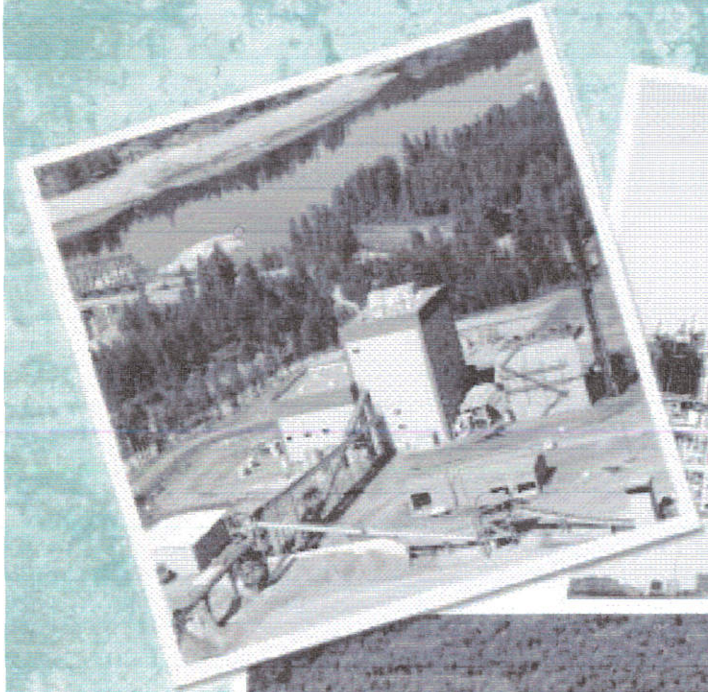
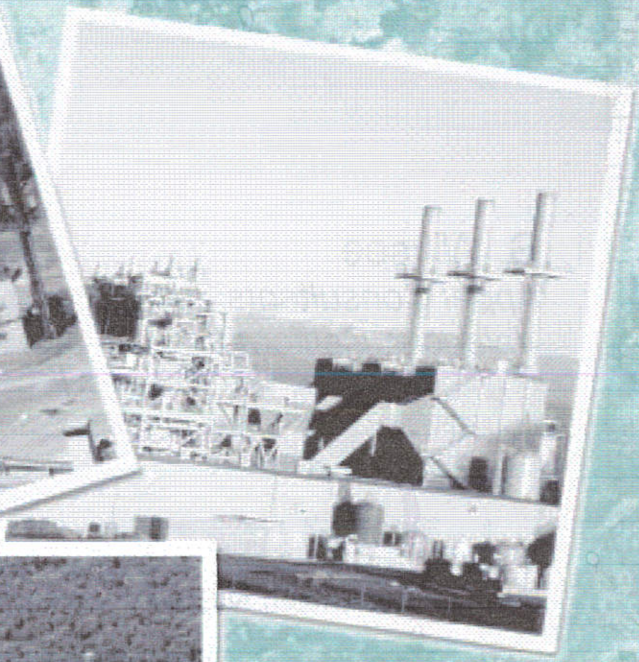
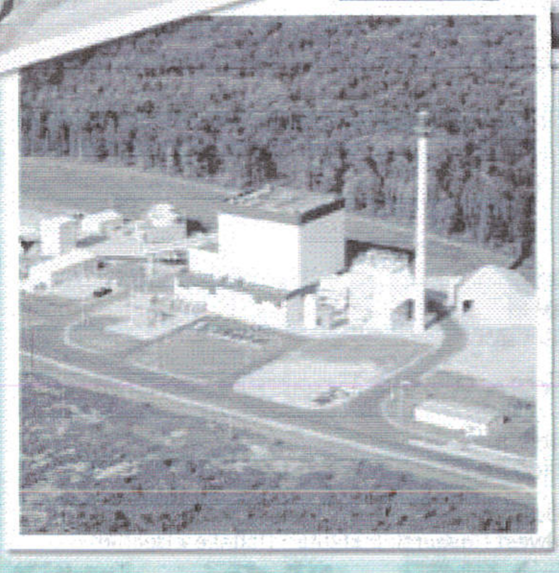
Lessons Learned

from Existing Biomass Power Plants







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EXECUTIVE SUMMARY

This report includes summary information on 20 biomass power plants—18 in the United States, one in Canada, and one in Finland, which represent some of the leaders in the industry. Table 1 lists the 20 plants in order of on-line date, the same order in which they are presented in the report. In some cases, the on-line date means the date an older fossil-fired plant started using biomass fuel commercially (not its original on-line date). Some of the information in the table is abbreviated, but can be clarified by referring to the specific plant sections.

Table 1
Summary of Biomass Power Plants in this Report

Plant	Online	Fuels	Boiler(s)	lb/hr	Psig	ÞF	MWe
Bay Front	Dec-79	Mill, TDF, coal	2 modified coal stokers	280,000			30
Kettle Falls	Dec-83	Mill	1 traveling grate stoker	415,000	1500	950	46
McNeil	Jun-84	Forest, mill, urban	1 traveling grate stoker	480,000	1275	950	50
Shasta	Dec-87	Mill, forest, ag,	3 traveling grate stokers	510,000	900	905	49.9
El Nido (closed)	Oct-88	Ag, forest, mill,	1 bubbling FBC	130,000	650	750	10
Madera (closed)	Jul-89	Ag, forest, mill,	1 bubbling FBC	260,000	850	850	25
Stratton	Nov-89	Mill, forest	1 traveling grate stoker	400,000	1485	955	45
Chowchilla II (closed)	Feb-90	Ag, forest, mill,	1 bubbling FBC	130,000	650	750	10
Tracy	Dec-90	Ag, urban	1 water-cooled vib grate				18.5
Tacoma (cofiring)	Aug-91	Wood, RDF, coal	2 bubbling FBCs		400	750	12
Colmac	Feb-92	Urban, ag, coke	2 CFB boilers	464,000	1255	925	49
Grayling	Aug-92	Mill, forest	1 traveling grate stoker	330,000	1280	950	36.17
Williams Lake	Apr-93	Mill	1 water-cooled vib grate	561,750	1575	950	60
Multitrade	Jun-94	Mill	3 fixed grate stokers	726,000	1500	950	79.5
Ridge	Aug-94	Urban, tires, LFG	1 traveling grate stoker	345,000	1500	980	40
Greenidge (cofiring)	Oct-94	Manufacturing	1 tangentially-fired PC	665,000	1465	1005	10.8*
Camas (cogen)	Dec-95	Mill	1 water-cooled vib grate	220,000	600	750	38-48
Snohomish (cogen)	Aug-96	Mill, urban	1 sloping grate	435,000	825	850	43
Okeelanta (cogen)	Jan-97	Bagasse, urban,	3 water-cooled vib grate	1,320,000	1525	955	74
Lahti (cofiring, cogen)	Jan-98	Urban, RDF	1 CFB gasifier + PC	992,000	2500	1004	25**

*108 total net MW, 10% from wood and 90% from coal.
**167 total net MW, 15% from biofuels and 85% from coal.

The on-line dates of the plants span about 18 years, from December 1979 to January 1998. The types of biomass fuels used are abbreviated: "mill" refers to mill wastes, etc. Many boiler types are represented: six traveling grate stoker boilers, four water-cooled vibrating grate boilers, four bubbling fluidized bed combustors (FBCs), one circulating fluidized bed (CFB) boiler, one fixed-grate boiler, one sloping grate boiler, and two pulverized coal (PC) boilers retrofitted to cofire solid or gasified biomass. Steam temperatures for the biomass-

Capacity Factors

Annual CFs range from 19% to 106%. Some plants with low CFs (e.g., Multitrade and McNeil) are peaking units. The plants with very high CFs have special circumstances. Shasta and Colmac were still under the first 10 years of California Standard Offer contracts when the data were obtained. Williams Lake can operate as high as 15% over its rated capacity, and can frequently sell extra power.

Heat Rates

The Williams Lake plant also holds the distinction of having the largest single boiler (60 MW) and the lowest heat rate (11,700 Btu/kWh) of any 100% biomass-fired power plant. Biomass-cofired coal plants can achieve slightly lower heat rates, as exemplified by Greenidge Station (11,000 Btu/kWh on the biomass portion of the fuel, compared to 9818 on coal alone). The least efficient plants in this report have heat rates of about 20,000 Btu/kWh. A "typical" value is about 14,000 Btu/kWh (24.4% thermal efficiency, HHV).

Cogeneration

The four cogeneration plants in the report—Okeelanta, Snohomish, Lahti, and Camas—are recent plants, using the latest technology, in traditional niches for biomass power: two at pulp and paper mills (Snohomish and Camas), one at a sugar mill (Okeelanta), and one at a municipal district heating plant (Lahti). The estimates given in Table 2 for these plants represent only the solid fuel biomass portion of the energy input. At the two pulp and paper mills, recovery boilers produce large fractions of the total steam from waste liquor; the wood waste boilers at these facilities constitute focus of this report. At Lahti, coal and natural gas produce most of the energy; wood wastes and refuse derived fuel (RDF) are fed to a gasifier that supplies low-Btu gas to the boiler. The Okeelanta cogeneration plant burns bagasse for about 6 months of the year, and burns urban and other wood wastes at other times.

Fuels

The cost of biomass fuel from mill wastes and urban wood wastes can range from about \$0/MBtu to about \$1.40/MBtu, depending on the distance from the fuel source to the power plant. Getting to zero fuel cost depends on locating a power plant in an urban area next to a wood waste processor, or next to a large sawmill or group of sawmills. Deregulation will make this zero fuel cost strategy more important in the future.

Agricultural residues (primarily orchard tree removals) can be processed into fuel and delivered to nearby biomass power plants for about \$1/MBtu. Only if open burning of residues is prohibited will transferring some of this cost to the orchard owners be possible.

Forest residues are much more costly (\$2.40-\$3.50/MBtu), because of the high costs of gathering the material in remote and difficult terrain, processing it to fuel, and transporting it to power plants. There are strong arguments for government programs to bear the costs of forest management and (in the West) fire prevention. Only if such programs are created will forest residues be as cost-competitive fuel as in the future.

Plants that have come close to zero fuel cost are Williams Lake, which is located very close to five large sawmills, and Ridge, which accepts raw urban wood wastes and whole tires, and burns landfill gas. Other plants burning primarily mill wastes include Shasta, Kettle Falls, Stratton, Snohomish, Grayling, Bay Front, Multitrade, and Camas. Other plants

- At the Williams Lake plant, with uncertainty in the forestry industry, unknown impacts of Asian market upheaval, high provincial stumpage fees, and closure of some coastal sawmills and pulp mills, the biggest threat to an enviable operating record appears to be fuel availability.
- The Ridge Generating Station is an urban waste recycling facility, working within the local waste management infrastructure to provide a low-cost recycling service to waste generators, and to obtain a free or negative-cost fuel mix (urban wood wastes, scrap tires, and landfill gas) for energy production.
- The Snohomish Cogeneration plant design anticipated the trend toward declining quantities of sawmill residues, and the increasing use of urban wood wastes in the region. Siting the plant at a paper mill provided an excellent fit for steam use, as well as expertise in wood waste handling and combustion.

Fuel Yard and Fuel Feed System

The area of a biomass power plant that can almost be counted on to be mentioned in response to the question "Have you had any significant problems or lessons learned?" is the fuel yard and fuel feed system. Most plants in this report spent significant time and money during the first year or two of operation, solving problems such as fuel pile odors and heating, excessive equipment wear, fuel hangups and bottlenecks in the feed system, tramp metal separation problems, wide fluctuations in fuel moisture to the boiler, etc., or making changes in the fuel yard to respond to market opportunities. Examples noted in this report include:

- At Bay Front Northern States Power (NSP) engineers installed and improved (over time) a system that allows feeding of 100% biomass, 100% coal, or any combination of the two. Because wood fuel quality varies more than coal quality, proper tuning of the automatic combustion controls is more important when firing wood. Operators must pay close attention and periodically adjust feeders.
- With the addition of a debarker, high-speed V-drum chipper, chip screen, and overhead bins, the Shasta plant was able to offer to custom chip logs, keeping the 35% of the log not suitable for chips. In times of low chip prices, Shasta still purchases the whole log. Shasta successfully marketed the program to some of the largest landowners in California.
- At Shasta, the operators learned to blend all the fuels into a homogeneous mixture that allowed the boilers to fire at a consistent rate and maintain maximum load under all conditions, without violating environmental standards, excessively corroding heat transfer surfaces, or slagging beyond the point where the boilers required cleaning more than twice per year.
- At Stratton, the original owners spent about $1.8 million during the first year of operation to improve the operation of the fuel yard.
- Tacoma personnel stress the need to take extra care at the beginning of the project with design of the fuel feed system. Selecting a proven fuel feed system is important.
- The only area of the Williams Lake plant that was modified after startup was the fuel handling system. Minor modifications were made to improve performance, such as adding the ability to reverse the dragchains on the dumper hoppers, to make it easier to unplug fuel jams; and adding three more rolls to each disk screen (12 rolls were provided originally), to reduce the carryover of fine particles that tended to plug up the hog.

- The primary lesson learned from the McNeil plant experience in Burlington, Vermont, is careful attention to the siting of a biomass-fueled plant. Siting the plant in a residential neighborhood of a small city has caused a number of problems and extra expenses over the years: a permit requirement to use trains for fuel supply, high taxes, high labor rates, local political involvement, and neighborhood complaints about odors and noise.
- The Colmac plant shows that urban wood waste can be a comparatively expensive fuel (~$1.50/MBtu) if the plant is located far outside the urban area. The transportation cost is significant. An urban biomass plant can derive income from its fuel with a location and tipping fees that attract wood waste generators with loads to dump.

Reliability and Dependability

Several plant managers with the best long-term operating records stressed the necessity for placing a high value on reliability and dependability. This is true during plant design and equipment selection, and during operation. For example:

- Outside of planned outages, the Kettle Falls plant has an availability factor of about 98% over a continuous 16-year period. The superintendent has high praise for the people on the staff. The plant is always exceptionally clean and neat.
- The Shasta general manager advises: "Always place a high value on reliability and dependability, for these will allow you to be considered a 'player' and thus a participant in the development of special programs with the utility."
- At Williams Lake, which has an outstanding performance record, the chief engineer stressed that staying on top of maintenance programs at all times is essential.

Partnerships

The most successful projects have developed formal or informal partnerships with their key customers and suppliers. The relationship with the utility company that buys the power is usually the most important. This may change as generators simply bid their power into a power pool. Cogeneration plants by definition must have close relationships with their steam users. Sometimes there are a few large fuel suppliers (such as sawmills) with whom special relationships are crucial. Examples in this report that illustrate the importance of strong partnerships include:

- In the words of the Shasta general manager: "But these new approaches must go forward on a very different basis than our past biomass developments. They must go forward in partnership with utilities. While the utility may want to participate in such systems, they will not and cannot do so unless the cost to ratepayers is very close to that of other generating options."
- Like several other biomass power plants, the Grayling Station is operated as a cycling plant. It has run at about a 70%-80% CF during peak demand periods, and at about a 40%-50% CF during off-peak periods. The McNeil, Multitrade, and Ridge plants are other examples of cycling plants.
- The arrangement between the Camas Mill and its electric utility (PacifiCorp) is mutually beneficial. The utility-financed turbine/generator provides the mill with an additional source of cash flow, without significantly changing the mill's steam generation and delivery system. The utility has added about 50 MW of reliable generating capacity to its system for a relatively small investment, and has strengthened its relationship with a major customer.

- In the forests near the Shasta plant: "The result is a healthier, faster growing forest that has a dramatically lowered potential to be destroyed by fire. There are now adequate moisture, nutrients and sunlight for the remaining trees and net growth often triples. The remaining trees regain their traditional resistance to insect and disease attack."
- The Grayling and Ridge projects were planned and the plants were designed with waste management roles in mind—one in a rural setting and the other in an urban setting. Efforts were made to fit constructively into the local economic and environmental landscapes, with clearly positive results.

Subsidy Programs Do Not Last

As a final note, the Shasta general manager's list of lessons learned includes this one: "Beware of entering a regulatory system in which the utility commission or legislature has determined that it is acceptable for ratepayers to pay the full cost of your technology. Such things do not last."

available, reliable, cost-effective, nonpolluting, and acceptable to the public. Using wood fuel as a generation source could produce important benefits: putting money back into the Vermont economy, improving the condition of the state's forests, and providing jobs for Vermonters.

The pulp and paper industry had proven for years that bark and wood chips could be burned efficiently and with good environmental controls. The real unknown was the availability of a fuel delivery network that could reliably supply wood fuel at a reasonable price. In 1977, Unit 1 at Moran Station was modified for wood chip cofiring. Based on the success with Unit 1, a second unit was converted to wood in 1979. In 1983 the Moran plant used more than 100,000 t of wood chips for fuel in addition to 30,670 tons of coal, 146 million ft^3 of natural gas, and 121,011 gal of No. 2 fuel oil. Economic and technical studies verified that expanded wood firing was viable.

A bond issue was passed by the voters of the City of Burlington in 1978 to finance the construction of the McNeil Generating Station. In 1979, C.T. Main was hired to design the plant and to help with the permitting requirements and construction management. The station was sited on a parcel of land known as the Intervale on the north side of Burlington. In September 1981, permits were received and site preparation began.

By October 1983 the ESP and steel building structure were essentially completed. Construction of the main power boiler began in August 1982; the boiler was hydrotested in April 1983. The turbine-generator set, manufactured in Switzerland, arrived in May 1983 and was first operated in January 1984. On June 1, 1984, the McNeil Generating Station began commercial operation, producing power as dispatched by New England Power Exchange.

The final cost of constructing McNeil was $67 million (1984 dollars)—$13 million below the budget estimate of $80 million. The McNeil Station is jointly owned by BED (50%), Central Vermont Public Service Authority (20%), Vermont Public Power Supply Authority (19%), and Green Mountain Power Corporation (11%).

Advanced Renewable Technology Development

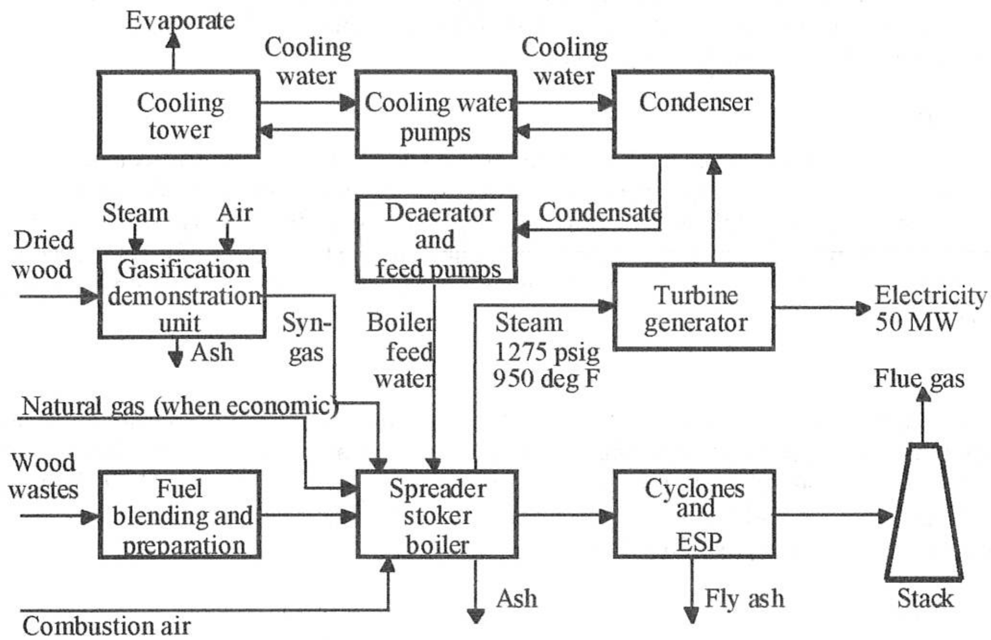
Vermont Gasification Project

In August 1994 the U.S. Department of Energy (DOE) entered into a cooperative agreement with Future Energy Resources Corp. and an industrial and utility consortium to design, construct, and validate large-scale integrated gasifier and gas turbine combined cycle technology at the McNeil Station. The "Vermont Gasification Project" is testing and operating an indirect biomass gasifier developed by Battelle Columbus Laboratories. During the initial operating phase (ongoing), the gas produced by the gasifier is burned in one of the natural gas burners of the McNeil boiler. Upon successful demonstration of the gasifier, a hot gas cleanup system and a commercial-scale (15-20 MW_e) gas turbine will be incorporated into the system.

The Battelle gasification process is an indirectly heated CFB system that has more than 20,000 successful hours of operation at Battelle Columbus at the 10 t/d pilot plant scale. Wood or other biomass is gasified with a mixture of steam and hot sand. Hot medium-Btu gas leaves the gasifier with the sand and a small amount of charred wood. The sand is captured and recycled, while the charred wood is combusted in an FBC that provides heat renewable portfolio requirement as a precondition to retail choice in Vermont, and creation of competitive "green markets" that use indigenous resources.

Plant Flowsheet and Design Information

McNeil Generating Station



Boiler

The boiler, a two-drum, top-supported Sterling design with water wall construction, was furnished and erected by Zurn Industries. It was originally designed to be capable of PC firing in the future. Initially, three oil burners were installed for startup and flame stabilization with a maximum heat input of 250 MBtu/h. Provisions were made for an additional three burners for future consideration. The boiler has two traveling grates and is rated at 480,000 lb/h at 1275 psig and 950°F when burning 100% wood at 55% moisture content.

Turbine Generator

The turbine generator for the McNeil Station was manufactured by Brown Boveri Corporation in Oerlikon, Switzerland. It has 36 stages of rotating blades, five extraction points for feedwater heating, and 25-in. last stage blades. The turbine is directly connected to a 3600-rpm air-cooled generator rated at 60,037 MVA. The turbine generator was specifically designed to accommodate the cycling service expected at the station, as well as possible future district heating capability. The turbine generator set can supply a maximum of 59.4 MW gross when exhausting 348,000 lb/h of steam to the condenser at 2 in. of mercury. Approximately 42,000 gpm of cooling water are required.

Based on figures published by the U.S. Forest Service, 50% of Vermont's forest inventory is made up of wood, branches, and bark that have no potential for manufacturing quality products such as woodenware or furniture. This unusable wood largely consists of tops and cull portions left behind after trees have been conventionally harvested as sawlogs or pulpwood. The amount of wood available for whole tree chip harvesting has been conservatively estimated at 1 million green t/yr in Northern Vermont alone. This is twice the forecasted need to operate the McNeil Station annually at an estimated 70% load factor.

Wood for the McNeil Station is harvested under strict guidelines developed in conjunction with the State of Vermont. Burlington Electric is required to have four professional foresters on staff to supervise the procurement. Every harvesting site and harvesting plan is reviewed by a forester and approved by the state before the trees are cut. The foresters ensure that the wood is cut in such a way as to minimize any adverse effects on wildlife and the land, while optimizing regrowth potential.

Clearcuttings are generally limited to areas where the trees are of very poor quality. It may also be used in some cases to promote wildlife habitat. In these cases, the size of the area is limited to a maximum of 25 acres. Clearing is used in cases where the land is converted to other uses such as development, agriculture, or tree planting.

The Vermont Public Service Board required that 75% of all wood fuel be delivered by rail to McNeil Station. Burlington is the largest city in Vermont and there were concerns about traffic congestion from the trucks bringing wood to the station. A typical wood truck carries 25 t of wood, so three truck loads of wood are required for every hour the plant is operating at full load on wood fuel.

A remote wood yard is located in Swanton, Vermont, 35 miles from Burlington and 8 miles from the Canadian border. Seventy-five percent of the station wood is delivered to Swanton by truck. This wood is stored temporarily and loaded into 21 bottom dump gondola railroad cars. Each car can carry 75 tons of wood chips, or 7000 ft^3. At the McNeil Station, the railcars are unloaded three at a time through an unloading trestle.

Wood chip costs depend on such factors as the distance from the point of delivery, the type of material (such as bark, sawmill residue, or whole tree chips), and the mode of transportation. Chips delivered directly to the plant by truck are less expensive than those delivered to the Swanton site and shipped by railcar to the McNeil Station. The range of prices is $10-$23/t delivered (~$20-46/dt, or ~$1.20-$2.70/MBtu). Shipping wood in by rail imposes an estimated 17% premium on the delivered fuel cost.

After an initial experience with over-storage onsite, which led to serious odor problems and spontaneous combustion in the wood piles, the plant developed a very tight management plan for on-site wood chip storage and handling. Piles are limited in size and are monitored to ensure that they do not reach the odor-producing stage. Fuel is consumed on a first-in, first-out basis to control the age of the material.

and a nine field-weighted wire ESP with an overall efficiency of 99.5%. The design gas velocity in the precipitator was limited to 3 ft/s, resulting in more than 7 acres of collection plates.

In actual operation, the stack particulate emissions are about 0.0007 gr/dscf. This is 10% of the state requirements and about 1% of the 0.1 lb/MBtu particulate standards that were typical of solid fuel stations built when McNeil was built.

The chimney at McNeil is a precast concrete design with a 10-ft diameter corten liner. It extends 257 ft above grade with a platform midway for monitoring opacity, CO_2, O_2, SO_2, flue gas flow, moisture, and NO_x. In addition, CO is monitored at the boiler gas outlet.

The plant's location is less than ideal. It is adjacent to a residential neighborhood of a metropolitan area. The topography is such that the top of the boiler is at about the same elevation as some residences on a nearby hill. Truck traffic, noise, odors, and emissions were problems during project planning and initial operations.

Ash produced from McNeil Station is temporarily stockpiled on site in a landfill area. A private contractor reclaims the ash, mixes it with agricultural-grade limestone, and markets it as a soil conditioner for farmlands.

Water removed from the McNeil Station is monitored for pH, temperature, flow, and metals. It is treated to maintain a balanced pH, allowed to cool to a temperature that will not adversely affect aquatic life, then pumped to the Winooski River, located about 1000 ft east of the plant. The wastewater quality is required to be equal to or better than that of drinking water before being discharged to the river.

Economic Information

The plant cost approximately $67 million to build, or $1340/kW, in 1984 dollars. Adjusted using the GDP deflator, this is about $2080/kW in December 1998 dollars. The interest rate on the municipal bonds that financed BED's 50% share of the plant in the early 1980s was about 12%. The bonds have been refinanced three times, a costly process. O&M costs total about $4 million/yr, including $1 million/yr in local property taxes. Spread over the annual plant output of about 155 million kWh/yr, O&M costs are about 2.6¢/kWh.

Fuel costs depend on market prices and the amount of fuel used to meet NEPOOL dispatch requirements. In late 1998, the price of natural gas was $2.80-$3.00/Mbtu, so gas was not used. Wood fuel cost varied between about $1.30 and $1.70/MBtu, which at a net plant heat rate of 14,125 Btu/kWh was equivalent to 1.8-2.4¢/kWh.

Lessons Learned

John Irving, the station superintendent, believes that the primary lesson learned from the McNeil plant experience is careful attention to the siting of a biomass-fueled plant. The plant's site has caused a number of problems and extra expenses over the years: a permit requirement to use trains for fuel supply, high taxes, high labor rates, local political involvement, and neighborhood complaints about odors and noise. There are advantages of an urban setting, such as the ability to obtain urban wood wastes. Although Burlington's urban wood waste supply is a small fraction of the plant's fuel requirement, it effectively lowers the average cost of fuel and avoids costly and environmentally poorer choices for