%. This technology is very near to commercial availability with one small (9MW equivalent) plant operating in Sweden. Costs of a first-of-a-kind biomass GCC plant are estimated to be in the $1,800-2,000/kW range, with the cost dropping rapidly to the $1,400/kW range for a mature plant in the 2010 time frame.

Direct-fired combustion technologies are another option, especially with retrofits of existing facilities to improve process efficiency. Direct combustion involves the oxidation of biomass with excess air, producing hot flue gases which produce steam in the heat exchange sections of boilers. The steam is used to produce electricity in a Rankine cycle. In an electricity-only process, all of the steam is condensed in the turbine cycle while, in CHP operation, a portion of the steam is extracted to provide process heat. Today's biomass-fired steam cycle plants typically use single pass steam turbines. In the past decade, however, efficiency and design features found previously in large-scale steam turbine generators have been transferred to smaller capacity units. These designs include multi-pressure, reheat and regenerative steam turbine cycles, as well as supercritical steam turbines. The two common boiler designs used for steam generation with biomass are stationary and traveling-grate combustors (stokers) and atmospheric fluid-bed combustors. The addition of drying processes and incorporation of higher performance steam cycles is expected to raise the efficiency of direct-combustion systems by about 10% over today's best direct-combustion systems, and to lower the capital investment from the present $2,000/kW to about $1,300/kW or below.

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The three technologies discussed in the detailed technology characterizations are all at either the commercial or commercial-prototype stage. There are additional technologies that are at the conceptual or research and development stage and thus do not warrant development of a comparable technology characterization at this time. However, these options are potentially attractive from a performance and cost perspective and therefore do merit discussion. These technologies include the Whole Tree Energy™ process, biomass gasification fuel cell processes, and small modular systems such as biomass gasification Stirling engines.

The Whole Tree Energy™ process is under development by Energy Performance Systems, with the support of EPRI and DOE, for application to large-scale energy crop production and power generation facilities, with generating capacities above 100 MW. To improve thermal efficiency, a 16.64 MPa/538 .
Whole trees are to be harvested by cutting the trees at the base, then transported by truck to the power plant, stacked in a drying building for about 30 days, dried by air heated in the second stage of the air heater downstream of the boiler, and burned under starved-air conditions in a deep-bed combustor at the bottom of the furnace. A portion of the moisture in the flue gas will be condensed in the second stage of the air heater and collected along with the fly ash in a wet particulate scrubber. The remainder of the plant is similar to a stoker plant. Elements of the process have been tested, but the system has not been tested on an integrated basis.

Gasification fuel cell systems hold the promise of high efficiency and low cost at a variety of scales. The benefits may be particularly pronounced at scales previously associated with high cost and low efficiency (i.e., from < 1MW to 20 MW). Fuel cell-based power systems are likely to be particularly suitable as part of distributed power generation strategies in the U.S. and abroad. Extensive development of molten carbonate fuel cell (MCFC) technology has been conducted under DOE and EPRI's sponsorship, largely with natural gas as a test fuel. Several demonstration projects are underway in the U.S. for long-term testing of these cells. A limited amount of testing was also done with MCFC technology on synthesis gas from a coal gasifier at Dow Energy Systems' (DESTEC) facility in Plaquamine, LA. The results from this test were quite promising.

No fuel cell testing has been done to-date with biomass-derived gases despite the several advantages that biomass has over coal in this application. Biomass' primary advantage is its very low sulfur content. Sulfur-containing species are a major concern in fossil fuel-based fuel cell systems since fuel cells are very sensitive to this contaminant. An additional biomass advantage is its high reactivity. This allows biomass gasifiers to operate at lower temperatures and pressures while maintaining throughput levels comparable to their fossil-fueled counterparts. These relatively mild operating conditions and a high throughput should permit economic construction of gasifiers of a relatively small scale that are compatible with planned fuel cell system sizes. Additionally, the operating temperature and pressure of MCFC units may allow a high degree of thermal integration over the entire gasifier/fuel cell system. Despite these obvious system advantages, it is still necessary for actual test data to be obtained and market assessments performed to stimulate commercial development and deployment of fuel cell systems.

The Stirling engine is designed to use any heat source, and any convenient working gas, to generate energy, in this case electricity. The basic components of the Stirling engine include a compression space and an expansion space, with a heater, regenerator, and cooler in between. Heat is supplied to the working gas at a higher temperature by the heater and is rejected at a lower temperature in the cooler. The regenerator provides a means for storing heat deposited by the hot gas in one stage of the cycle, and releasing it to heat the cool gas in a subsequent stage. Stirling engine systems using biomass are ideal for remote applications, stand-alone or cogeneration applications, or as backup power systems. Since the Stirling engine is an external combustion system, it requires less fuel-gas cleanup than gas turbines. A feasibility test of biomass gasification Stirling engine generation has been performed by Stirling Thermal Motors using a 25 kW engine connected to a small Chiptec updraft gasifier. While the results were encouraging, further demonstration of the concept is required.

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Markets

Biopower systems encompass the entire cycle -- growing and harvesting the resource, converting and delivering electricity, and recycling carbon dioxide during growth of additional biomass. Biomass feedstocks can be of many types from diverse sources. This diversity creates technical and economic challenges for biopower plant operators because each feedstock has different physical and thermochemical characteristics and delivered costs. Increased feedstock flexibility and smaller scales relative to fossil-fuel power plants present opportunities for biopower market penetration. Feedstock type and availability, proximity to users or transmission stations, and markets for potential byproducts will influence which biomass conversion technology is selected and its scale of operation. A number of competing biopower technologies, such as those discussed previously, will likely be available. These will provide a variety of advantages for the U. S. economy, from creating jobs in rural areas to increasing manufacturing jobs.

The near-term domestic opportunity for GCC technology is in the forest products industry. A majority of its power boilers will reach the end of their useful life in the next 10-15 years. This industry is already familiar with use of its low-cost residues ("hog" fuel and even a waste product called "black liquor") for generation of electricity and heat for its processing needs. The higher efficiency of gasification-based systems would bolster this self-generation (offsetting the need for increased electricity purchases from the grid) and perhaps allow sales of electricity to the grid. The industry is also investigating the use of black liquor gasification in combined cycles to replace the aging fleet of kraft recovery boilers.

An even more near-term and low-cost option for the use of biomass is co-firing with coal in existing boilers. Co-firing biomass with coal has the potential to produce 10 to 20 GW in the next twenty years. Though the current substitution rate is negligible, a rapid expansion is possible using wood residues (urban wood, pallets, secondary manufacturing products) and dedicated feedstock supply systems such as willow, poplar and switchgrass.

Resource Issues

Nationally, there appears to be a generous fuel supply. However, the lack of an infrastructure to obtain fuels and the current lack of demonstrated technology to combust or gasify new fuels currently prevents utilization of much of this supply. According to researchers at Princeton University, of the total U.S. biomass residues available, half could be economically used as fuel. They estimate that of the 5 exajoules (4.75 quads) of recoverable residues per year, one third are made up of agricultural wastes and two thirds composed of forestry products industry residues (60% of which are mill residues). Urban wood and paper waste, recoverable in the amount of 0.56 EJ per year, will also be an important source. Pre-consumer biomass waste is also of increasing interest to urban utilities seeking fuels for co-firing, and such use also provides a useful service to the waste producer.

In the Southeast, biomass resources are plentiful, with 91.8 Tg of biomass fuel produced annually according to a study done in the mid-1980s by the Southeast Regional Biomass Energy Program. This translates to an estimated potential of 2.3 EJ of annual energy. North Carolina and Virginia are the biggest wood fuel producers (10.4 and 10.1 Tg, respectively). These residues come primarily from logging applications, culls and surplus growth, and are in the form of whole tree chips. In the western U.S., California is another major user of biomass energy. The California biomass market grew from about 0.45 Tg in 1980 to about 5 Tg in the early 1990s. Feedstocks include mill residues, in-forest residues, agricultural wastes and urban wood waste.

Worldwide, biomass ranks fourth as an energy resource, providing approximately 14% of the world's energy needs. In developing countries, biomass accounts for approximately 35% of the energy used, and in the rural areas of these nations, biomass is often the only accessible and affordable source of energy [1,2]. There is much optimism that biomass will continue to play a significant, and probably increasing, role in the world's future energy mix. The basis for this optimism stems from: (1) the photosynthetic productivity of biomass (conservatively an order of magnitude greater than the world's total energy consumption); (2) the fact that bioenergy can be produced and used in a clean and sustainable manner; and (3) continuing advancements in biomass conversion technologies along several fronts. Increased bioenergy use, especially in industrialized countries, will depend on greater exploitation of existing biomass stocks (particularly residues) and the development of dedicated feedstock supply systems.

Because the future supply of biomass fuels and their prices can be volatile, many believe that the best way to ensure future fuel supply is through the development of dedicated feedstocks. Large-scale dedicated feedstock supply systems designed solely for use in biomass power plants do not exist in the U.S. today on a commercial basis. The DOE Biomass Power Program (BPP) recognizes this fact, and a major part of the commercial demonstration program directly addresses dedicated feedstock supply issues. The 'Biomass Power for Rural Development' projects in New York (willow), Iowa (switchgrass), and Minnesota (alfalfa) are developing the commercial feedstock infrastructure for dedicated feedstocks. The Minnesota Valley alfalfa producers project will involve the production of 700,000 tons/yr of alfalfa on 101,000 hectares (250,000 acres) of land. Unused agricultural lands in the U.S. (31.6 million ha in 1988) are primary candidates for tree plantations or herbaceous energy crops. About 4% of the land within an 80 km radius could supply a 100 MW plant operating at 70% capacity. Although, there are requirements for water, soil type and climate that will restrict certain species to certain areas, an assured regional fuel supply can reduce variability in prices.

Oak Ridge National Laboratory also has an extensive feedstock development and resource assessment program that is closely integrated with the DOE BPP. ORNL is responsible for development and testing of the switchgrass and hybrid poplar species that are receiving intense interest by not only the commercial power project developers, but also the forest products industry.

Although not directly applicable, there are numerous examples in the agriculture and pulp and paper industries that serve to illustrate the feasible size of sustainable commercial biomass operations. There are over fifty pulp and paper mills in the U.S. that produce more than 500,000 tons/yr of product [3]. The feed into such plants is at least one third higher than the product output, with the additional increment being used for internal power and heat generation. The sugarcane industry also routinely harvests, transports, and processes large quantities of biomass. In the U.S. alone, more than a dozen sugar mills each process more than 1.3 million tons of cane per year, including four plants in Florida that process more than 2.25 million tons/yr [4]. Sweden and the other Scandinavian countries have long been leaders in the biomass energy arena. Currently, Sweden has over 16,500 hectares of farmland planted in willow for energy use. The market for woody biomass for energy in Sweden has experienced strong growth, with a steady increase equivalent to 3-4 TWh extra each year for the last five years. This equals one nuclear power station in aggregate every two years. Additionally, Denmark annually produces roughly 7 million tons of wheat straw that cannot, by law, be burned in-field. This straw is increasingly being used for energy production. Thus, there is ample evidence that agricultural, harvest, transport, and management technologies exist to support power plants of the size contemplated.

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Environmental Issues

Two primary issues that could create a tremendous opportunity for biomass are: (1) global climate change and (2) the implementation of Phase II of Title IV of the Clean Air Act Amendments of 1990 (CAAA). Biomass offers the benefit of reducing NO_x, SO_2, and CO_2 emissions. The environmental benefits of biomass technologies are among its greatest assets. The first issue, global climate change, is gaining greater salience in the scientific community. There now appears to be a consensus among the world's leading environmental scientists and informed individuals in the energy and environmental communities that there is a discernable human influence on the climate, and that there is a link between the concentration of carbon dioxide (i.e., greenhouse gases) and the increase in global temperatures. The recognition of this link is what led to the signing of the Global Climate Change treaty. Co-firing biomass with fossil fuels and the use of integrated biomass-gasification combined cycle systems can be an effective strategy for electric utilities to reduce their emissions of greenhouse gases.

The second issue, the arrival of Phase II emission requirements, could also create a number of new opportunities for biomass to be used more widely in industrial facilities and electric power generating units. The key determinant will be whether biomass fuels offer the least expensive option for a company when compared to the installation of pollution control equipment or switching to a "cleaner" fossil fuel.

The second, and more restrictive, phase of the CAAA goes into effect in 2000. CAAA is designed to reduce emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), that make up acid rain, and are primarily emitted by fossil-fuel powered generating stations. The first phase of CAAA affects the largest emitters of SO_2 and NO_x, while the second phase will place tighter restrictions on emissions not only from these facilities, but also from almost all fossil-fuel powered electric generators of 25 MW or greater, utilities and non-utilities alike. The impact of Phase II will be tempered by the fact that most of the utilities that had to comply with Phase I chose to over comply, thereby creating a surplus of allowances for Phase II use. The planned strategies for compliance by utilities suggest that fuel switching will be the compliance of choice. Fuel switching will be primarily to low sulfur coal. Other strategies include co-firing with natural gas, purchasing of allowances, installing scrubbers, repowering of existing capacity, and retirement of existing capacity. An opportunity exists for biomass, especially if credit is given for simultaneous reduction in greenhouse gases.

Use of biomass crops also has the potential to mitigate water pollution. Since many dedicated crops under consideration are perennial, soil disturbance, and thus erosion can be substantially reduced. The need for agricultural chemicals is often lower for dedicated energy crops as well leading to lower stream and river pollution by agri-chemical runoff.

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