WTE^{TM} BIOMASS POWER PLANT IN CENTRAL WISCONSIN

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1. OVERVIEW OF POWER PLANT

A 50 MW Whole Tree Energy (WTE™) Biomass Power Plant is envisioned for central Wisconsin. Hybrid poplar trees are planted and grown on land within 50 miles of the power plant site. The time from planting to harvest is five years, and the harvest yield is typically 25 dry tons per acre. The harvested trees are trucked to the power plant site and dried in a drying dome, which utilizes waste heat from the power plant. The whole (not chipped) trees are then fed by conveyor into a deep, fixed-bed furnace which provides heat for a high pressure steam boiler. The steam cycle powers a steam turbine-electrical generator. This biomass system provides renewable, dispatchable power to the electric grid. The total system is sustainable, efficient, and robust (1-6).

The three-stage combustion system converts the wood to heat, carbon dioxide and water. There is no net increase in carbon dioxide because CO_2 is sequestered in new trees. Emissions from the power plant are minimal. Flyash is removed from the stack gas with a scrubber or electrostatic precipitator, and the ash is pelletized and used as fertilizer for the trees. Nitrogen oxides are controlled with extensive over-fire air. There is very little sulfur or chlorine in the wood.

A 50 MW power plant requires 50,000 acres of tree farms, which is about 1% of the land within a 50 mile radius. The required land is leased for a 15 year period. The estimated cost of electricity is similar to an equivalent coal fired power plant. The benefits of a biomass fired power plant in Wisconsin are:

1) generates dispatchable electric power 24 hr/day throughout the year,

2) provides a stable source of income to farmers,

3) offers soil stabilization and the potential to remove pollutants from ground water in certain locations, and

4) contributes to the State of Wisconsin renewable energy portfolio.

This report presents a comprehensive description of a WTE™ biomass fired power plant, including the fuel supply, power plant technology, and costs. The WTE™ system is a novel technology that builds on past experience with generating renewable energy from biomass.

2. FUEL SUPPLY

The fuel supply is hybrid poplar and cottonwood trees grown as short rotation woody farm crops on plots averaging 80 acres or more. The land is leased from the landowner. Each year for five years 10,000 acres will be planted. Over the last 15 years various clones of hybrid poplars have been bred to be fast growing and disease resistant. Improvements in the genetic stock are ongoing. Hybrid poplars are beginning to be widely used in the forest and paper industries. Cottonwood, which is in the same genus, is also very fast growing and disease resistant. Poplars will grow almost anywhere but best yield for energy crops is obtained by following proper agricultural practice. The trees grow tall and straight with relatively small branches. In the first four years of operation before the energy crop is established, waste wood, over-aged stands, and natural gas would be used as the fuel.

2.1 Planting and Farming

Cuttings from two year old stool bed trees are used to establish the tree farms. The two-year-old trees are harvested in winter and cut into 10 in. lengths with diameters of 0.375 in. to 1.25 in. The cuttings are stored in boxes in an industrial freezer. The dormant cuttings are planted in May when the soil temperature reaches 50°F. A rapid planting machine inserts a cutting into the soil such that one bud is exposed to the air. The cuttings are planted on 5 ft centers, and a total of up to 1800 cuttings per acre are required.

The most successful clone developed to date for the upper Midwest is hybrid poplar NM-6 (Nigra X Maximawitzii), and this will be the main cutting. Other fast growing and disease resistant clones such as the eastern cottonwood varieties will also be used. Cuttings will be purchased from nurseries in Wisconsin, Minnesota, Michigan, North Dakota and Oregon.

A pre-emergent herbicide is applied after planting, which provides weed control for most of the season. Young hybrid poplars cannot out-compete weeds. One tilling may be required in the first year for weed control, but not in the following years. A single final application of pre-emergent herbicide is applied in the second year. The clones selected have good pest resistance but some pest management may be required. Nitrogen, phosphorous and potassium levels in the soil must be maintained for optimum growth. The inorganic requirements are only about 10% of that required for a corn crop. The main source of nitrogen is from decomposition of fallen leaves. Flyash pellets from the biomass-fired power plant are applied to the fields once during the five year growing cycle to recycle the phosphorous, potassium and other trace elements.

2.2 Harvesting and Transporting

The trees are ready for harvest beginning in the fall of the fifth growing season. The trees are typically 6-8 in. diameter and 40-45 ft tall. A special harvesting machine has been designed by EPS with a grant from the Department of Energy. This machine, which is mounted on four rubber tracks, grabs the tree, cuts it off at the base, and holds the tree upright in an accumulator, while continuing to move down the row at up to 6 mph. Near the end of the row the trees are loaded into a trailer carrying a 27 ton load of whole trees. In applications where wider row spacing and longer harvest cycles are used, trucks may be directly loaded when a single row produces more than 27 tons. A 50 MW plant requires 52 truck loads per day of whole trees.

After harvesting, the poplar trees sprout from the stumps and grow vigorously with little attention except fertilization with ash pellets from the power plant. Harvesting is done every fifth year.

3. PROJECT SITE AND LAND REQUIREMENTS

An 80 acre site for the power plant is needed which has good road access, is close to an electric transmission line, has a natural gas supply for startup, and a makeup water supply. Approximately 15 acres are needed for the drying dome and power plant, while the remaining 65 acres would be planted with trees to provide a noise barrier and be aesthetically pleasing. Plover, WI, is an example of an area that has these requirements. Plover is within the electric service territory of Wisconsin Public Service Corporation.

The dedicated farmland should be within 50 miles of the power plant site. The best soils for poplar trees are loam, sandy loam, and clay loam. Relatively fertile soil is recommended. Planting in very sandy soil is not recommended unless a sufficiently high water table is present. Areas prone to summer flooding should be avoided. Poplars can tolerate standing water for short periods of time but not prolonged periods. Soils which form a hardpan surface should be avoided. The soil pH should be in the range 5.5-7.5, but up to 8.4 can be tolerated by some cottonwood clones. The slope should be less than 14 degrees (or 25%) for efficient harvesting because of mechanical constraints. Five years is required from planting to harvest. The yield is a function of the soil quality, tree spacing, clone type, fertilization, cultivation, pesticide application, and most importantly water availability. The design yield is 25 dry tons per acre after five years of growth. For a 50 MW power plant 50,000 acres are required. If each tree farm averaged 80 acres, then a total of 625 fields would be needed and 125 fields would be planted each year.

As an example, consider the area within 50 miles of Plover, WI. The towns of Stevens Point, Wisconsin Rapids, Marshfield, and Wausau lie within this circle. The Plover area has good roads for transporting the trees and is near a 345 kV transmission line. The current land use in this region is given in Table 1. Of the 2,619,535 acres of agricultural land (crop or pastureland), 489,994 acres is considered marginal agricultural land (7). Although poplar trees can be grown on marginal land, the yield may be less than the design yield of 25 dry tons after five years. For a 50 MW power plant 1% of the agricultural land with in 50 miles of the power plant site would be dedicated for tree farms.

Table 1. Land Use within 50 miles of Plover, WI

Land Cover Type	Total Area (acres)	Percent of Total
Agricultural	2,619,535	47.6%
Forested	1,875,870	34.1%
Barren	22,146	0.4%
Water	129,120	2.3%
Wetlands	769,542	14.0%
Urban	91,463	1.7%
Total	5,507,676	100.0%

4. POWER PLANT TECHNOLOGY

The key power plant technologies are the drying and storage dome, the furnace, the boiler, steam turbine, generator, and emissions control equipment. The general layout of the plant is shown below.

4.1 Drying and Storage Dome

Whole trees are delivered to the drying and storage dome at the rate of 52 trucks per day, and the trees are removed from the trailer truck by a tower crane with grapple. A 30 day supply of wood totaling 42,000 green tons is maintained. The pile is 80 ft high by 280 ft diameter (this is based on a pile density of 17.0 lb/ft^3 at 44% moisture). The dome, which is a pressurized two-layer fabric facility similar to those used to cover sports stadiums, is 120 ft high by 500 ft diameter. Heated air from heat exchangers, which transfer heat from the furnace flue gas to the drying air, is circulated by means of zoned ducting underneath the pile and flows up through the pile and out through an opening in the top of the dome. The drying air enters the drying dome at 130°F and exits at 72°F. The delivered wood typically has 44-50% as-received moisture, and after 30 days it is dried to 20-25% moisture. The whole trees are removed from the stack in the dome on a first-in, first-out basis by the overhead crane with a specially designed grapple and placed on a conveyor in batches for delivery to the furnace/boiler.

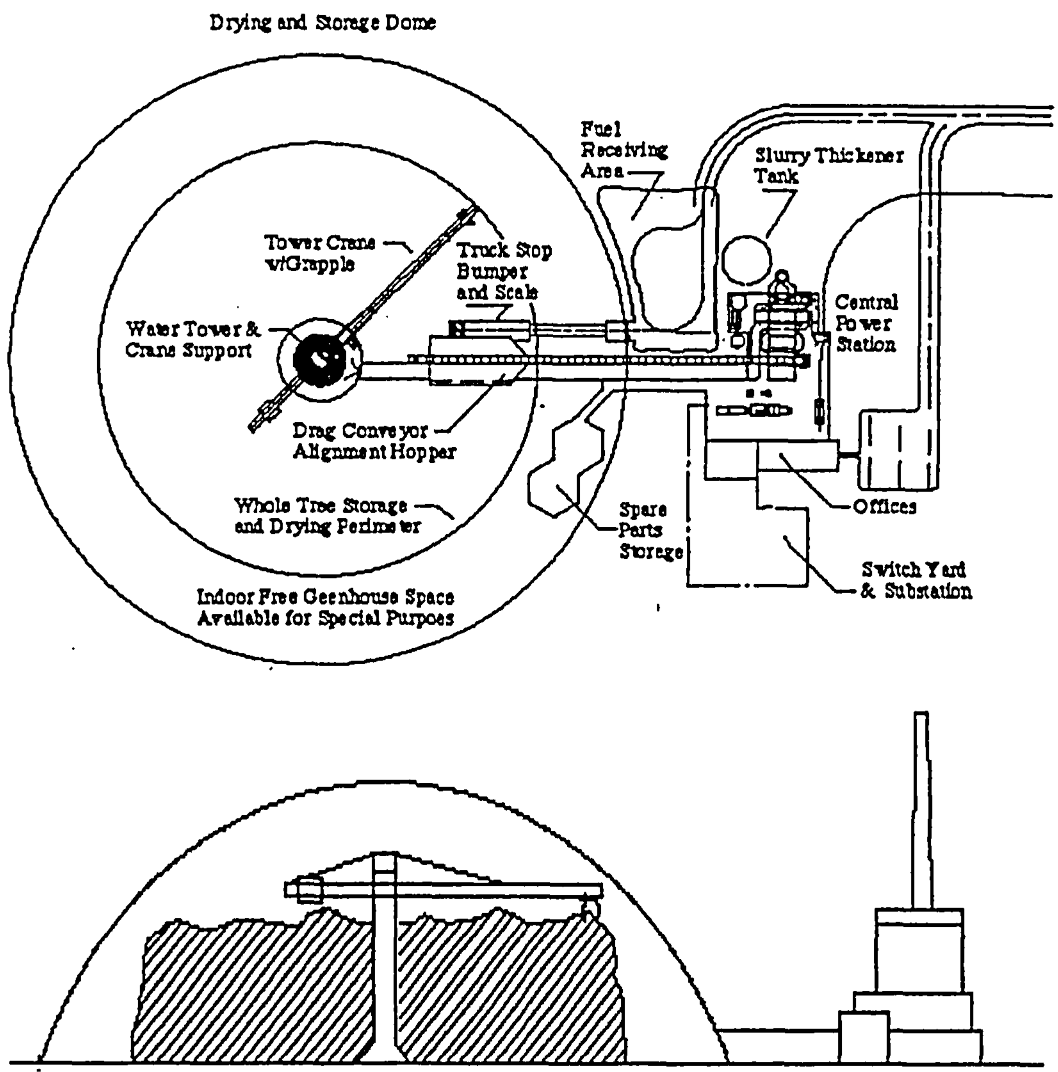

Figure 1. Top and side views of drying/storage dome and power plant.

There is a possibility to plan for greenhouse space between the outside of the tree drying pile and the dome walls, pending consideration of safety issues. The greenhouse area available in the drying dome would be up to 20,000 ft^2.

4.2 Furnace

Whole tree batches are transported on the conveyor to the furnace charge chamber. While on the conveyor a heavy duty sectioning saw cuts the batch to length (25 ft for a 50 MW system) and the batch (up to 5 ton) is pushed into the charge chamber from the top. The top door closes, sealing the chamber , and a charge ram forces the wood charge through a furnace entry door and onto the top of the fuel bed. The fuel bed, which is typically 12-16 ft deep, is supported by a patented water cooled grate that uses controlled circulation. Preheated air from a second heat exchanger, which transfers heat from the flue gas to the furnace air, flows upward under the grate and also above the fixed fuel bed (over-fire air).

The furnace has a design heat release rate of 2.5 million Btu/hr-ft^2 based on pilot-scale test results (see below).

The combustion process involves a patented three-stage process:

- First, char in the bottom 1-2 ft of the deep bed burns on the grate where available oxygen is consumed. The hot gases from the burning char flow upward through the fixed bed of whole trees and drive the volatiles from the wood (pyrolysis). As the char at the bottom is consumed, the bed partially subsides and another batch of wood is fed from the charge chamber above the bed.

- Second, above bed over-fire air is strategically mixed with the volatiles, which consist of CO, CO_2, H_2, CH_4, H_2O, N_2 and tars. Combustion of the volatiles proceeds, the tars are burned out, and heat is transferred to the boiler walls and convective tubes. Combustion above the bed occurs first in a reducing environment, and then excess air is added near the end of the upper combustion zone.

- Third, any char that falls through the openings of the grate at the bottom of the bed is collected on a lower grate and burns out below the bed.

The furnace has a design heat release rate of 2.5 million Btu/hr-ft^2. For a 50 MW design the grate is 25 ft long and 9 ft wide. This configuration facilitates efficient utilization of over-fire air.

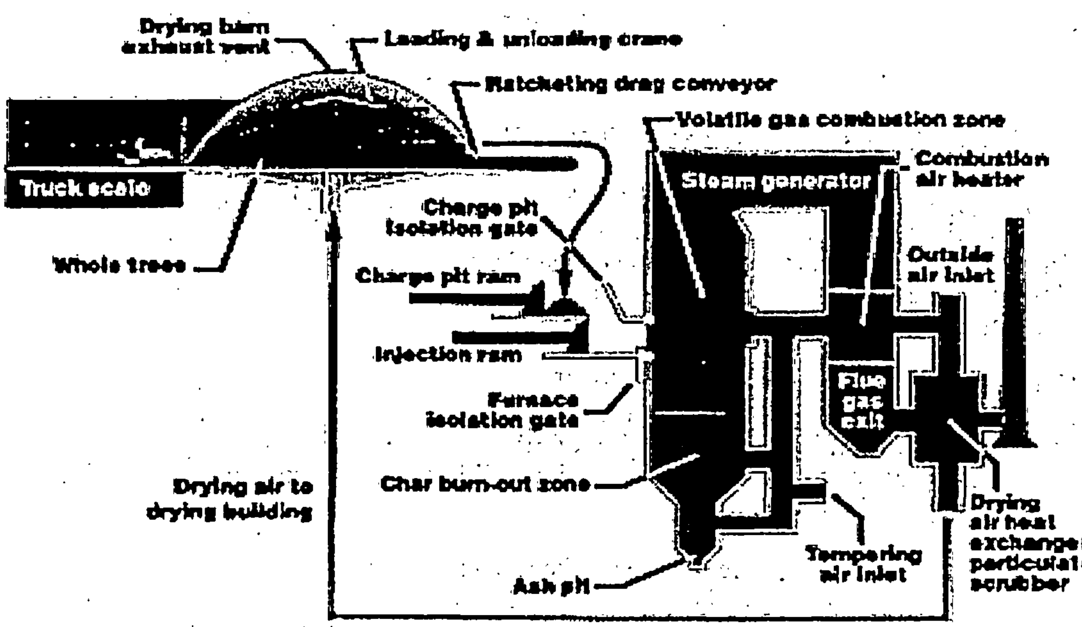

Figure 2. Schematic showing furnace, ram feeder, steam generator, flue gas heat exchanger, and drying dome.

4.3 Boiler-Steam Turbine-Generator

The boiler produces 325,000 lb/hr of steam at 2000 lb/in^2 and 1000°F exhausted to a pressure of 1 lb/in^2 absolute. The steam turbine is a dual casing, single axis machine with six extraction points and one reheat at 1000°F. The turbine heat rate is 7,800 Btu/kWh. The generator is rated at 57,800 kVA, 3600 rpm, 3-phase, 60 Hz, 13.8 kV. The generator has a gross capacity of 52.4 MW to provide for 4.8% auxiliary power for boiler feedwater, scrubber and cooling tower pumps; combustion air and wood drying air fans; crane, conveyor, and ram feeder power; and miscellaneous power. The boiler efficiency is 83%. The overall heat rate of the power plant is 10,200 Btu/kWh.

4.4 Emissions Control

Particulate control is by means of either a wet scrubber or a wet electrostatic precipitator located after the condensing heat exchanger. The choice of particulate control equipment depends on the degree of control required. The particulate slurry collected by the scrubber or precipitator is circulated through a pug mill that de-waters and pelletizes the ash. The ash pellets are spread on the tree fields as a fertilizer. The ash content of the wood is less than 1% so that a maximum of 6 tons/day are collected and pelletized. The particulate emission standard to be met for new wood fired power plants in the State of Wisconsin is based on best available control technology (BACT) and can be expected to be about 0.05 pound per million Btu depending on the current state of the art.

Nitrogen oxide control is by means of over-fire air jets which are located at strategic positions above the reducing zone of the fuel bed. Nitrogen oxide formation is expected to be low because of the deep reducing zone of the fuel bed and the extended ovefire air. The nitrogen oxide emission standard for wood fired power plants in the State of Wisconsin is based on BACT and is set on a case by case evaluation.

The sulfur dioxide and carbon monoxide emissions are very low and emission standards do not apply. However, CO is used as a surrogate for products of incomplete combustion (PICs), and it is likely that the CO emissions would be limited to 300 ppm (dry volume basis) at 7% oxygen.

5. TECHNOLOGY TESTING TO DATE (also see references 1 & 2)

Planting Tests: A prototype machine has been developed to plant 10 in. long tree cuttings at high speed. Approximately 180,000 cuttings were planted at the rate of 1 per second in a single row. In the operational version of the planter six rows at a time will be planted. The planter can be used on unprepared Conservation Reserve Program land and difficult-to-farm land also.

Harvesting, Loading, and Transportation Tests: Tree harvesting at the rate of 50 green ton/hr has been demonstrated using a single harvesting "train" of one feller-buncher, one skidder, and one loader. Transportation of 30 ton whole tree loads on logging roads and public highways was done. Crowns and limbs did not pose a problem with loading or transporting whole trees.

Stacking Tests (2): Whole trees were stacked to a height in excess of 100 ft. Each layer of trees was placed at 90° to the layer below. The weight of the trees tended to compress a notch in the wood where the trees made contact, which enhances the stability of the stack. As a test, a 45,000 lb side load, which was applied to trees near the top of the stack, had no visible affect on the tree stack. In another test a stack with a 110° angle of repose overhang was created without any apparent instability. Thus the lateral stability of a large stack of whole trees is exceptional.

Drying Tests (2): A 70 ft by 70 ft by 87 ft tall stack of whole hardwood trees was supported by an air distribution manifold. Air was heated by a heat exchanger using a propane burner and ducted into the manifold. The stack of trees was dried with 136°F air for 30 days, and the average moisture level of the trees was reduced from 44% to 20%.

There was no pressure drop through the stack of trees because of buoyancy; rather the pressure was –0.5 in. water at the base of the stack. These tests established the feasibility of drying a large stack of green trees with waste heat from the flue gases.

Combustion Tests (2): Tests were conducted at the Bay Front Unit No. 3 of Northern States Power Co. in Ashland, WI. The coal-fired underfeed stoker with boiler rated at 100,000 lb/hr steam at 740 psi drum pressure and 850°F superheat was modified to receive 15 ft long logs from charge chamber by means of a ram feeder. A higher pressure over-fire air system was added. The tests demonstrated the feasibility of replacing coal with logs on a grate without loss in boiler performance.

Pilot scale combustion tests (2,8) of a deep fixed bed of sectioned whole trees on a grate were conducted in a 4 ft by 8 ft by 20 ft high open-top test chamber located in Northern Minnesota. Under-fire air was preheated to 600°F, and the fuel bed, which was supported by a water cooled grate, was maintained at 12 ft deep by feeding wood in from the top. The air flow rate was set at 1240 lb/min which gave an air velocity under the bed of 13 ft/s. The fuel bed, which was supported by an air cooled grate, was maintained at a depth of 12 ft by feeding wood into the top of the furnace with an inclined chain conveyor. The tree sections were 8 ft long, with log diameters up to 8 in., and the average moisture level was 31.6%. The weight of each tree section was measured on a weighing table before being placed on the conveyor. The average void fraction of the bed was 0.65. There was no overfire air and combustion/pyrolysis products were vented to the atmosphere. Based on the wood feed rate required to maintain the level of the bed over a 2 hr period, the average effective heat rate during the tests was 3.2 million Btu/hr-ft^2. These tests demonstrated the intense nature of the combustion and pyrolysis in the deep bed of sectioned whole trees. A CO_2 inerting method for rapid emergency shutdown was also demonstrated. From the measured wood consumption rate and data from single log tests (see below) a computer model of a deep fixed bed was developed and validated. The model relates heat release rate to under-grate air flow and preheat, fuel moisture, size and void fraction, and bed height. Based on this, a design heat release rate of 2.5 2 million Btu/hr-ft^2 was selected for the first full-scale unit.

Single log combustion tests (9) were conducted at the U. S. Forest Products Laboratory in Madison, WI, in a specially designed furnace supported by load cells. These single log tests established the burning rate of individual logs up to 8 in. in diameter in high temperature oxidizing and reducing environments and confirmed the high heat release rate observed in the pilot scale tests. The detailed data obtained was used to develop a computer model that simulates the performance of the deep fixed bed furnace over a range of conditions.

Scrubber Tests: The wet scrubber was tested in 1978 at the Sherbourn County Generating Station of Northern States Power on Unit 1, a 747 MW coal-fired power plant. In this power plant the combustion products were ducted to 11 scrubbers each cleaning the equivalent of 68 MW of gas. The "multiple angle scrubber" was installed in one of the ducts, and particulate emissions averaged 0.075 lb/million on coal. L. David Ostlie was granted US patent number 4,313,742 for the multiple angle scrubber in 1982. If the wet scrubber is deemed to be inadequate, a wet electrostatic precipitator will be used.

6. EQUIPMENT PARAMETERS

Net power: 50 MW
Gross power: 52.4 MW
Power plant annual operating time at full load (capacity factor): 86%
Net electricity generated per year: 376,000,000 kWh
Gross electricity generated per year: 395,000,000 kWh

Steam generation: 325,000 lb/hr
Stack gas flow rate: 103,000 scfm
Net power plant heat rate: 10,200 Btu/kWh
Fuel consumed per year: 220,000 dry tons
Ash collected per year and applied to fields as pellets: 2200 dry tons
Ash pellets per acre per five year cycle applied to fields: 440 lb/acre

7. ENVIRONMENTAL IMPACT

The energy crops provide vegetative cover throughout the year, reducing soil erosion and improving wildlife cover, compared annual row crops. Much lowered applications of agricultural chemicals and reduced tillage benefit water quality. Conversion of agricultural land from row crops to woody crops improves soil structure, organic matter content, and water quality. Woody crops develop an extensive root structure that adds organic matter to the soil, slows wind and water erosion, and helps to reduce soil compaction. Soil nitrogen and inorganic nutrients are maintained by means of a controlled combination of fertilizer, leaf litter, and fly ash pellets from the power plant. In regions with high levels of nitrate pollution in the ground water, planting hybrid poplar trees has been shown to reduce the nitrate levels by a factor of ten or more when the water table is 5 ft or less below the surface (10).

Woody crop cover in agricultural areas benefits a wide variety of birds, small mammals, and deer. Woody crops provide edge effects and corridors with native habitats thereby improving wildlife diversity. Plots averaging about 80 acres are envisioned so that landscape diversity is preserved.

The Whole Tree Energy™ power plant is clean burning, and will meet all Federal and State of Wisconsin emission standards. The power plant is carbon dioxide neutral since the carbon emitted by the power plant is balanced by the carbon sequestered by the trees and roots.

8. PROJECT DEVELOPMENT

The first Whole Tree Energy power plant is under development by EPS/Beck Power, which is a limited liability corporation formed by Energy Performance Systems, Inc. (EPS) and R. W. Beck, Inc. EPS develops and holds patents on the WTE™ bioenergy technology, and R. W. Beck is an engineering consulting company. A similar arrangement may be established for a power plant in Wisconsin. A LLC limits the liability and allows standard tax treatment for the owners. A long-term power purchase agreement would be negotiated with a utility in the area. Individual long-term (15 yr) leases of land for the tree farms would be negotiated with landowners within 50 miles of the power plant site.

Once a power purchase agreement from an electric utility and regulatory approvals from the Wisconsin Public Service Commission are obtained, financing is obtained by a combination of private equity and debt arrangements. Also, use of the Federal alternative energy tax credit of 1.5-2 cents per kWh is important.

9. PROJECT ECOMOMICS

Project costs consist of fuel costs, capital equipment and construction costs, fees, operations and maintenance, and financing costs. Farmland rent for tree acreage is assumed to be $70/acre/year. The estimated cost to establish and tend the trees is $310/acre for the first year, $220/acre for the second year; each year thereafter is $100/acre. Harvesting and transporting the trees to the power plant site at the end of the fifth growing season is $163/acre. For a new power plant one-fifth of the acreage is planted in each of the first five years; then the trees are cut in five year periods. The cost of the fuel, excluding establishment, but including rent, tending, harvesting and transportation is $1.38/million Btu based on year 2000 costs.

The amount of land required depends on the tree yield and the power plant heat rate and capacity factor. The average biomass yield is assumed to be 5 dry ton/acre. The heat rate is the Btu/hr input based on a dry higher heating value of the fuel (8700 Btu/lb) divided by the net kW output of the power plant. A power plant annual capacity factor of 86.3% was assumed. Power plant sizes of 25 MW, 50 MW, and 150 MW were considered.

Table 2. Fuel supply for 20 year period.

Net Power Plant Size* (MW)	Heat Rate (Btu/kWh)	Wood Growth Rate (dry ton/acre/yr)	Total Land (acres)
25	12,000	5	26,000
50	10,500	5	45,500
150	10,000	5	130,000

*Gross size includes 4.8% for auxiliary power and capacity factor of 86.3%

Capital equipment includes fuel handling, storage, drying and feeding systems; steam generator and support systems; turbine-generator and support systems; condensate and feedwater systems; circulating water and treatment systems; electrical and control systems; power plant facility; and power station construction. Engineering, procurement and construction costs on a turn key basis are shown in Table 3 along with additional site costs, fees, and contingencies.

Table 3. Capital costs (year 2000 basis).

Power Plant Size (MW)	EPC Equipment Unit Costs ($/kW)	EPC Equipment Costs ($ million)	Site Costs, Fees, Contingen. ($ million)	Tree Farm Establish. ($ million)	Total Capital Cost ($ million)
25	1840	46	18	21	85
50	1500	75	26	37	138
150	1090	163	52	106	321

To fund the project the assumed financial arrangement is 25% equity and 75% debt. Return on equity is assumed to be 25%, and interest on the debt is assumed to be 8.5%. Hence, the effective interest rate is 12.63%. The annual operating costs are $3.2 million, $3.9 million, and $8.6 million year respectively for the three power plant sizes on a year 2000 basis, excluding the fuel. The property tax rate is 2.1% in Wisconsin. For power plants that are over 50 MW and sell at least 95% to a power company that sells at retail, a gross receipts tax can be paid instead of a property tax, which is 3.19% of the sales revenues and is a significant savings over a property tax. No tax moratorium was assumed. No federal capital contribution was assumed, but a closed-loop biomass tax credit of 1.79 cents/kWh was taken for the year 2000 and escalated at 2.6% per year for 20 years. Year 2000 costs were calculated by discounting the revenues each year using 3.75% discount rate, which was the rate used to escalate operating costs. The 20 year cumulative discounted revenues were divided by the 20 year cumulative value of electricity delivered. The 20 year average of the present value of electricity is shown in Table 4.

Table 4. Average present value of electricity (year 2000).

Net Power Plant Size (MW)	Cost of Electricity ($/kWh)
25	0.064
50	0.049
150	0.036

The benefit of economy of scale is evident in Table 4. Several factors could change the cost of electricity. For example, if the tree farm yield was improved from 5.0 to 6.5 dry ton/acre and the heat rate was improved from 10,500 to 9,800 Btu/kWh for the 50 MW case, then electricity would be 13% cheaper. If the return on equity were 12.5% (as is the case with regulated utilities) instead of a 25% return expected by a private equity holder, then electricity would be 12% cheaper. All of these costs are estimates since the first power plant of this type is yet to be built and operated.

10. COGENERATION OF ELECTRICITY AND PROCESS HEAT

If large users of process heat are located near the power plant site, then the overall energy efficiency can be increased by combining utilization of electricity and heat. Examples of possible process heat users include vegetable cooking, drying, canning, freezing; pulp and paper manufacturing; greenhouses, aquaculture and hydroponics; and space heating for residential and commercial districts. The economic feasibility of modifying the power plant to provide process heat depends on the specific user requirements.

There are several types of heat sources that could be made available to large long-term customers. To obtain the highest electricity generating efficiency the steam turbine is designed for the lowest possible back-pressure of about 1 lb/in.^{2} absolute. The pressure and density of this exhaust steam are too low to transport the steam to an outside user. In the power cycle this low-pressure steam is condensed in a large condensor/heat exchanger that uses external water to cool the steam. The steam and the external water do not mix, and this water exits the powerhouse at about 90°F. Rather than send this water to a cooling tower or cooling pond, this warm water from the condensor could be used for low-grade process heat. If higher heat content is needed, part of the steam can be extracted from the turbine at higher pressure (say 25 psi or 150 psi) for an outside steam user. If users need all of the available steam, the turbine can be designed with less blade stages and a higher exhaust pressure. Both of these latter options reduce the amount of electricity generated but increase the overall energy utilization.

The heat content of steam/water depends on the temperature and pressure as indicated in Table 5. The enthalpy is a measure of the heat content per pound relative to water at 32°F. From the table the difference between the energy extracted from state change a-d is 368 Btu/lb, and from state change a-c is 314 Btu/lb. This represents a loss of 14.7% in electric generation if all of the steam is extracted at 25 psia and a loss of 24% if all the steam is extracted at 150 psia. However, this steam has over 1100 Btu/lb of energy for heating purposes. A suitable price for steam for a large, long-term user, probably in the range of $2 to $4 per 1000 pounds of steam, could make this a win-win situation for energy conservation. Since the total steam flow is 325,000 lb/hr for a 50 MW power plant, additional revenue of up to $5-10 million per year from cogeneration could be used to offset loss in electricity sales and additional capital costs associated with cogeneration. For example, at $0.075/kWh a 14.7% loss in elec tricity costs $4.2 million and a 24% loss costs $6.8 million. Use of low–grade heat from the condensor water or hot air in the drying dome (see section 4.1) could be less costly for some applications. Innovative planning for process heat utilization should be encouraged.

Table 5. Selected steam and water enthalpies.

State	Temperature (°F)	Pressure (psi absolute)	Enthalpy (Btu/lb)
Superheated steam-a	1000	2000	1474
Saturated steam-b	358	150	1194
Saturated steam-c	240	25	1160
Saturated steam-d	102	1	1106
Water	90	14.7	58

11. CURRENT STATUS OF WHOLE TREE ENERGY

Research on poplar tree clones for bioenergy by Oak Ridge National Laboratory and its affiliated Universities, by the US Forest Service-North Central Forest Experiment Station, and by members of U.S. Poplar Council is extensive. As a result of this research, the EPS affiliated nursery near Long Prairie, MN, is currently growing 20 acres with NM-6 hybrid poplar stool trees. Other commercial nurseries are also growing hybrid poplar and willow clones for cuttings.

EPS has patents in 30 countries in North and South America, Western and Eastern Europe, Asia, and Australia covering the Whole Tree Energy technology. A rapid harvesting machine has been designed and is being built and tested under a contract with the U.S. Department of Energy. A machine for harvesting whips (two-year-old trees from which the 10 in. long cuttings are made) is being developed. A prototype machine for rapid planting of the tree cuttings also is beingdeveloped.

The first Whole Tree Energy power plant is under development by EPS/Beck Power, which is a limited liability corporation formed by Energy Performance Systems, Inc. (EPS) and R. W. Beck, Inc. EPS develops and holds patents on the WTE™ bioenergy technology, and R. W. Beck is an engineering consulting company. In August 2000 a power purchase agreement between Northern States Power and ESP/Beck Power for a 50 MW Whole Tree Energy™ power plant was approved by the Minnesota Public Utilities Commission. Startup is scheduled for the mid-2004 at a site near St. Peter, MN. The agreement covers 20 years of operation at a capacity factor of 86.3%. Equity and debt arrangements are being negotiated.

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