Silver Bay
Biomass Binary Power Co-generation

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Silver Bay Biomass Binary Power Co-generation
Table of Contents

Silver Bay Biomass Binary Power Co-generation
Glossary

Binary Power: Also known as Organic Rankine Cycle (ORC), the process of using 2 fluids to transfer heat and generate electricity. The second fluid is a low boiling point organic fluid that is pressurized, heated and vaporized, expanded in a turbine generator and condensed to a liquid to complete a closed cycle.

Co-generation: Sequential generation of thermal (usually steam) and electrical energy. FCP for co-generation electric power electric is between 4000 and 5000 Btu/kWh. Co-generation is also known as Combined Heat and Power (CHP).

Combined Cycle: Usually, the combination of a Combustion Turbine Generator (CTG, Brayton cycle) followed by a Heat Recovery Steam Generator (HRSG) and a Steam Turbine Generator (STG, Rankine cycle). The HRSG uses the 900°CTG exhaust (waste heat) from the CTG to produce steam, which is subsequently used to generate electricity in the STG. Combined cycle plants can have NHR's as low as 7500 Btu/kWh.

Combustion: A heat generating (i.e., exothermic) reaction between a combustible and an oxidant (usually air).

Condensing Power: Electrical generation where the used steam is condensed, giving up a considerable amount of heat to an air or water cooled condenser. FCP for condensing power is between 13,000 and 17,000 Btu/kWh.

District Heating: Supplying multiple building heating systems (and sometimes cooling) from a centralized plant. While very common in Northern Europe, District Heating is not as common in the US. Minnesota examples with co-generation include; Virginia, Hibbing and St. Paul. Duluth has District Heating without co-generation.

Fuel Chargeable to Power (FCP): The incremental fuel for electric power generation. When only electrical power is produced, the FCP is equal to the NHR. US units are usually Btu/kWh.

Gasification: Converting carbon based material into carbon monoxide and hydrogen gases in an oxygen deficient (less than stoichiometric) environment.

Higher Heating Value (HHV): Is the gross amount of heat energy released by a combusted fuel. HHV is commonly used in the U.S. and includes latent energy needed to evaporate water in the fuel.

Silver Bay Biomass Binary Power Co-generation
Glossary (continued)

Lower Heating Value (LHV): Is the net amount of heat energy released by a combusted fuel. LHV is commonly used in Europe and excludes latent energy needed to evaporate water in the fuel.

mmBtu: 1,000,000 British Thermal Units (Btu's). 1 Btu is the energy required to raise 1 lb of water 1 degree. 1mmBtu is equivalent to the energy in 1000 cubic feet of natural gas. There are 9 mmBtu in a ton of wood waste (as received), 135,000 Btu's in a gallon of fuel oil and 91,600 Btu's in a gallon of propane.

Octamethyltrisiloxane (OMTS): The low boiling point, high molecular weight organic fluid used in a closed cycle by Turboden in their biomass fired ORC unit. OMTS is a clear, colorless silicon oil commonly found in suntan lotions and cosmetics

Organic Rankine Cycle (ORC): Using an organic fluid such as iso-pentane, propane, butane, octamethyltrisiloxane (OMTS), etc in a binary power cycle to generate electricity.

Producer Gas: A low Btu (approximately 100 Btu/cu ft) gas made from gasification of various biomass sources, but most commonly wood (also referred to as Wood Gas). Clean-up of tars and soot can add significant cost.

Pyrolysis: Chemical decomposition of organic material in the absence of oxygen. Biomass Pyrolysis can yield Pyrolysis oil, charcoal, and/or combustible gases.

Simple Cycle: Usually referring to a standalone CTG. Simple cycle electrical generation has a NHR of greater that 11,000 Btu/kWh.

Synthetic Gas: Sometimes referred to Synthetic Natural Gas (SNG), higher heating value than produced gas, approximately 300 Btu/cu ft. SNG can be produced from wood through the use of steam rather than oxygen.

Thermal Oil (TO): A synthetic oil especially created for heat transfer applications. Some TO can be used up to 650°F.

Tri-generation: Sequential generation of thermal energy (steam or hot water), electrical energy and chilled water. The waste heat in the biomass fired ORC system using OMTS has enough energy to power an absorption chiller (similar to a propane refrigerator or AC unit). Thus, an ORC unit can be a tri-generation unit as well.

Wood Waste/Refuse: Bark, sawdust, brush, waste chips, dead or diseased wood, etc. In short, wood retrieved from the forest that is not used for lumber, OSB, paper, extractives, pellets, etc.

Silver Bay Biomass Binary Power Co-generation
Introduction and Acknowledgements

LHB was contracted to perform a summary study for the proposed Eco-industrial Park located in Silver Bay, Minnesota in June of 2009. The study's objective was for "Data collection and the generation of a summary of projected environmental benefits and the projected economics (business model) of the renewable energy production system".

LHB's portion was focused on Biomass/Binary Co-generation and biomass fueled district heat and binary power (aka, Organic Rankine Cycle, ORC). This later grew into looking at the synergy of a Pellet Plant with ORC power. Natural gas and electrical usage for the existing AmericInn Lodge and Suites were supplied, and an estimate of the proposed Eco-industrial Park heating load was summarized.

Wood pellet manufacturing and ORC power plants have a unique synergy. Bark, which can't be used in pellet manufacturing due to premium pellet quality ash standards, can be combusted for the ORC system generating more electricity than the pellet plant requires. The waste heat from the ORC dries the pellet feedstock in a low Volatile Organic Carbon (VOC) emission belt dryer. There are 12 pellet plants with Turboden ORC units operating in Europe.

Some of the information in this report is based upon a study performed by the author for the US Forest Service and Iron Range Resources entitled "Using Biomass-Fired Energy Systems to Help Minnesota's Primary Forest Products Industry Reduce Fossil Fuel Consumption and Ensure Long term Viability" as well as similar studies for other clients.

LHB gratefully acknowledges the help of several people including; Project Manager Bruce Carman, City Administrator Lana Fralich, Economic Development Authority President Wade LeBlanc and Bill Mittlefehldt, the NE Minnesota Clean Energy Resource Team Coordinator.

Silver Bay Biomass Binary Power Co-generation
Executive Summary

Silver Bay is developing an Eco-Industrial Park (SBEIP) on land adjacent to Lake Superior for the purpose of economic diversification and showcasing ecological technologies. The system specifically addressed in this study is a biomass binary power co-generation system for a proposed wood pellet manufacturing site and District Heat for the rest of the eco-industrial park.

District Heating (DH), is a prime example of the efficiency of co-generation, also known as Combined Heat and Power (CHP). By bundling individual heating systems together, the economy of scale allows for the sequential production of electricity and heat, increasing fuel efficiency from about 37% in utility sized coal fired electric power plants to about 75% in biomass CHP systems. When using a renewable fuel such as wood, net CO2 emissions are zero. Regionally, District Energy of St. Paul and Laurentian Energy of Virginia and Hibbing burn wood in conventional steam district heat and CHP systems. The major drawback to steam systems is that they require a heat load of about 100 mmBtu per hour to be minimally cost effective.

Italian based Turboden and Austrian based V.A.S., both represented regionally by GPM of Duluth, is now ready to deliver small community sized biomass binary (Organic Rankine Cycle, ORC) systems for process and district heating co-generation in the US. Instead of using steam and generating lukewarm water as waste heat, ORC uses a low boiling point organic fluid to generate electricity and hot water (175°F) as the condensing medium, allowing CHP on a much smaller scale.

A 2500 kilowatt electric (kWe) ORC Pellet Plant Power & District Heating system, firing about 10 tons per hour (85,000 tpy) of biomass is recommended for the SBEIP ORC/pellet plant. Local Forest Service personnel and the National Renewable Energy Laboratory have suggested that there are over 400,000 tons of wood in Northern Minnesota for biomass fuel. We have included a University of Minnesota Pellet Plant Study and the latest DNR Resource Study as an appendix.

Besides the ORC system, the proposed biomass binary power system for SBEIP will consist of a 98 mmBtu/hr Thermal Oil Heater, large enough for the 100,000 tpy pellet plant and about 10 mmBtu of DH and 500 kW of excess electricity. Two (2), 8 or 10 mmBtu/hr fossil fuel back-up hot water heaters are also envisioned. It is estimated that the total ORC system cost, including buried DH piping to the future tenants of the SBEIP, will be about $15 million.

Silver Bay Biomass Binary Power Co-generation
Executive Summary (continued)

The pellet plant will cost approximately $15 million as well. At a $150 per ton average selling price and a $110 per ton manufacturing cost (raw materials, supplies and Operating and Maintenance , O&M), the 100,000 tpy plant will generate about $4,000,000 in pre-tax net income. The renewable electricity generated has an estimated value of $650,000 per year and the biomass District Heat has an estimated savings of $200,000 when compared to natural gas. The total revenue and savings from the plant is estimated at about $4,850,000 per year.

Approximately forty (40) construction jobs, fifteen (15) permanent pellet plant operating (included in the O&M costs) and 6 logging jobs could be created.

Emissions would be very low with this system. The Thermal Oil Heater has flue gas recirculation for Oxides of Nitrogen (NOx) control, Overfire Air for Carbon Monoxide (CO) control and an Electrostatic Precipitator (ESP) for Particulate Matter (PM) control. Complete system emissions at Maximum Potential to Emit (24/7 365 days per year at permitted rates) will be less than 235 tpy.

At full park build-out and full pellet production, approximately 150,000 tpy of CO_2 will be displaced. This is roughly equivalent to taking nearly 75,000 cars off the road. Local forest management and wildfire prevention will be enhanced and there is abundant wood available.

There is a growing consensus that our carbon based economy has to evolve to renewables. With limited solar and an obvious abundance of heating demand and wood, it appears that wood-based pellets is an excellent economic diversification opportunity and ORC district energy is a practical and cost effective heating alternative for the SBEIP.

Alternative biomass technologies, i.e., pyrolysis and gasification, have some distinct disadvantages, specifically the need to dry feedstock first and either handling the pyrolysis oil (said to be worse than No. 6 Fuel Oil) or clean the producer (synthetic) gas of tars and ash.

Silver Bay Biomass Binary Power Co-generation
Findings

Silver Bay is located 55 miles up the north shore of Lake Superior from Duluth and adjacent to the Superior National Forest. The town was built to accommodate employees of Northshore Mining, currently owned by Cliffs Natural Resources (CNR). Cliffs is a good employer, unfortunately the plant's reliance on natural gas for pellet manufacturing and the cyclic nature of iron ore makes the community vulnerable to economic hardship when the plant is idled.

Silver Bay is looking at economic diversification through the development of an Eco-Industrial Park (SBEIP). The park's only current business, the AmericInn Lodge and Suites current uses about 80 kW of electricity and about 0.6 mmBtu/hr of natural gas for heat at a cost of about $50,000 and $22,000 per year respectively. Associated current Carbon Dioxide (CO2) emissions are about 900 tons per year (tpy).

District Heat, also known as centralized heating, is a time tested heating method, tracing its roots back to Roman bath houses. The US Naval Academy at Annapolis began a steam district heating system service in 1853 (Wikipedia, "District Heating"). Europe has been aggressively promoting and installing district heating systems since the early 1950's. Here in the US, historical low cost fossil fuels and resistance to co-generation by regulated public utilities has slowed adoption of district heating.

Instead of having multiple heating units serving individual buildings, a centralized district heating plant supplying steam or hot water through a network of pipes can realize higher thermal efficiencies and reduced fuel costs while facilitating the co-generation of electricity by combining loads, allowing the economy of scale to make turbine generators financially attractive. Co-generation electricity is about 75% fuel efficient compared to about 37% fuel efficiency from utility generated condensing power where heat is wasted through cooling towers or discharged into rivers or lakes.

In the US, district heat has been predominantly from fossil fuels, and many older systems lack co-generation. Some of the growing interest in district heat is a result of the efforts of the International District Energy Association (IDEA) and some of the renewed interest in co-generation is due in large part to the US EPA Combined Heat and Power (CHP) Partnership. Whatever the source, district heat and co-generation is an efficient use of fuel.

Silver Bay Biomass Binary Power Co-generation
Findings (continued)

While there are some regional examples of conventional district heat and co-generation fired with wood based biomass (St. Paul District Energy consumes about 50 ton/hour, Laurentian Energy of Virginia and Hibbing consumes 36 tph), smaller communities and institutions have not had the opportunity to utilize the locally abundant wood resource as a fuel for district heating and co-generation.

Brescia, Italy based Turboden and Groβgmain, Austria based V.A.S., both represented regionally by GPM of Duluth, are now ready to deliver their biomass binary (Organic Rankine Cycle, ORC) systems for district heating co-generation in the US. In ORC biomass applications, heat is transferred in the efficient and low emission V.A.S. "Dutch Oven" style combustor to thermal oil followed by the thermal oil heat being transferred to a compressed, low boiling point, high molecular weight organic fluid, e.g., pentane, propane, octamethyltrisiloxane (OMTS, commonly found in cosmetics, suntan lotion and deodorants).

The heated organic fluid expands through a turbine producing electricity and is condensed. Turbo expander condenser heat is rejected to either air or water systems. Water systems can be used to generate hot water for building or process heating. Turboden's standard units range from 300 to 2500 kWe (kilo watt electrical) with other custom sizes available. Based on Higher Heating Value (HHV), fuel to electricity conversion ratio is about 14.5%. When used in a co-generation application, about 60.5% of the fuel is converted to relatively high grade (175°F) district heating water, suitable for building heating, Domestic Hot Water (DHW) service or absorption chilling for air conditioning. During the summer, condensing power and a lower return water temperature can increase the electric conversion ratio to over 16.5%.

A biomass ORC system also fits extremely well with wood pellet manufacturing. The ORC unit supplies hot water for drying the chipped pellet feedstock while generating a net excess of about 500 kW of electricity. About 10 mmBtu/hr of District Heat could be available for the rest of the SBEIP, allowing for multiple process energy businesses as well as condominiums, apartments, etc.

It might be possible to develop a relationship with an electric utility that has interest in using the ORC plant to meet their Renewable Portfolio Standard. It would be possible to purchase coal based electricity while allowing the entire generation of the ORC to be sold as a renewable.

Silver Bay Biomass Binary Power Co-generation
Findings (continued)

Environmental Benefits:

Environmental benefits, specifically CO2 emission reductions associated with the proposed pellet plant ORC system may be categorized as either SBEIP ORC displaced electricity and fossil fuel or fossil fuel displaced by pellets.

Electricity displaced by system could range from a low of 500 kW, the excess generated by the ORC plant, on up to 2.5 MW, the total plant output. The high side estimate assumes that a pellet plant and individual heating plants (using parasitic energy equivalent to the ORC) are built and uses conventional coal based electricity. With an average of 1.1. ton of CO2 per coal based MWh and 8300 operating hours, a minimum of 4150 and a maximum of 20,750 tpy of CO2 will be displaced.

Assuming natural gas heating for the fully built SBEIP of about 24,000 mmBtu at about 83% unit efficiency yields a projected natural gas use of 29,000 mmBtu/yr. At 117 lbs/mmBtu for natural gas, wood based DH would save displaced about 1700 tpy of CO2. Total CO2 from the SBEIP ORC is then as much as 22,450 tpy.

100,000 tpy of wood pellets at 17 mmBtu/ton displacing a 50/50 mix of propane (139 lbs/mmBtu) and fuel oil (161 lbs/mmBtu) yields a total of 127,500 tpy of CO2 displaced. This can be higher if coal based electricity for heating is displaced. Total CO2 displaced by the project could approach 150,000 tpy.

Emissions: Relevant emissions can be categorized as Criteria pollutants (NOx, CO, Particulate, VOC, etc.) and CO2 . We estimated criteria pollutants using the TO heater manufacturer's guarantee's and a conservative "guesstimate" of belt dryer VOC emissions.

	Heat Source mmBtu/hr	PM	PM10	SO2	N0x	CO	VOC	Total Criteria
VAS Rates (lbs/mmBtu)		0.040	0.030	0.025	0.200	0.080	0.200	
T O Heater (mmBtu/hr)	98	17.17	12.88	10.73	85.85	34.34	85.85	233.93

With the belt dryer, the emissions stay below the 250 tpy major source threshold. As a frame of reference, MN Power's Taconite Harbor had over 10,000 tons and Northshore Mining had over 8700 tons of actual emissions in 2006 (the most current year on the MPCA's website).

Environmental Benefits (continued):

The major environmental impact comes from the 150,000 tpy decrease in CO_2 emissions, however there is also a decrease in emissions from wood stoves, open air combustion of wood waste and wild fires and it should be noted that pellet stoves are estimated by the EPA to emit less than 10% the emissions of cord wood.

Projected Economics: Please see attached spreadsheets in appendix.

The pellet plant detailed economics are beyond the scope of this effort, but the attached report and previous efforts in this regard suggest that the total project (pellet plant and 2.5 MW ORC) cost will be about $30,000,000.

With ORC cogeneration, it is expected that pellet production cost will be about $110/ton. At an average selling price of $150/ton and 100,000 tpy production rate, pre-tax net income should be about $4,000,000 per year.

Using the Department of Energy (DOE) Energy Information Agency's (EIA) latest annual outlook estimate of commercial electricity at $0.108 per kWh (adjusted by $0.015/kWh for Cap and Trade), the excess 500 kW of electricity and the renewable attribute of the 1600 kW of electricity in the pellet plant could generate about $650,000 in revenue, net of fuel and O&M costs attributable to the ORC plant.

The DOE EIA predicts 2010 commercial natural gas to cost $10.55 per mmBtu. Considering fuel and O&M attributable to District Heat, the net savings is estimated at $200,000 per year.

Total Revenue and Savings is estimated at $4,850,000 per year.

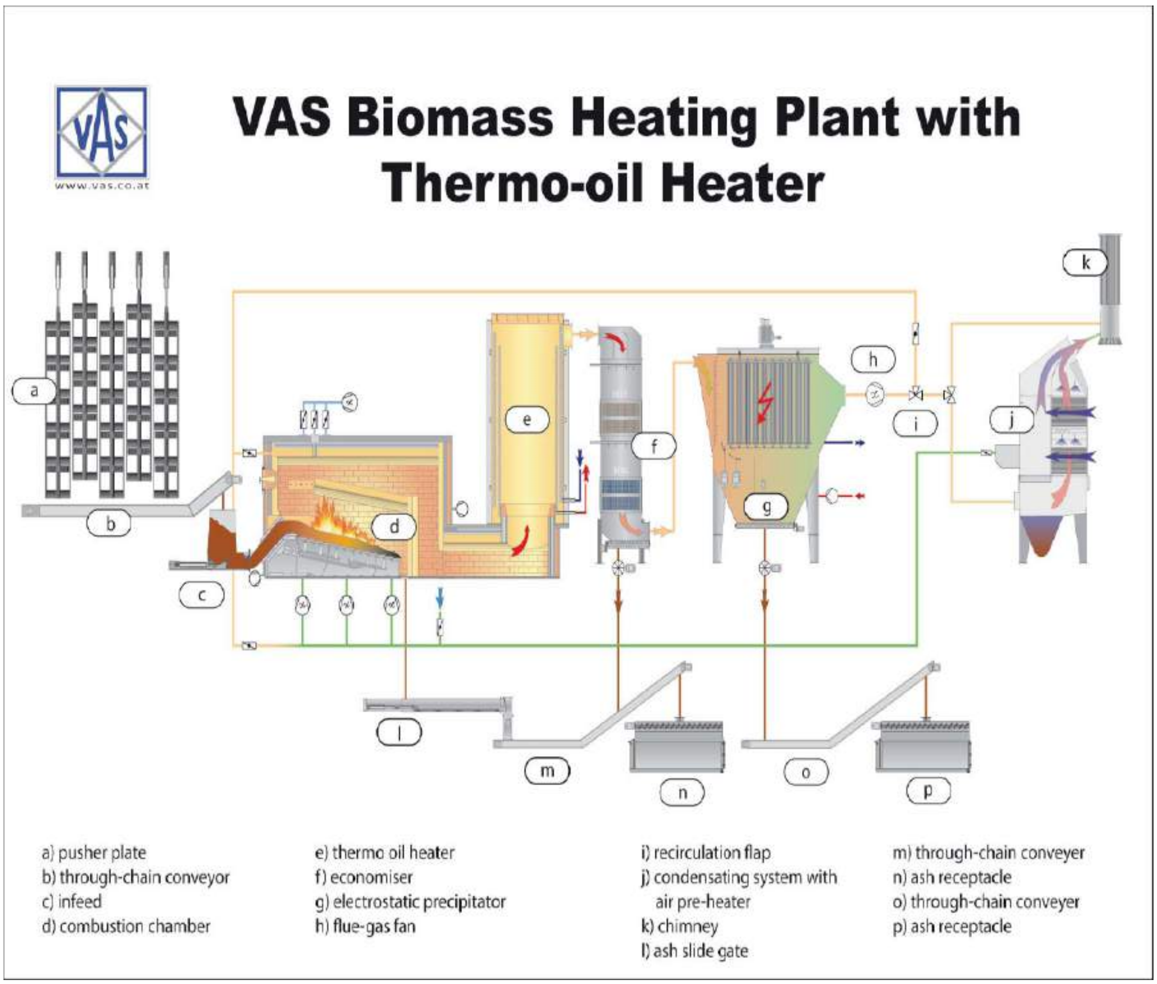
Non-CHP heat for pellet drying is included in the detailed pellet economics. It should be noted that full electrical production from the ORC during the non-heating months can be achieved by sending more ORC cooling water to the belt dryer and less non-CHP heat.

Silver Bay Biomass Binary Power Co-generation
Findings (continued)

Process Description:

Forest chipped wood refuse (also known as "hogged" fuel), in the form of tops and branches (logging slash), brush, whole tree chipping (chipped at the point of collection), etc. will be trucked to the plant in tractor trailers, either self unloading (slat-type walking floor or side dumping) tractor trailers or through a truck dump. Trailers average about 24 tons per load.

Please refer to the V.A.S. schematic below (a larger version is included on p. 18). Trucks may be unloaded directly into a storage bin (a) or on a concrete slab for later feeding by a front end loader.



Silver Bay Biomass Binary Power Co-generation
Findings:

Process Description (continued)

The storage bin will have a hydraulically driven pusher plate (wedge)-type walking floor that continuously delivers fuel to a through (drag) chain conveyor (b) that supplies fuel to the infeed bin (c) and conveyor. The infeed conveyor, also hydraulically driven pusher type and driven by the centralized hydraulic system, pushes the fuel up through a widening plenum and onto the grate and the rear of the refractory lined combustion chamber.

Pre-heated under grate (primary) combustion air is provided by separate fans supplying different grate zones. Flue Gas Recirculation (FGR) is provided to minimize the generation of Nitrogen Oxides (NOx). A single secondary air fan supplies a mixture of ambient air and FGR through multiple high pressure nozzles designed for maximum turbulence, allowing for complete combustion and low Carbon Monoxide (CO) emissions. Grate and bottom ash is collected and discharged through a slide gate (l) to a series of drag (through) chain conveyors (m) for collection and storage in a steel ash dumpster (n).

Hot (>1900°F) combustion gases travel to the Thermal Oil (TO) heater (e), which is removed from the radiation zone of the combustion chamber. By not having radiation heat transfer and fluid temperatures lower than conventional Rankine (steam) boilers, tube corrosion and fouling is reduced, allowing for the use of air sootblowers and sonic horns to maintain the cleanliness of convection heat transfer surfaces.

The TO travels around the perimeter of the heater within concentric loops of tangent tubes, heated by the flue gas traveling on the outside of the tubes. Flow of the TO and flue gas is counter-current to increase thermal efficiency. Flue gas temperature is about 750°F as it exits the TO heater and enters the economizer section (f).

In the economizer, TO is preheated in 2 stages. The lower temperature TO economizer stage is typically used to pre-heat primary (under-grate) air. The higher temperature economizer preheats all the TO entering the TO heater. Fly ash from the economizer hopper is usually discharged into the bottom ash storage bin.

Particulate emissions may be controlled by either a multi-clone dust collector or an electrostatic precipitator (ESP, g) or a series of both (the scope for the Grand Marais project includes both the multi-clone and ESP). Occasionally, European installations include a direct contact scrubber (j) after the ESP for very low grade heat collection followed by a system for warming the flue gas above the dewpoint to prevent the scrubber caused condensed flue gas from being visible. ESP fly ash is discharged to a drag chain (o) and into another steel ash receptacle (p).

Silver Bay Biomass Binary Power Co-generation

Findings:

Process Description (continued)

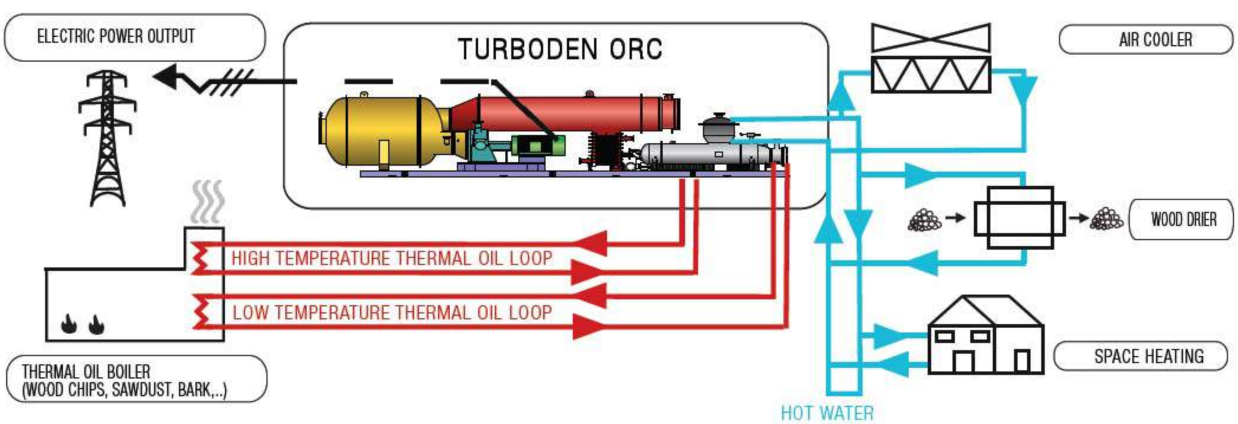
Referring to the schematic below, the V.A.S. Thermal Oil Heater (the TO does not boil so it is inappropriate to call it a "boiler"), raises the TO temperature from 500° to about 630°F. The hot TO evaporates and then preheats the pressurized (to 150 psig) Octamethyltrisiloxane (OMTS, silicone oil organic fluid) in the evaporator, colored gray in the schematic.

Vaporized OMTS travels through welded and flanged high pressure piping to the turbine (small green unit next to the gold colored regenerator. Each OMTS flange is air swept and connected to a leak detection system that automatically shuts down the unit in the rare event of a leak.

The OMTS spins the turbine which is coupled to an asynchronous generator. Asynchronous generators have no brushes to maintain, but must be connected to the grid for frequency control. The pressure and temperature of the OMTS decreases as potential energy is transferred to kinetic energy in the turbine.

The OMTS exhausted from the turbine is further cooled as it preheats liquid OMTS on its way to the evaporator. The red shell and tube condenser cools the OMTS under a vacuum to the condensing point while transferring the heat of condensation to pellet drying and district heat water at about 175°F.

The liquid OMTS is pumped back up to the 150 psig operating pressure and returned to the evaporator, completing the closed system cycle.



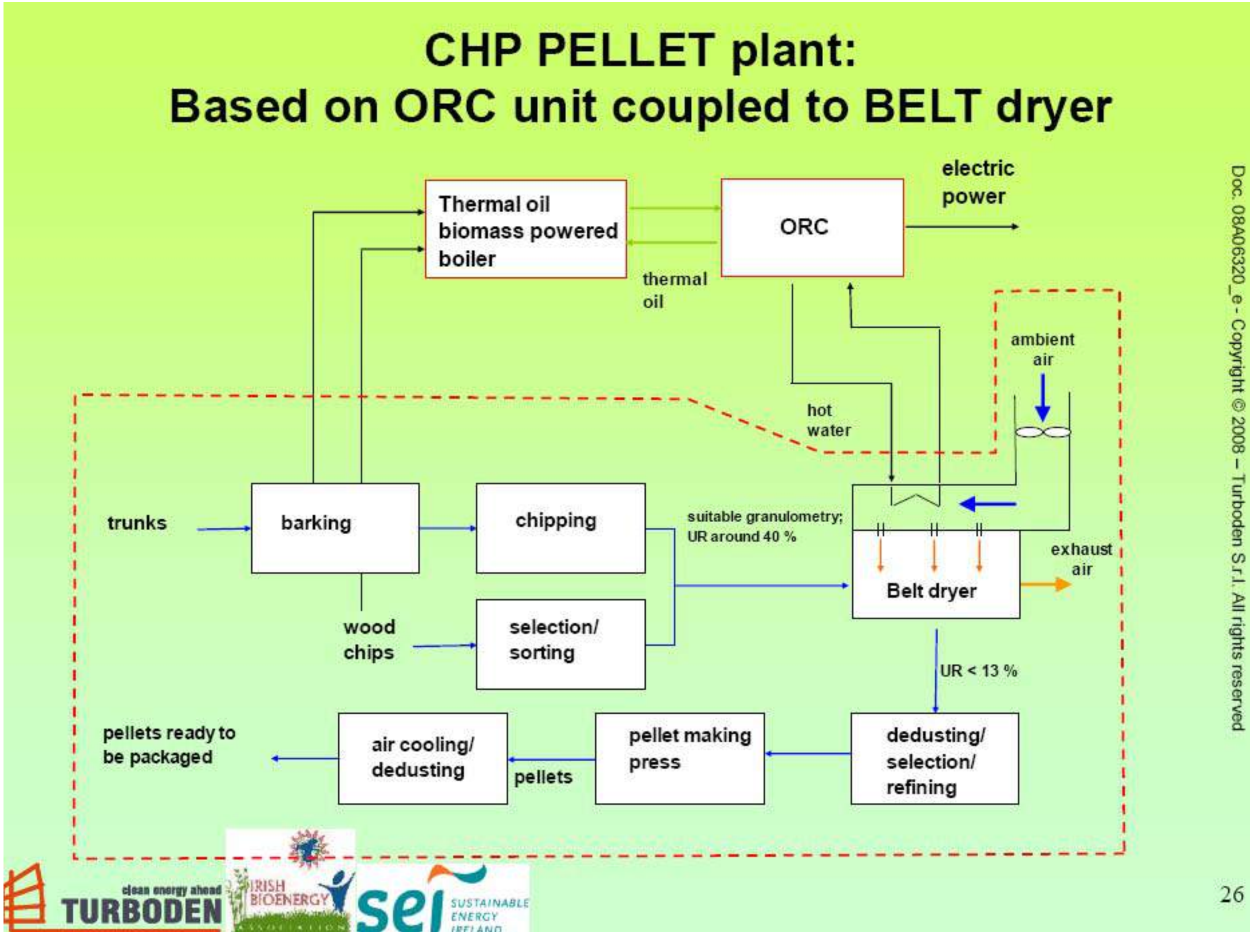
As both the TO and OMTS are closed systems, Minnesota does not require a boiler/turbine operator license and the units are operated unattended, with the exception of a weekday fuel attendant.

Silver Bay Biomass Binary Power Co-generation

Findings:

Process Description (continued)

For the pellet plant, the 175°F water is supplied to air heating coils within the belt dryer. Using a lower temperature drying process than conventional rotary dryers decreases the VOC emissions by more than 50%.



While the majority of Turboden's 100 units in operation are associated with District Heat, there are 12 in operation at pellet plants. We do not know if some of the pellet plant applications also supply district heat.

Silver Bay Biomass Binary Power Co-generation
Findings (continued)

Specifications:

Hogged Fuel: 1.5” minus (<1.5”) chips, bark, sawdust, shavings, etc.

Thermal Oil Heater: VAS, 98 mmBtu, complete with:

- Firing system including fuel infeed
- Ash conveyors and disposal equipment
- Multi-clone dust collector
- Electrostatic Precipitator
- Thermal piping
- Transportation and assembly at site
- Insulation
- Cables and labeling
- Mobile crane and assembly platforms

ORC Unit: 2500 kW Turboden, complete with:

- Skid mounted turbine, generator, evaporator, condenser, controls and piping

2, Fossil Fuel (Nat Gas) Back-up Hot Water Heaters: Hurst (or equivalent) 250 Boiler HP

Silver Bay Biomass Binary Power Co-generation
Findings (continued)

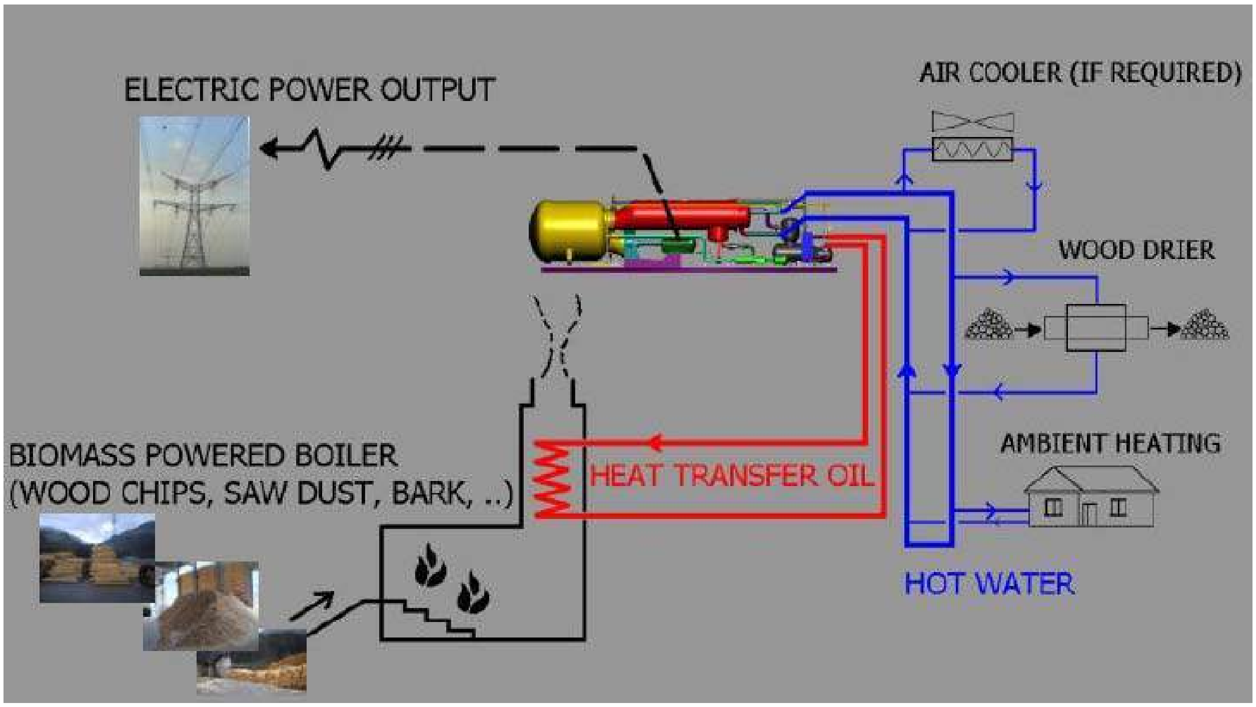
Opinion of Cost

Estimated opinion of cost is as follows:

Turboden ORC unit	$3,100,000
Thermal Oil Heater	$6,000,000
Fossil Fuel Hot Water Boilers	$200,000
Mechanical & Electrical, DH Piping	$3,000,000
10,000 sf Bldg Construction, Including Civil & Structural	$1,400,000
Engineering & Other Soft Costs	$1,300,000
Total	**$15,000,000**

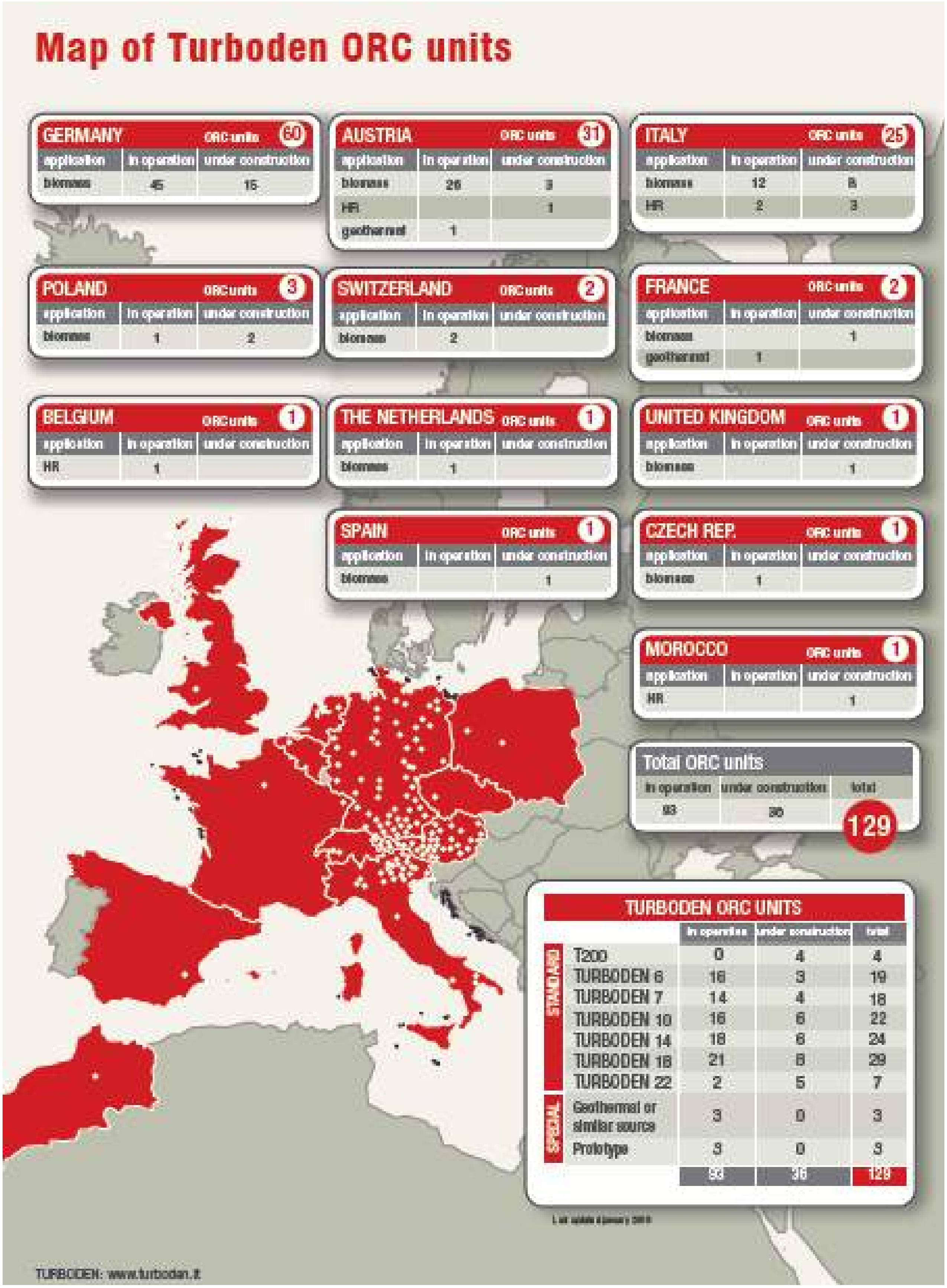
APPENDIX:

Turboden Schematic



Turboden ORC Skid

Map of Turboden ORC units



GERMANY	ORC units	60
application	in operation	under construction
biomass	45	15

AUSTRIA	ORC units	31
application	in operation	under construction
biomass	26	3
HR		1
geothermal	1	

ITALY	ORC units	25
application	in operation	under construction
biomass	12	8
HR	2	3

POLAND	ORC units	3
application	in operation	under construction
biomass	1	2

SWITZERLAND	ORC units	2
application	in operation	under construction
biomass	2	

FRANCE	ORC units	2
application	in operation	under construction
biomass		1
geothermal	1	

BELGIUM	ORC units	1
application	in operation	under construction
HR	1	

THE NETHERLANDS	ORC units	1
application	in operation	under construction
biomass	1	

UNITED KINGDOM	ORC units	1
application	in operation	under construction
biomass		1

SPAIN	ORC units	1
application	in operation	under construction
biomass		1

CZECH REP.	ORC units	1
application	in operation	under construction
biomass	1	

MOROCCO	ORC units	1
application	in operation	under construction
HR		1

Total ORC units		
in operation	under construction	total
93	36	129

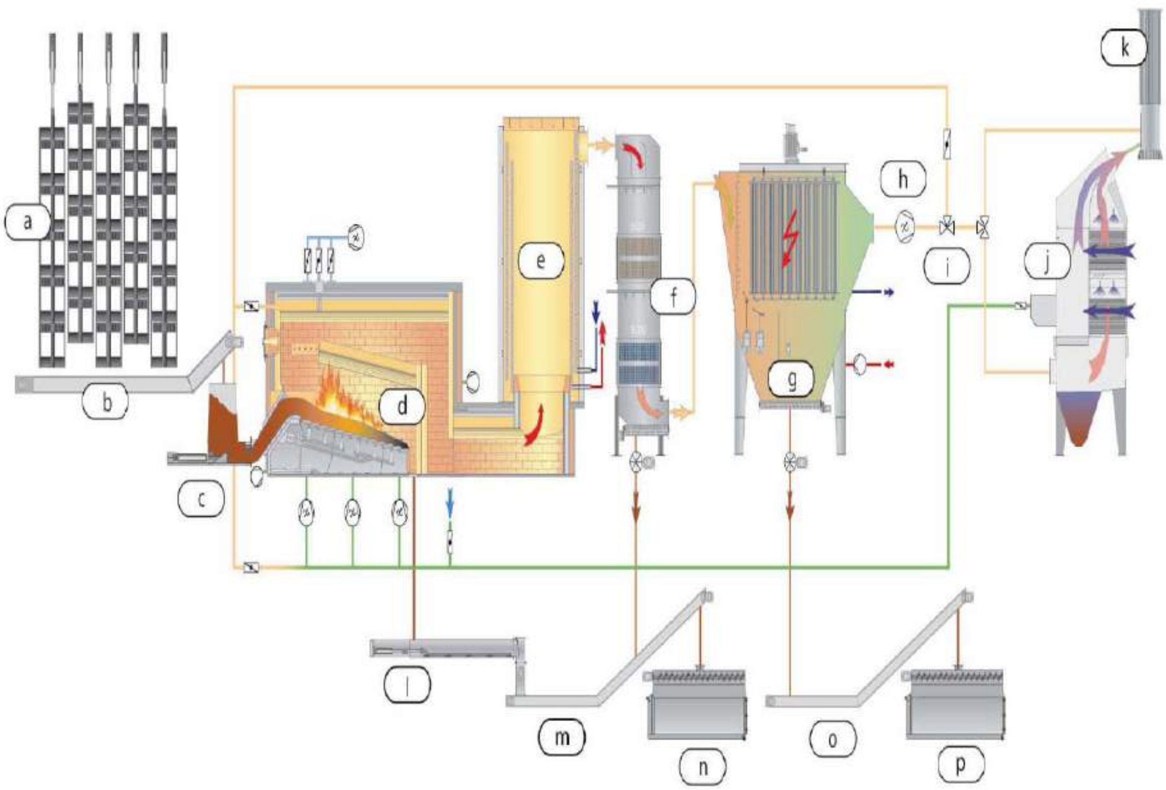
TURBODEN ORC UNITS

		in operation	under construction	total
STANDARD	T200	0	4	4
	TURBODEN 6	16	3	19
	TURBODEN 7	14	4	18
	TURBODEN 10	16	6	22
	TURBODEN 14	18	6	24
	TURBODEN 18	21	8	29
	TURBODEN 22	2	5	7
SPECIAL	Geothermal or similar source	3	0	3
	Prototype	3	0	3
		93	36	129

TURBODEN: www.turboden.it

www.vas.co.at

VAS Biomass Heating Plant with Thermo-oil Heater



a) pusher plate
b) through-chain conveyor
c) infeed
d) combustion chamber
e) thermo oil heater
f) economiser
g) electrostatic precipitator
h) flue-gas fan
i) recirculation flap
j) condensating system with air pre-heater
k) chimney
l) ash slide gate
m) through-chain conveyer
n) ash receptacle
o) through-chain conveyer
p) ash receptacle

District Heating Plant in Tyrol, Austria

District Heating Plant in Varna, Italy

SBEIP Pellet Plant/ORC Emissions & DOE EIA Projection

	Heat Source mmBtu/hr	PM	PM10	SO2	NOx	CO	VOC	Total Criteria		
VAS Rates (lbs/mmBtu)		0.040	0.030	0.025	0.200	0.080	0.200		75.0%	PM10/PM
Thermal Oil Htr (mmBtu/hr)	98	17.17	12.88	10.73	85.85	34.34	85.85	233.9		
Turboden Co-gen (MW)	2.50								0.145	Fuel to Elec Conversion
Belt Dryer (mmBtu/hr)	55.00								0.605	Fuel to Heat Conversion

Price Case Comparisons

Table C3. Energy Prices by Sector and Source
(2007 Dollars per Million Btu, Unless Otherwise Noted)

Sector and Source	2007	Projections 2010 Low Oil Price	2010 Reference	2010 High Oil Price	2020 Low Oil Price	2020 Reference	2020 High Oil Price	2030 Low Oil Price	2030 Reference	2030 High Oil Price
Residential										
Liquefied Petroleum Gases	24.98	21.82	25.86	27.93	20.47	32.88	47.65	20.53	35.11	50.76
Distillate Fuel Oil	19.66	15.29	18.69	20.69	13.48	24.10	36.51	13.39	26.67	39.19
Natural Gas	12.69	11.53	12.09	12.33	11.93	12.50	12.91	13.85	14.31	14.61
Electricity	31.19	30.40	30.89	31.14	31.68	32.72	33.78	34.81	35.84	36.49
Commercial										
Liquefied Petroleum Gases	23.04	18.65	22.69	24.75	17.25	29.60	44.35	17.27	31.77	47.40
Distillate Fuel Oil	16.05	12.74	16.15	18.14	11.59	22.11	34.23	11.67	24.69	36.99
Residual Fuel Oil	10.21	7.04	10.97	12.82	5.86	16.68	27.02	5.99	17.98	29.99
Natural Gas	10.99	9.99	10.55	10.78	10.57	11.13	11.53	12.46	12.96	13.24
Electricity	28.07	26.81	27.29	27.53	26.92	28.15	29.30	29.99	31.01	31.70

2010 Commercial Nat Gas	$10.55	per mmBtu
2010 Commercial Elec	$27.29	per mmBtu
Btu/kW	3413	
per kW	$0.093	
Cap & Trade Estimate	$0.02	per EPA
per kW	$0.108	

SBEIP Heating Calculations

1	**ORC**		**Comment**
2	Thermal Oil Heater Efficiency	0.75	2 economizers
3	Generation (kW)	2500	T22 capacity
4	Elec. Conversion (mmBtu/hr)	3413	Constant
5	Elec. Conversion (Btu/kW)	8.53	Line 3 x Line 4 divided by 1,000,000
6	ORC Elec Conv. Factor	0.145	Net electricity from fuel
7	ORC Fuel (mmBtu/hr)	58.8	Line 5 divided by Line 7
8	ORC Heat Conv. Factor	0.605	Net heat from fuel
9	ORC Heat (mmBtu/hr)	35.60	Line 7 x Line 8
10	District Heat (mmBtu/hr)	10.00	Iteration for <100 mmBtu Combustion Source
11	Process Heat for Belt Dryer	25.60	Line 9 minus Line 10
12			
13	**Belt Dryer**		
14	Belt Dryer Heat Req'd (mmBtu/hr)	55.00	Per Clean Energy by Design
15	Less Process Heat from ORC (mmBtu/hr)	25.60	Line 11
16	Additional Heat from TO (mmBtu/hr)	29.40	Line 14 minus Line 15
17	Additional Fuel for TO (mmBtu/hr)	39.20	Line 16 divided by TO Eff (Line 2)
18			
19	**TO Heater**		
20	Full Rating for TO Heater (mmBtu/hr)	98.0	Line 7 plus Line 17
21			
22	**District Heat**		
23	District Heat Peak (mmBtu/hr)	10.00	Line 10, conservative
24	Annualized Max (mmBtu/hr)	83000	
25	Heating Season Average (mmBtu/hr)	4.75	
26	Non Heating Season Ave (mmBtu/hr)	1.00	
27	Annualized Actual (mmBtu/yr)	24030	175 days x 24 hours/day
28	District Heating Load Factor	0.29	
29	AmericInn (mmBtu/yr)	3500	Increased from provided for higher load
30	Process Heat Business (mmBtu/yr)	5000	Estimate
31	Process Heat Business (mmBtu/yr)	5000	Estimate
32	Eco Park Condominiums (mmBtu/yr)	3500	Estimate
33	10 Misc. Shops, Restaurants (mmBtu/yr)	2500	Estimate
34	Future Community Center (mmBtu/yr)	2500	Estimate
35	Possible Greenhouse, etc. (mmBtu/yr)	2000	Estimate
36	Remainder	30	
37			
38	TO Heater ORC Load (mmBtu/hr)	11.4	12.9%
39	TO Heater DH Load (mmBtu/hr)	3.2	3.6%
40	TO Heater Belt Dryer Load (mmBtu/hr)	73.3	83.4%
		87.9	
	TO Heater O& M	$275,000	
	ORC O&M	$125,000	

SBEIP Pellet & ORC Economics

		Comments
Pellet Plant		
Ave Selling Price per ton	$150	
Ave Production Cost per ton	$110	
Gross Margin per ton	$40	
Annual Production (tpy)	100,000	
Pre-tax Net	**$4,000,000**	
ORC Unit -Electricity		
Gross Elec Generation (kW)	2500	
ORC Elec Conv. Factor	0.145	Net electricity from fuel
Thermal Oil (TO) Heater Efficiency	0.75	
Elec. Conversion (mmBtu/hr)	3413	Constant
TO Heater Fuel for Elec (tph)	1.3	
Parasitic Load (kW)	400	Estimate
Net Elec Generation (kW)	2100	
Pellet Plant Load (kW)	1600	Per Clean Energy by Design
Net Excess Elec (kW)	500	
Operating Hours	8300	
Net Annual Gen (kWh)	17430000	Gross minus parasitic
Renewable Power ($/kWh)	$0.11	DOE EIA plus $0.015 for Cap & Trade per EPA
Gross Value	$1,884,894	Assumes all but parasitic sold as Renewable
Fuel Btu Value (mmBtu per ton)	9.0	
Fuel Cost (per ton)	$25	
Less Fuel	$262,295	
Less O&M	$160,587	
Net on Net ORC Generation	$1,462,011	
Pellet Plant "Brown" Power Rate	$0.06	
Pellet Plant Brown Power Cost	$796,800	
Net After Pellet Plant	**$665,211**	
ORC Unit - Heating		
Annual Htg Load (mmBtu/yr)	24030	
Fossil Fuel Unit Eff	0.83	
Nat Gas use (mmBtu/yr)	28952	
DOE EIA 2010 Nat Gas ($/mmBtu)	$10.55	
NG Equiv	$305,442	
ORC Hot Water Conv Factor	0.605	
Wood Waste attributable to DH (tpy)	3,560	
Wood Waste attributable to DH	$89,000	
Heating O&M	$10,020	
Net DH Savings	**$206,421**	
Total Pre-tax Rev/Savings per yr	**$4,871,633**	

Charles E. Hartley, PE, CEM, GBE™, CDT Director of Energy Management Services

Registrations
• Licensed Engineer in Minnesota and Nevada
• Licensed Chief Grade A Steam Engineer in Minnesota

Certifications
• CEM®
• GBE™
• Vocational Instructor

Education
• U.S. Navy Nuclear Power Program, Submarine Service
• Bachelor of Science in Mechanical Engineering, University of Minnesota

Affiliations
• Association of Energy Engineers (AEE)
• Black Liquor Recovery Boiler Advisory Committee

Presentations/Publications
• "Widening the Operating Envelope of Recovery Boilers by Using High Dry Solids Firing," Technical Association of Pulp & Paper Industries (TAPPI) Conference
• "Energy Savings Opportunities in the Taconite Industry," *Skillings Mining Review*
• "Analysis and Applications of Waste Heat Recovery and Binary Cycle Electric Generation in Commercial and Industrial Facilities," Minnesota Power

- "Using Biomass Fired Energy Systems to Help Minnesota's Primary Forest Products Industry", USFS and Iron Range Resources

Chuck's professional background includes working as a U.S. Navy Nuclear Plant Operator, Pulp & Paper Utilities Maintenance Coordinator and Department Manager, and Forest Products Corporate Energy and Environmental Engineering Manager. He has more than 25 years of energy operations, maintenance and engineering experience, including scoping, owner engineering, training and commissioning of boilers and co-generation systems utilizing a wide variety of fossil, biomass and waste fuels.

Chuck is a recognized leader in the fields of biomass energy, waste heat recovery and power generation, researching and publishing detailed reports on the subjects. He has performed numerous biomass and waste heat engineering studies on a variety of streams and heat transfer mediums, including steam and hot/warm water, as well as thermal oil and low boiling point organics.

Chuck is a licensed Professional Engineer, a Certified Energy Manager® (CEM), a Green Building Engineer™ (GBE), and holds a Minnesota Chief A Steam Boiler/Turbine operator license. While he was the president of his own energy management firm, Chuck developed the unique Energy Confidence Process™. This process identifies and develops energy savings and co-generation optimization measures for clients that could total 20% or more.

A senior member of the Association of Energy Engineers, Chuck also has significant experience in environmental permitting, serving as an energy trainer for plant operators and negotiating energy and alternative financing contracts.

Project Experience

- Several Municipal and Confidential Client Biomass Binary (Organic Rankine Cycle) Studies
- US Forest Service Biomass Fired Energy Systems Studies
- Empire Mine Waste Heat to Medium Temperature Hot Water Study
- United Taconite Waste Heat to Thermal Oil and Binary Electric Power Feasibility Study
- Northshore Mine Waste Heat to Low Pressure Boiler Study
- US Steel Waste Heat Recovery Pre-feasibility Study
- Utility Biomass and Renewable Portfolio Strategic Planning
- Minnesota Power Waste Heat Recovery Research Project; Duluth, Minn.
- Boise Cascade Energy & Biomass Engineering Services; International Falls, Minn.
- Potlatch, Las Vegas, Nev. and Elwood, Ill.
  - Boiler scoping, training, and commissioning
  - Energy engineering, energy contract management, and environmental permitting
  - 10MW Combustion Turbine Co-generation scoping, project development, and permitting
- Potlatch Corporation*
  - 2001 Energy Crisis Response and Environmental Permitting; Lewiston, Idaho
  - Biomass Recovery Boiler Rebuild; McGehee, Ark.
  - Numerous energy and boiler audits and boiler and TG maintenance/modification projects
  - Boilers and co-generation plant maintenance and operations management
  - $85 Million Recovery Boiler scoping, owner engineering, training and commissioning
  - 40 MW Condensing Turbine Generator scoping and selection
  - 26 MW Backpressure Turbine Generator scoping and alternative financing
  - Energy contract negotiation and management

**Experience prior to LHB*

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ENERGY STAR PARTNER

Firm Profile

Duluth Office

LHB is a full-service design firm. With a staff of over 180, we provide integrated design solutions from our offices in Duluth and Minneapolis. Since 1966, our people have focused their talents and expertise on providing creative, practical and cost-effective design solutions for our clients.

LHB works to serve you by providing excellent design, quality documents and high performance/sustainable design. We create sustainable designs for all types of facilities and infrastructure to produce energy-efficient buildings; promote ecological use of materials; and utilize natural systems that provide healthy, cost-effective benefits from natural lighting to stormwater reuse.

LHB is committed to sustainable design, as shown by our early and continuous involvement in the United States Green Building Council's Leadership in Energy and Environmental Design (LEED®) program, and in the development and participation of other sustainable guidelines. We currently have over 15% of our staff LEED accredited from the various service sectors we offer, so that projects are reviewed by LEED staff members who are specialists in each area. LHB was involved with four of the first five LEED certified projects in Minnesota, and with six more registered, we understand how

Minneapolis Office

to help you attain LEED certification. Our belief in using LEED has led us to provide training for contractors in the LEED program, since they play a crucial role in helping clients accomplish their goals. In addition to LEED, LHB and its staff are currently leading the process to update Minnesota's Sustainable Design Guidelines, Buildings, Benchmarks, and Beyond (B3), and are ENERGY STAR™ and Energy Management Certified.

Quality Bicycle Products, LEED NC Gold Certified

LHB Staff by Discipline

Licensed Architects	30
Graduate Architects	7
Licensed Civil Engineers	21
Licensed Mechanical Engineers	5
Licensed Fire Protection Engineers	1
Licensed Electrical Engineers	4
Licensed Structural Engineers	10
Graduate Engineers	13
Licensed Land Surveyors	3
Graduate Land Surveyor	1
Licensed Landscape Architects	7
Certified Interior Designers	4
Interior Designers	1
A/E Technicians	46
Administrative Staff	26
Planning & Development	1
TOTAL LHB STAFF	**180**