Minnesota Department of Natural Resources

NRRI Greenhouse

Biomass Energy System

Preliminary Feasibility Report

FINAL

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1.0 EXECUTIVE SUMMARY

The NRRI greenhouse is located adjacent to the institute's primary building in Duluth, MN. The greenhouse is heated by natural gas-fired unit heaters and has used an average of 1,832 ccf of natural gas per year with an average annual cost of $1,517 (2012-2015). The facility is considering adding a biomass boiler system to heat the greenhouse. A biomass system has the potential to reduce greenhouse gas emissions, while utilizing a renewable, local fuel source generated on-site and providing further research opportunities for the NRRI.

A comparison of the cost of delivered heat using natural gas and various biomass fuels is presented in Table ES1 to demonstrate fuels available for purchase. For this project, it is anticipated that the NRRI would use briquettes formed from wood residuals from its wood shop as its fuel source. The proposed option evaluated in this report would require an estimated annual use of 7 tons of biomass fuel generated from wood residuals at the NRRI.

Table ES1: Fuel Pricing and Cost of Delivered Heat

Fuel	Units	Unit Price ($/unit)	System Efficiency	Cost of Delivered Heat ($/mmBtu)
Natural Gas[1]	ccf	$0.83	80%	$10.05
Briquettes (on-site wood residuals)[2]	ton	$240	80%	$19.87
Green Wood Chips[3]	ton	$40	70%	$5.71
Dry Wood Chips[4]	ton	$80	75%	$8.89
Wood Pellets[5]	ton	$304	80%	$23.17
Torrefied Wood Pellets[6]	ton	$220	80%	$13.75

Note 1: Unit price reflects the four-year average price, from 2012-2015.
Note 2: Cost for briquettes is based on a student labor rate of $12/hr and a production rate of 100 lb/hr.
Note 3: Cost for green wood chips is estimated by WES as a fair market price.
Note 4: Cost for dry wood chips is estimated by WES as a fair market price.
Note 5: Cost for wood pellets is based on the delivered cost of 1-ton super sacks from a local supplier.
Note 6: Cost for torrefied wood pellets is based on estimated price by the NRRI.

The following biomass system options were evaluated:

Option 1 –Biomass Boiler with Fan Coils: A hot water biomass boiler, rated between 100,000 and 200,000 Btu/hr and capable of utilizing multiple types of biomass fuels, would be installed in the NRRI building garage area. A 500 gallon thermal storage tank would also be installed with the boiler. The biomass boiler system would supply hot water to two hydronic unit heaters to heat the greenhouse.

Option 2 –Biomass Boiler with Fan Coils and Radiant Floor: A hot water biomass boiler, rated between 100,000 and 200,000 Btu/hr and capable of utilizing multiple types of biomass fuels, would be installed in the NRRI building garage area. A 500 gallon thermal storage tank would also be installed with the boiler. The biomass boiler system would supply hot water to two hydronic unit heaters and a radiant floor system to heat the greenhouse.

A fuel use profile is provided in Table ES2 showing the estimated annual fuel use for the proposed options compared to the use of the existing natural gas system.

Table ES2: Proposed System Fuel Use Profile

Biomass Fuel Type	Gas System	Biomass System		
	Annual Natural Gas Use (ccf)	Biomass Demand Coverage	Estimated Biomass Use (tons)	Estimated Natural Gas Use (ccf)
Wood residuals briquettes	1,832	60%	7	733

Table ES3 provides a comparison of fuel costs and operating costs for the proposed options.

Table ES3: Fuel and Operating Cost Comparison

Biomass Fuel Type	Gas System	Biomass System			Estimated First Year Operational Savings
	Natural Gas Cost	Biomass Cost	Natural Gas Cost	O&M Increase	
Wood waste briquettes	$1,517	$1,799	$607	$490	($1,379)

The installation of a biomass boiler system would allow the NRRI Greenhouse to reduce fossil fuel use while utilizing a local and renewable source of energy. The proposed option evaluated in this report would provide the outcome as summarized:

- Option 1 is to install a multi-fuel biomass boiler with two hydronic fan coil unit heaters. This option would have a capital cost of $47,825.
- Option 2 is to install a multi-fuel biomass boiler with two hydronic fan coil unit heaters and a radiant floor system. This option would have a capital cost of $57,395.

Although the proposed biomass system would not provide operational cost savings through the use of wood residuals produced on site, its primary value is likely as an educational tool. The installation of a biomass heating system provides the opportunity to utilize bio-fuels produced or tested in NRRI labs. It also provides students the opportunity to gain hands-on experience operating the briquetter and biomass boiler. Ash from the boiler could also potentially be used in greenhouse projects.

The installation of the proposed biomass system would provide the following additional benefits through the use of local biomass at the facility:

- Net reduction of greenhouse gas emissions by up to 5.8 metric tonnes annually,
- Diversification of fuels used at NRRI,
- Reduction in operating budget volatility due to wide fluctuations in fossil energy pricing,
- Creating markets for low-value woody biomass to enhance opportunities for forest management activities to reduce pests and disease, prevent fires, and manage for ecological diversity, soil health, and water quality.

Should the NRRI be interested in pursuing a biomass option at its greenhouse, WES recommends that staff visit modern biomass boiler installations to develop a detailed understanding of the equipment and its capabilities. The MN SWET is available to assist in arranging tours of existing facilities. As the NRRI continues to pursue renewable biomass energy options, WES recommends that the next level of evaluation includes detailed consideration of the following items:

- Work with the MN SWET to identify alternative funding sources (low interest loans, grants, and incentives).
- Perform site investigations for the installation of a boiler system in the existing garage/storage area and further develop layout and capital costs based on investigation results.
- Continue to evaluate the wood and paper residuals streams generated on-site

2.0 INTRODUCTION

2.1 MN SWET PROGRAM

The Minnesota Statewide Wood Energy Team (MN SWET) is working to implement commercially available wood energy systems by strategically identifying businesses, government buildings and other institutions that are:

- Currently using propane or fuel oil for heating and do not have direct access to natural gas
- Located in an area of the state with sufficient wood resources and in need of forest market expansion and/or wildfire risk management
- Capable of meeting the space and operational requirements needed for contemporary wood heating systems, and
- Financially committed to thermal wood energy options.

Wilson Engineering Services, PC (WES) was contracted by the Minnesota Department of Natural Resources (MN DNR), on behalf of the MN SWET, to provide Intermediate Woody Biomass Thermal Energy feasibility assessments. The feasibility assessments provide a preliminary engineering and financial analysis for potential projects that are recommended by MN SWET after preliminary screening. The purpose of the feasibility assessments is to facilitate sound decision making by the facilities regarding the installation of wood energy systems. The feasibility assessments address key design parameter choices, such as fuel type (chips, pellets, and cord wood), layout, thermal storage needs, heat distribution, and estimated capital and operating costs.

2.2 UMN NRRI GREENHOUSE OPPORTUNITY

The University of Minnesota's Natural Resources Research Institute (NRRI) is located in Duluth, MN. The NRRI operates a small greenhouse adjacent to the research building (see Figure 1). The greenhouse is currently heated by unit heaters firing natural gas. The NRRI is investigating whether it is feasible to install a wood energy system to supply heat to the greenhouse by using wood residuals produced on site. A wood energy system has the potential to reduce greenhouse gas emissions while providing an opportunity to utilize a renewable local fuel source, including fuels produced at the NRRI.

Figure 1: NRRI Greenhouse

3.0 FACILITY OVERVIEW

WES personnel conducted a site visit on November 1, 2016 in order to evaluate the existing systems and become familiar with the facility's operation. The NRRI is a research facility located in a four-story concrete building, originally built to house large computers and networking equipment for an air defense system during the Cold War era. The NRRI's mission is "to deliver research solutions to balance our economy, resources and environment for resilient communities." The NRRI focuses on developing sustainable, natural resource-based industries, informing environmental management and policy, supporting business and industry, and promoting entrepreneurial opportunities. The facility includes a wood shop and a biorefinery technology lab, and employs up to 70 undergraduate and graduate research assistants each year.

The NRRI also operates a 1,547 square-foot greenhouse, built in 1992 adjacent to the original structure. The greenhouse is separated into two sides by a baffle wall, with each side heated by a Modine natural gas-fired unit heater. Each of the two unit heaters have a 225,000 Btu per hour rated input capacity and 180,000 Btu per hour rated output capacity. The unit heaters each provide heated air to a plastic duct running the length of the greenhouse for heat distribution. A picture of the heating duct is shown in Figure 2. Each duct has a 3,120 cfm fan jet supplying outdoor air for ventilation. Two 3,090 cfm exhaust fans on the end wall exhaust air from the greenhouse to the outdoors.

The annual operating schedule of the greenhouse can vary depending on the varying greenhouse projects.

The NRRI owns and operates a Biomass Briquette Systems BP-100 briquette press. It is anticipated that wood residuals (shavings, sawdust, etc.) from the wood shop are provided at no cost and then can be used to produce briquettes at cost that only includes labor and energy for NRRI to run the system. Anecdotal reports indicate that there are sufficient residuals from the wood shop to fuel a biomass boiler for the greenhouse.

Figure 2: Greenhouse Heating Duct

4.0 FACILITY HEATING DEMAND

4.1 ENERGY USE

The NRRI provided annual natural gas use and cost for the greenhouse for calendar years 2012 to 2015. A summary of the annual gas use and cost is presented in Table 1. The large increase in use in 2015 is accounted for by an increase in greenhouse activity, particularly in winter months. The four-year average use of 1,832 ccf and unit cost of $0.83 per ccf of natural gas are used as a basis for the economic analysis of this study.

Table 1: Annual Natural Gas Use and Cost Summary

Year	Natural Gas Use (ccf)	Natural Gas Cost ($)	Average Natural Gas Unit Cost ($/ccf)
2012	554	$474	$0.86
2013	532	$554	$1.04
2014	1,101	$1,141	$1.04
2015	5,139	$3,899	$0.76
Average	***1,832***	***$1,517***	***$0.83***

Electric service is provided by Minnesota Power. Minnesota Power's published rate schedule gives an energy charge of $0.071 per kWh, including adjustments.

4.2 HEATING DEMAND MODELING

The peak heating demand was modeled using procedures from ASHRAE and Manual J. Optimal greenhouse air temperatures for cold climates are typically between 35°F and 75°F. A set-point air temperature of 55°F is used for modeling the greenhouse. Ventilation presents a heating load for the greenhouse as cold outdoor air must be heated as it is brought into the greenhouse. The greenhouse supply and exhaust fans have a capacity of approximately 6,000 cfm, however, ventilation requirements are highest during the summer when high ventilation rates are needed to keep the greenhouse from overheating. During colder months, ventilation is mostly required to control air humidity. With two natural gas-fired heating units, it is also important to have ventilation to remove any combustion gases from the greenhouse. A commonly used minimum greenhouse ventilation rate of 2 air changes per hour (722 cfm) is used as the basis for the ventilation heating load during the winter season. The full design parameters used are listed in Table 6. A summary of the estimated peak heating demand is presented in Table 2.

Table 2: Estimated Peak Heating Demand Summary

Heating Load Type	Estimated Peak Heating Demand (Btu/hr)	Estimated Peak Heating Demand per degree °F[1] (Btu/hr/°F)
Building Envelope Heating Load	251,606	3,544
Ventilation Heating Load (2 ACH)	56,370	794
Total	***307,976***	***4,338***

Note 1: Heating demand per degree based on design temperature of -16°F.
Note 2: Estimated loads do not account for solar gains, which are significant during daylight hours.

A model of the daily average heating demand was developed for the greenhouse using surface weather data and the peak heating demand calculations. Surface weather data was obtained from Richard Helgeson Airport in Two Harbors, MN for the calendar years 2014 and 2015. Daily mean temperatures were used to calculate the heating degree days (HDD) for each day of the year. Heating degree days are a measurement of the daily mean outdoor air temperature relative to a theoretical base temperature in which a building has no heating demand. The model uses a HDD base temperature of 55°F. The daily average heating demand models based on 2014 and 2015 are presented in Figure 3. Average heating demand per day was assigned based on the daily HDDs and the heating demand per degree °F presented in Table 2.

Due to the nature of greenhouse design, during the day a large portion or even the entire heating demand may be covered by solar energy. With sudden changes in solar energy (due to cloud cover, etc) and lack of insulation of the greenhouse, greenhouse heating demand can fluctuate considerably. The average heating demand models presented in Figure 3 don't take into account solar energy gains.

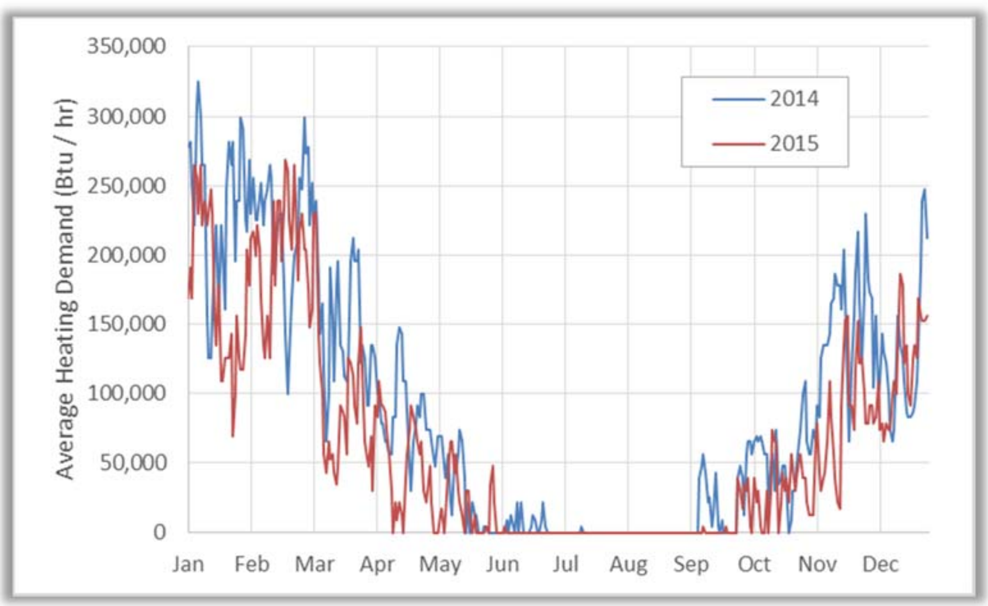

Figure 3: Average Heating Demand Models

Note: Values shown are daily average demands. During the course of a 24 hour period, it is expected that the hourly demand would fluctuate above and below the values shown. Heating *demand does not include solar gains made by the greenhouse, which may offset a portion or all of the heating demand during the day.*

The average heating demand models presented in Figure 3 were sorted in descending order, as opposed to chronologically, to develop load duration curve models. The load duration curve models are presented Figure 4. It is important to note how these demand models can be used appropriately. The models present the daily average hourly demand. Over the course of a 24 hour period, the loads will vary above and below the average. Thus, the load curve models are useful for sizing a biomass boiler to ensure efficient operation and demand coverage, but do not indicate actual peak or minimum heating demands.

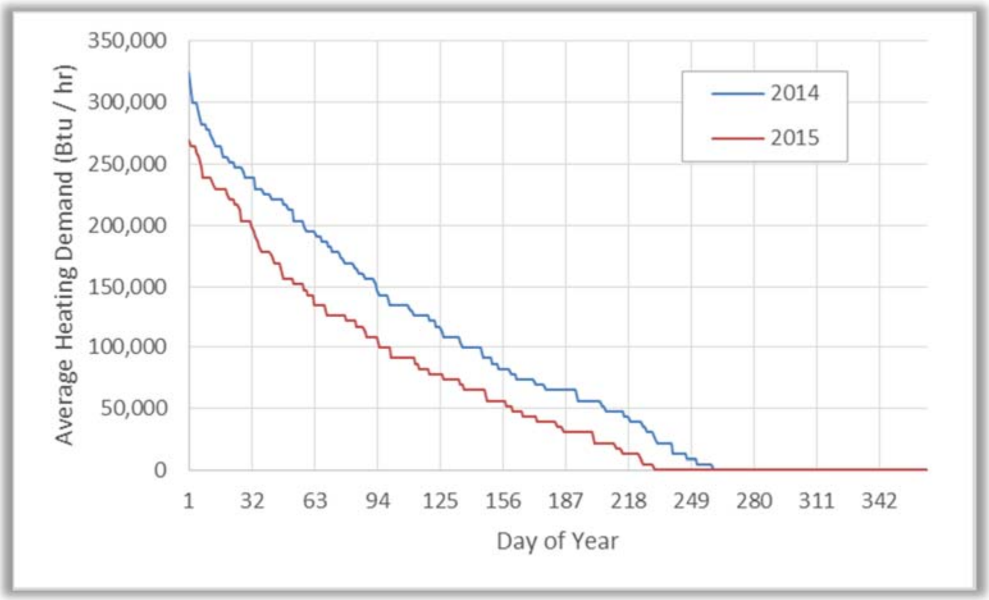

Figure 4: Load Duration Curves Models

Note: Values shown are daily average demands. During the course of a 24 hour period, it is expected that the hourly demand would fluctuate above and below the values shown. Heating demand does not include solar gains made by the greenhouse, which may offset a portion or all of the heating demand during the day.

5.0 BIOMASS FUEL AND PRICE

Modern biomass combustion systems can efficiently and cleanly utilize a variety of fuels with a wide range of moisture content. Due to the variations in the potential fuels available in various locations, there are differing systems for each fuel type. Wood pellet systems are commonly limited to firing on pelletized fuel or dry wood chips with allowable moisture content (wet basis) typically in the range of 5-30%. Systems capable of utilizing green wood chips are typically designed for fuel with a moisture content of 20-50%. Cordwood systems are typically designed to use cordwood with a moisture content of approximately 20% wet basis, which is what can be achieved by air drying. Some manufacturers offer equipment able to utilize a variety of biomass fuel types, although the control parameters and system options would likely need to be adjusted when targeting one of these fuels in order to maintain efficiency.

A comparison of the cost of delivered heat using natural gas and various biomass fuels is presented in Table 3 to demonstrate fuels available for purchase. However for this project, it is anticipated that the

NRRI would use briquettes formed from wood residuals from its wood shop as its fuel source. Based on historical fuel use and an assumed wood moisture content of 12%, the proposed system would require an estimated annual use of 12 tons of fuel if 100% of the average annual heating demand were to be covered. Actual use will vary based on coverage and the annual heating load.

Table 3: Fuel Pricing and Cost of Delivered Heat

Fuel	Units	Unit Price ($/unit)	System Efficiency	Cost of Delivered Heat ($/mmBtu)
Natural Gas[1]	ccf	$0.83	80%	$10.05
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Note 5: Cost for wood pellets is based on the delivered cost of 1-ton super sacks from a local supplier.
Note 6: Cost for torrefied wood pellets is based on estimated price by the NRRI.

5.1 BRIQUETTES

Briquettes are typically made "in-house" from various sources of biomass residuals or residuals by machines which crush, dry, mix, and compress these materials into a briquette shape. Sources for producing briquettes agricultural residuals (switchgrass, corn husks and cobs, etc.), wood residuals (sawdust, bark, wood shavings, chips, etc.), or animal and municipal waste (animal bedding and manure, wood crates and pallets, paper and cardboard waste, etc.). Briquettes at NRRI are expected to be made from wood residuals from its wood shop and cardboard and paper waste from the facility.

The NRRI owns and operates a Biomass Briquette Systems BP-100 briquetter machine. This machine can produce briquettes with a 1.25" diameter and 0.75"-5" in length, and has an output capacity of up to 140 lbs per hour. Biomass residual materials processed into briquettes are required to have a moisture content less than 15%.

Briquettes produced onsite can be stored in 1-ton tote bags as they are produced throughout the year and loaded manually into the biomass hopper.

5.2 WOOD CHIPS

Sources of wood chips could be local loggers, regional wood products manufacturers, MN DNR, or the US Forest Service. Wood chip CHP (combined heat and power) plants in Virginia and Hibbing are the primary outlets for low value residuals. WES spoke with several local loggers and learned that there are a significant number of logging operations which are doing in-woods chipping. The in-woods chipping is done in conjunction with harvesting of saw timber or pulpwood. The general unofficial chip spec in the woods is a 2” whole tree chip, and these are for the most part delivered to the power plants in Virginia and Hibbing for a delivered cost of $30 to $40 per ton.

Wood chip moisture content and quality are important considerations when selecting a biomass boiler and fuel handling system. Some boilers require moisture contents of 30% (wet basis) or less and chip size of 1-1/2” or less, while others can tolerate wetter/larger chips. In addition to moisture content, ash content is another quality measure. Bark, leaves, and twigs all have a higher ash content than debarked roundwood. Paper and OSB mills use debarked roundwood chips as their primary feedstocks, and therefore these materials will command a higher price.

Dried or partially dried chips are able to be used in many commercial pellet boilers, and represent a lower-cost fuel compared to wood pellets. Compared to the 2” whole tree chips being produced by in-woods chippers, these chips must be sized less than 1.5” and oversize pieces must be removed. These chips can be commercially produced by screening chips and then drying chips using a rotary dryer heated by a wood chip furnace. In some cases, facility owners themselves produce dry chips from dry residuals and use them in their own boilers. Rather than using a dryer, 30% moisture or less can be achieved if logs are air dried for a year prior to being chipped. There is the potential that a local logging or tree service company could be willing to stage logs and chip them, however, no potential suppliers have been identified at this time.

Chips are typically transported by walking floor trailer and either dumped directly into storage areas with automated reclaim equipment, or stored under cover and then loaded into a hopper using a skid steer loader. Wood chips may also be blown into storage using specialty blower trucks that are common in the commercial mulch industry.

5.3 WOOD PELLETS

Typical premium grade wood pellets are approximately ¼” in diameter and 1” in length with a moisture content less than 8%. Premium grade wood pellets are manufactured from debarked wood stock, resulting in a very low ash content, typically less than 1%.

Wood pellets are typically delivered in bulk loads of 10-30 tons. Bulk delivery of pellets can be delivered in a variety of ways, depending on the storage system at the facility and the capabilities of local truckers, including by end dump tractor trailers, walking floor tractor trailers, or grain trucks or trailers with an auger or pneumatic discharge hose. Delivery by grain truck is often the most convenient, because the pellets can be discharged directly into the top of a silo. Auger trucks in this region generally have a maximum height capability of 24’. Deliveries by a pneumatic delivery truck would involve the driver attaching a hose to a tube near the base of the silo. This tube would be permanently attached to the silo and would run up to the top to discharge the pellets. The higher cost and/or lower capacity of grain trucks can make walking floor or end dump delivery slightly cheaper. These methods would require a conveyor system to carry the pellets up to the top of the silo. The nearest pellet plant offering bulk delivery is Great Lakes Renewable Energy, located in Hayward, WI. Bulk pricing at the gate is approximately $176 per ton, and trucking costs are in the range of $4-$5 per loaded mile.

Pellets can also be delivered in super sacks. Super sacks are large format reusable tote bags, typically 1-ton, and are delivered on a pallet. Pellets can be manually emptied from the super sack into the biomass boiler’s hopper. Based on the size of the proposed biomass system, super sacks would be the most appropriate delivery method of pellets for the NRRI greenhouse. A local pellet supplier, MMT Heating in Hermantown, MN, offers super sacks of premium wood pellets, delivered, for approximately $304 per ton.

5.4 Torrefied Wood Pellets

Torrefied wood pellets are an energy-dense woody biomass fuel. The pellets are created through a process called torrefaction, where wood is heated at temperatures up to 300°F in an oxygen-deprived environment. This process drives off water contained in the wood as well as volatile compounds. After the torrefaction process the material is then pressed into pellets or briquettes. The end product is a dry, blackened pellet with similar properties to coal. Torrefied wood pellets are more hydrophobic than traditional wood pellets and can be stored in environments with high moisture. Torrefied wood can have heating values ranging from 9,000 - 11,000 Btu per lb. These are also produced by NRRI as part of research efforts.

6.0 EVALUATED BIOMASS SYSTEM

Two biomass hot water boiler system options were evaluated for the NRRI greenhouse. The biomass systems were sized based on the analysis in Section 4.2.

Option 1 –Biomass Boiler with Fan Coils: A hot water biomass boiler, rated between 100,000 and 200,000 Btu/hr and capable of utilizing multiple types of biomass fuels, would be installed in the NRRI building garage area. A 500 gallon thermal storage tank would also be installed with the boiler. The biomass boiler system would supply hot water to two hydronic unit heaters to heat the greenhouse.

Option 2 –Biomass Boiler with Fan Coils and Radiant Floor: A hot water biomass boiler, rated between 100,000 and 200,000 Btu/hr and capable of utilizing multiple types of biomass fuels, would be installed in the NRRI building garage area. A 500 gallon thermal storage tank would also be installed with the boiler. The biomass boiler system would supply hot water to two hydronic unit heaters and a radiant floor system to heat the greenhouse.

6.1 Option 1 –Biomass Boiler with Fan Coils

A non-pressurized hot water biomass boiler, rated at between 100,000 and 200,000 Btu/hr output capacity and capable of utilizing multiple types of biomass fuels, and a 500 gallon thermal storage tank would be installed in the NRRI building garage area. The garage area is already heated with a natural gas hydronic system, and has plenty of space for the boiler installation which would only need 155 square feet. Access to the boiler feed hopper would be needed to allow loading by a forklift carrying a supersack. Piping would be run from this area to the greenhouse.

Two hydronic fan coil unit heaters, rated 200,000 Btu/hr output capacity each, would be installed in the greenhouse, one on each side of the baffle wall. The existing gas-fired unit heaters would be left in place to provide for backup and peak loads. The hydronic unit heaters would be connected to the thermal storage through a heat exchanger, allowing the unit heater side of the system to be pressurized. The fluid in the pressurized loop should be a solution of at least 50% glycol to protect against freezing.

Due to the fluctuating heating demands typical of a greenhouse, a relatively large amount of thermal storage is important to buffer the demand on the biomass boiler, reduce cycling, improve system efficiency, and reduce emissions.

The biomass boiler system would be installed with a day bin hopper with a storage capacity of approximately 2 yards. The day bin hopper would be filled with biomass fuel from a supersack or in loose form. The anticipated biomass fuel are briquettes manufactured on site from wood residuals, however, other biomass fuels could be used as well. A rotating spring arm at the bottom of the day bin sweeps briquettes (or chips or pellets) into an auger which automatically feeds the biomass boiler. Briquettes manufactured on site would be stored in 1-ton tote bags. It is anticipated that NRRI staff and students would manufacture the briquettes throughout the course of the year in preparation for the heating season. A 2-yard storage bin could provide a fuel supply for 2-5 days depending on boiler firing rate. An approximate amount of time that a full 2-yard bin would last is presented in Table 4.

Table 4: Days of Fuel Supply of a 2-yd Storage Bin

Firing Rate	Days of Fuel Supply
	Wood Residual Briquettes[1]
100,000 Btu/hr	5.1
150,000 Btu/hr	3.4
200,000 Btu/hr	2.5

Note 1: Based on a bulk density of 30 lbs per cubic foot.

Biomass boilers capable of utilizing multiple biomass fuels control combustion by varying the fuel feed rate and combustion air rates. Biomass fuels with a higher moisture content combust more slowly and are fed at a more constant rate to ensure moisture is driven off and full combustion takes place. Briquettes, wood pellets, or torrefied wood pellets with little to no moisture would burn hotter and faster. These fuels are fed into the boiler in pulses. The types of biomass boilers proposed in this study would require manually adjusting the feed rates and combustion air. A series of control settings should be recorded based on moisture content of the fuel to allow for ease of changing fuel types. Mixing various fuel types is not recommended due to varying moisture content levels.

Load coverage for the boiler is evaluated based on the models presented in Figure 4 and a boiler output capacity of 100,000 Btu/hr. Figure 5 shows the expected load coverage to be approximately 62% based on the 2014 LDC model. Figure 6 shows the expected load coverage to be approximately 71% based on the 2015 LDC model. This study assumes a 60% load coverage for the biomass system for purposes of estimating fossil fuel offset.

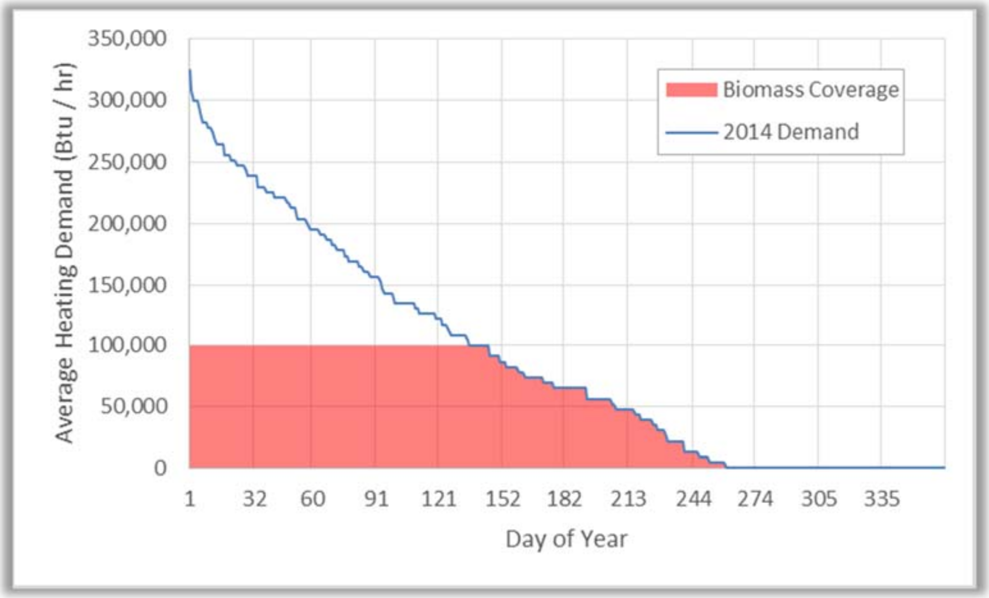


Figure 5: 2014 LDC and Coverage of 100,000 Btu/hr Biomass Boiler

Note: Values shown are daily average demands. During the course of a 24 hour period, it is expected that the hourly demand would fluctuate above and below the values shown. Heating demand does not include solar gains made by the greenhouse, which may offset a portion or all of the heating demand during the day.

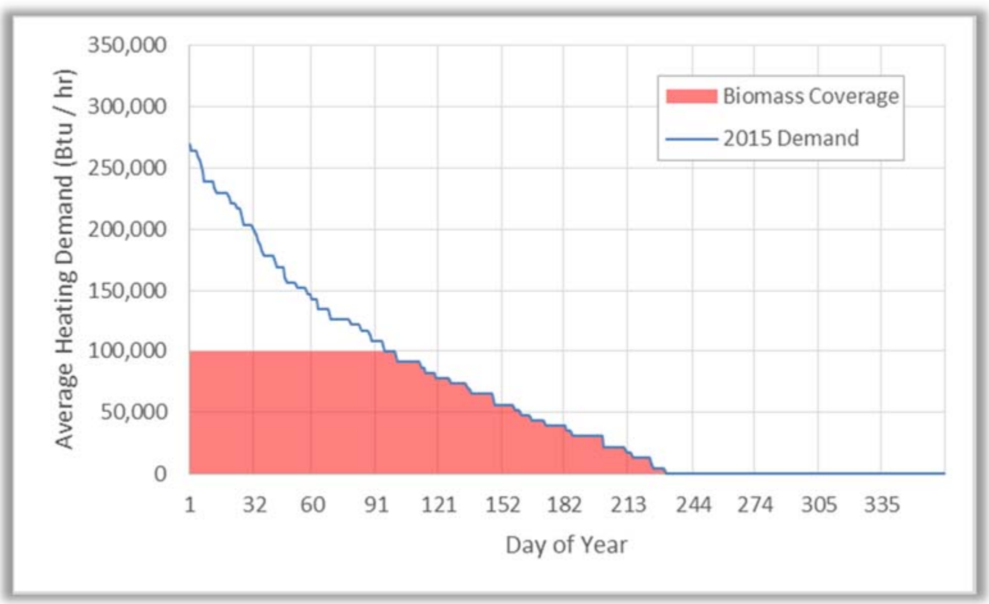


Figure 6: 2015 LDC and Coverage of 100,000 Btu/hr Biomass Boiler

Note: Values shown are daily average demands. During the course of a 24 hour period, it is expected that the hourly demand would fluctuate above and below the values shown. Heating demand does not include solar gains made by the greenhouse, which may offset a portion or all of the heating demand during the day.

6.2 Option 2 –Biomass Boiler with Fan Coils and Radiant Floor

Option 2 would also install a non-pressurized hot water biomass boiler, rated between 100,000 and 200,000 Btu/hr output capacity and capable of utilizing multiple types of biomass fuels, and a 500 gallon thermal storage tank in the NRRI building garage area. This boiler system would be located and operated in the same manner as Option 1.

Two hydronic fan coil unit heaters, rated 200,000 Btu/hr output capacity each, would also be installed in the greenhouse as with Option 1. In addition, a radiant floor heating system would be installed over the existing concrete slab for one half of the greenhouse. A radiant floor system would provide a heat sink that would help mitigate the changes in heating demand of the greenhouse. Installation of the radiant floor on only one side of the greenhouse allows for a control for which to compare the benefits of a radiant floor system for greenhouse operation.

Installation of a radiant floor also offers the opportunity for the NRRI to use its recycled taconite rock as a flooring material for the greenhouse.

With the installation on top of a pre-existing insulated slab, the radiant floor tubing can be installed directly without additional insulation. The concrete slab with provide additional mass for the effective heat sink. The radiant floor system would use a 5/8" PEX tubing secured to a wire mesh and installed directly over top of the existing concrete slab to circulate hot water through the flooring. A pea gravel or taconite rock would be installed on top of the tubing at a total depth of 4". A system schematic and radiant floor layout are provided in Appendix A.

With a 55°F set-point air temperature, a radiant floor with a maximum floor temperature would be able to provide approximately 40,000 Btu/hr to one side of the greenhouse. The hydronic fan coil unit heater would cover heating demands above the radiant floor system's capacity.

6.3 Boiler Models

Two boiler models are provided as examples for the proposed biomass systems: the Goliath KWH-55 and the LEI Bio-Burner 100. These boilers were chosen to give examples of boilers with varying features and controls that are capable of utilizing multiple fuel types, but do not reflect all potential boiler models. There are many other qualified vendors that could be considered.

The Goliath KWH-55 boiler is a solid fuel boiler with a dual pass heat exchanger. The boiler can be fitted with an external combustion unit with moveable grates to burn multiple biomass fuels. The boiler system comes with a 1.5 yard day bin hopper which automatically feeds the boiler. The combustion unit can handle fuels with moisture contents up to 50%, although lower moisture contents are recommended during temperatures below freezing if the fuel is stored outside. The combustion unit must be manually lit during startup and will idle when there is no heating demand. Ash from the grates is automatically removed from the unit with an auger. Fuel feed rate and combustion air must be manually set depending on fuel type. The Goliath KWH-55 has an output capacity of 204,720 Btu/hr.

The LEI Bio-Burner 100 is a non-pressurized, multi-fuel biomass boiler. The boiler can handle fuels with moisture contents up to 40%, although lower moisture contents are recommended during temperatures below freezing if the fuel is stored outside. The Bio-Burner models are connected to an existing gas supply and have an auto start function. This allows the boiler to turn off as opposed to idling when there is no heating demand, leading to more efficient operation. With a gas connection, the boiler can also serve as a backup boiler and fire on natural gas. Fuel feed rates should be set manually based on moisture content. The boiler is capable of self-adjusting the combustion air rate, however. The boiler also offers remote access to the controls system. Day bin hoppers ranging from 2-100 yards are available. The Bio-Burner 100 has an output capacity of 100,000 Btu/hr.

A summary of the boiler models and price is presented in Table 5.

Table 5: Biomass Boiler Model Examples

Manufacturer	Model	Rated Output Capacity (Btu/hr)	Budget Price
Goliath[1]	KWH-55	204,720	$14,650
LEI[2]	Bio-Burner 100	100,000	$14,000

Note 1: KWH-50 boiler coupled with AZSD-50 combustion unit. Price includes 1.5 yd fuel hopper.
Note 2: Price does not include fuel hopper.

7.0 GRANTS AND INCENTIVES

7.1 BIOMASS THERMAL PRODUCTION INCENTIVE

Minnesota Statutes 2015, section 41A.18, and Minnesota Session Laws 2016, chapter 189, article 2, section 21 provide for a “biomass thermal production incentive” which pays eligible facilities $5 for each mmBtu of heat supplied to a building or process using biomass fuel. In order to be eligible, a facility must install a biomass boiler or other similar device after July 1, 2015, and this system must deliver no less than 250 mmBtu to the facility during one single calendar quarter. For a period of 10 years after qualification, the facility owner can receive $5 per mmBtu of thermal output for calendar quarters in which thermal production exceeds 250 mmBtu.

250 mmBtu of thermal output is approximately equal to using 3,034 ccf of natural gas. Based on the historical fuel usage data, the NRRI greenhouse would not qualify for this incentive during any of its quarters.

8.0 BIOMASS SYSTEM ANALYSIS

Table 6 lists the values and assumptions used in the analysis.

Table 6: Values and Assumptions

Assumption	Value	Unit	Source
Greenhouse set-point temperature	55	°F	WES Assumption
99% heating design temperature (dry bulb), Duluth MN	-16	°F	WES Assumption
Greenhouse winter ventilation rate	2	ACH	WES Assumption
Poured concrete (per inch) R-value	0.08	hr*ft2*°F/Btu	WES Assumption
Single pane glass R-value	0.91	hr*ft2*°F/Btu	WES Assumption
Rigid insulation board R-value	4.00	hr*ft2*°F/Btu	WES Assumption
Four-year natural gas average price	$0.83	$/ccf	NRRI
Natural gas HHV	103,000	Btu/ccf	WES Assumption
Natural gas unit heater efficiency	80%	percent	NRRI
Green wood chip price	$40	$/ton	WES Assumption
Green wood chip HHV	10.0	mmBtu/ton	WES Assumption
Green wood chip boiler efficiency	70%	percent	WES Assumption
Dry wood chip price	$80	$/ton	WES Assumption
Dry wood chip HHV	12.0	mmBtu/ton	WES Assumption
Dry wood chip boiler efficiency	75%	percent	WES Assumption
Wood pellet price	$304	$/ton	WES Assumption
Wood pellet HHV	16.4	mmBtu/ton	WES Assumption
Wood pellet boiler efficiency	80%	percent	WES Assumption
Torrefied wood pellet price	$220	$/ton	WES Assumption
Torrefied wood pellet HHV	20.0	mmBtu/ton	WES Assumption
Torrefied wood pellet boiler efficiency	80%	percent	WES Assumption
Wood residuals briquette (12% m.c.) cost	$240		WES Assumption
Wood residuals briquette (12% m.c.) HHV	15.1	mmBtu/ton	WES Assumption
Wood residuals briquette (12% m.c.) boiler efficiency	80%		WES Assumption
Electric energy charge	$0.071	$/kWh	Minnesota Power
NRRI labor cost	$12	$/hr	NRRI
CO_2 emitted during combustion of natural gas	53.06	kg/mmBtu	EPA
CH_4 emitted during combustion of natural gas	0.005	kg/mmBtu	EPA
N_2O emitted during combustion of natural gas	0.0001	kg/mmBtu	EPA
CO_2 emitted due to use of Electricity (includes line losses)	0.0441	kg/kWh	EPA
CH_4 emitted due to use of Electricity (includes line losses)	0.0000644	kg/kWh	EPA
N_2O emitted due to use of Electricity (includes line losses)	0.0000566	kg/kWh	EPA
CH_4 100-year Global Warming Potential	25	* CO_2	IPCC
N_2O 100-year Global Warming Potential	298	* CO_2	IPCC

8.1 Capital Cost Estimates and Operating Cost Savings

Estimated capital costs for the proposed options are listed in Table 7. A detailed breakdown of capital costs is provided in Appendix B.

Table 7: Capital Cost Estimate Summary

Biomass System	Estimated Capital Cost
Option 1 - Biomass Boiler with fan coil units	$47,825
Option 2 - Biomass Boiler with fan coil units and radiant floor	$57,395

Table 8 gives a breakdown of estimated operating and maintenance costs for the proposed biomass systems. An increase in electric costs is expected as biomass boilers use more electricity than the existing equipment due to fuel handling equipment, pumps, and larger blowers. Staff time to run the system is assumed to have no cost as this would be used for research purposes.

Table 8: Estimated Operating and Maintenance Costs

Electric Use Cost	Maintenance / Wear Parts	Staff Time	Total O&M Cost
$390	$100	$0	$490

A proposed system fuel use profile is provided in Table 9 showing the estimated annual fuel use for the proposed options compared to the existing natural gas use.

Table 9: Proposed System Fuel Use Profile

Biomass Fuel Type	Gas System	Biomass System		
	Annual Natural Gas Use (ccf)	Biomass Demand Coverage	Estimated Biomass Use (tons)	Estimated Natural Gas Use (ccf)
Wood residuals briquettes	1,832	60%	7	733

Table 10 provides a comparison of fuel costs and operating costs for the proposed option.

Table 10: Fuel and Operating Cost Comparison

Biomass Fuel Type	Gas System	Biomass System			Estimated First Year Operational Savings
	Natural Gas Cost	Biomass Cost	Natural Gas Cost	O&M Increase	
Wood waste briquettes	$1,517	$1,799	$607	$490	($1,379)

9.0 EMISSIONS, PERMITTING, AND LICENSING

9.1 PARTICULATE MATTER EMISSIONS

All fuel combustion equipment emits some level of particulate matter from the combustion process. For all fossil fuels and renewable fuels, properly tuned systems are critical to ensure optimal conversion efficiencies and minimal emissions. Modern biomass boilers utilize oxygen sensors and variable speed drives to optimize the combustion process with the proper air/fuel mixture. This results in high combustion efficiencies and low emissions, and this section compares particulate matter emission rates for various fuels and equipment.

Note that in this section, the term lb/mmBtu refers to pounds of a certain pollutant emitted in the flue gas per million Btu of fuel (HHV) input. Based on the assumed efficiencies in Table 6, the proposed biomass boiler would have a maximum fuel input rate of approximately 428,600 Btu/hr.

Minnesota Administrative Rules section 7011.0550 Table II sets the maximum particulate emissions from a boiler at 0.4 lb/mmBtu. This emission requirement can be met by modern wood boilers. Visually, the flue gas of a modern wood boiler would exhibit no opacity.

The EPA publishes emissions factors for a wide range of fuel burning devices in its publication AP-42. Table 11 presents these emissions factors along with the expected emissions factors for wood boilers based on stack test data obtained by WES.

Table 11: Emissions Factors for PM

Fuel and Source	PM Emissions	Unit
Residential Fireplace[1]	2.01	lb/mmBtu
Residential Wood Stove[2]	1.12	lb/mmBtu
Wood Chip Boiler[3]	0.08 – 0.15	lb/mmBtu
Wood Pellet Boiler[3]	0.05 – 0.15	lb/mmBtu
#2 Fuel Oil Boiler[4]	0.014	lb/mmBtu
Propane Boiler[5]	0.008	lb/mmBtu

Note 1: EPA AP-42, PM10 value is 34.6 lb/dry ton, conversion based on 17.2 mmBtu/dry ton
Note 2: EPA AP-42, EPA Phase II noncatalytic, PM10 value is 14.6 lb/ton, conversion based on 13.0 mmBtu/ton
Note 3: Values are representative of independent lab testing of boilers comparable to the ones in the proposed options
Note 4: EPA AP-42, boiler < 100 mmBtu/hr
Note 5: EPA AP-42

9.2 GASEOUS EMISSIONS

Besides PM, other pollutants from fuel combustion include VOC, NO_X (NO and NO_2), SO_X, and CO. Ozone (O_3) is a byproduct of NO_X and VOC emissions. Emissions factors for the gaseous pollutants mentioned are presented in Table 12.

Table 12: Emissions Factors for Gaseous Pollutants

Fuel and Source	Emission Factors (lbs/mmBtu)			
	VOC	NOx	SOx	CO
Wood Pellet Boiler[1]	0.004	0.140	0.001	0.150
Wood Chip Boiler[1]	0.004	0.180	0.002	0.150
#2 Fuel Oil Boiler[2]	0.004	0.144	0.207	0.036
Propane Boiler[3]	0.005	0.142	0.0002	0.082
Natural Gas Boiler[4]	0.005	0.098	0.0001	0.082

Note 1: Wood chip and wood pellet values are obtained from stack test results.
Note 2: Oil factors are taken from AP-42 for boilers <100 mmBtu/hr, using values of 0.2% sulfur and HHV of 0.139 mmBtu/gal
Note 3: Propane factors are taken from AP-42, S content of 0.2 g/100ft^3
Note 4: Natural gas values taken from AP-42 for boilers <100 mmBtu/hr, and EIA listed values from IPCC for Industry

Based on this table, a wood boiler would be comparable to a propane boiler in terms of VOC and NO_X. The elevated level of SO_X is due to naturally occurring sulfur in the wood, and can vary regionally. While SO_X emissions for a wood boiler are an order of magnitude larger than for propane, they are two orders of magnitude smaller than for #2 fuel oil.

9.3 GREENHOUSE GAS EMISSIONS BENEFITS

By displacing fossil fuel used for heating (natural gas), the use of the biomass boiler system would result in reduction of the NRRI greenhouse's annual net CO_2 equivalent greenhouse gas emissions by up to 5.8 metric tonnes, as shown in Table 13. Although combustion of wood releases CO_2, the use of wood fuel provides net carbon benefit as long as the fuel is sourced in a sustainable manner. CO_2 equivalent values presented in this report include CO_2, as well as CH_4 and N_2O adjusted for their 100-year global warming potential relative to CO_2. These values are listed in Table 6.

Table 13: Greenhouse Gas Emission (CO_2 equivalent) Reductions

Gas System	Biomass System			Reduction in CO_2 Equivalent Emissions (tonnes)
Natural Gas CO_2 Equivalent Emissions (tonnes)	Biomass CO_2 Equivalent Emissions (tonnes)	Biomass Boiler Electric CO_2 Equivalent Emissions[1] (tonnes)	Natural Gas CO_2 Equivalent Emissions (tonnes)	
10.0	0.0	0.3	4.0	5.8

Note 1: Biomass boilers use more electricity than comparable gas boilers due to fuel handling equipment, larger blowers, etc. Table 6 contains the assumptions used to develop the above values.

9.4 Air Permitting

Boilers in Minnesota can be subject to both state and federal emissions and permitting requirements. Using EPA AP-42 factors for wood and propane boilers, the PTE (potential to emit) of the NRRI would not exceed the state or federal emissions thresholds for air pollutants. The PTE of a facility also includes non-combustion emissions sources such as VOCs and dust. WES estimates that there are no significant emissions sources at this facility that would affect the permitting status other than the boilers.

9.5 Use of Wood Residuals as Fuel

Wood pellets are a manufactured product and would not be considered by the Minnesota Pollution Control Agency (MPCA) to be a solid waste.

The MPCA has issued a Standing Beneficial Use Determination (SBUD) codified in Minn. R. 7035.2860, subpart 4(a), that allows for the use of "unadulterated wood, wood chips, bark, and sawdust" as a fuel, as long as the material is stored and managed appropriately. Unadulterated wood means wood that is not contaminated with paints, stains, glues, preservatives, or other chemicals. This SBUD allows facilities to use clean wood chips, regardless of their source, as a fuel without any further action from MPCA's solid waste program.

Use of other wastes at NRRI, such paper or cardboard, for fuel would require an application for a case-specific beneficial use determination (CSBUD) from the MPCA.

9.6 Ash

Whole tree wood chips generally contain about 3% ash by weight, while wood pellets contain 0.5-1.0% ash by weight. Modern chip and pellet boilers have automated or semi-automated ash handling systems which deposit ashes in a drawer or portable metal container. The proposed system and biomass fuel described in this report have the potential to generate 250 lbs of ash per year.

Wood ash is a valuable soil amendment which has properties similar to lime. Studies have shown that land application of wood ash can improve forest health[1]. Wood ash is classified and regulated as a solid waste in Minnesota. However, the MPCA has a process whereby it will make a case-specific beneficial use determination (CSBUD) to decide whether a specific management option for the solid waste is a beneficial use. Because wood ash is known to have valuable properties when used as a soil amendment, the MPCA has made determinations for several other facilities with biomass boilers that ashes can be spread on land, and therefore it is likely that permission will be granted in future cases. In particular, the DNR French River Hatchery has a CSBUD allowing for beneficial use of ash from their pellet boiler.

Beneficial use of the ash is anticipated to be significantly cheaper than landfilling, and for the purposes of this study, it is assumed that the ash can be used beneficially at no cost to the facility. Additional information on ash use from UMN Extension is provided in Appendix C.

9.7 Boiler Operator Requirements

Minnesota Administrative Rules section 5225.1110 requires all boilers be operated, maintained, and attended by a licensed operating engineer, unless specifically exempted. Minnesota Statutes section 326B.988 exempts hot water heating boilers that do not exceed a combined heat input capacity of 750,000 Btu per hour.

[1] https://www.forestry.umn.edu/sites/forestry.umn.edu/files/Staffpaper153.PDF

Minnesota Statutes section 326B.978 sets the classifications and qualifications for operating engineers. Engineers are divided into four classes based on individual boiler size allowed to be operated: chief, first class, second class, and special engineers. The maximum boiler size allowed to be operated by license class is presented in Table 14. Licenses classes are also divided into Grade A, B, C licenses. Grade C licenses allow for the operation of low pressure boilers (steam less than 15 psig, or hot water less than 160 psig or 250°F). Grade B licenses allow for the operation of low or high pressure boilers. Grade A licenses allow for the operation of low or high pressure boilers with engines, turbines or other appurtenances.

Table 14: Maximum Boiler Size by License Class

Class	Maximum Boiler Size
Chief Engineer	Unlimited
First Class Engineer	500 HP (16.7 mmBtu/hr)
Second Class Engineer	100 HP (3.35 mmBtu/hr)
Special Engineer	50 HP (1.67 mmBtu/hr)

Attendance requirements for low pressure boilers are set by the chief boiler inspector. A boiler attendance policy issued on July 29, 2014 requires a licensed operating engineer check the boiler(s) at least once each day during normal workdays. For weekends and holidays, boiler attendance policy requires a licensed operating engineer check the boiler(s) if: outside air temperature is forecasted to reach 10°F or below, a situation occurs that impacts the safety of the boiler or equipment, or the building will be occupied by employees or the public. No boiler should be left unattended for more than two consecutive days. A check of the boiler includes visual examination of all associated equipment and a logbook entry of the conditions observed.

The NRRI facility is heated by two 150 HP (5.0 mmBtu/hr) natural gas-fired steam boilers. The addition of a biomass boiler would not change the boiler operator license requirements. However, the biomass boiler would not be exempt from the attendance requirements discussed above.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The installation of a biomass boiler system would allow the NRRI Greenhouse to reduce fossil fuel use while utilizing a local and renewable source of energy. The proposed option evaluated in this report would provide the outcome as summarized:

- Option 1 is to install a multi-fuel biomass boiler with two hydronic fan coil unit heaters. This option would have a capital cost of $47,825.
- Option 2 is to install a multi-fuel biomass boiler with two hydronic fan coil unit heaters and a radiant floor system. This option would have a capital cost of $57,395.

Although the proposed biomass system would not provide operational cost savings through the use of wood residuals produced on site, its primary value is likely as an educational tool. The installation of a biomass heating system provides the opportunity to utilize bio-fuels produced or tested in NRRI labs. It also provides students the opportunity to gain hands-on experience operating the briquetter and biomass boiler. Ash from the boiler could also potentially be used in greenhouse projects.

The installation of the proposed biomass system would provide the following additional benefits through the use of local biomass at the facility:

- Net reduction of greenhouse gas emissions by up to 5.8 metric tonnes annually,

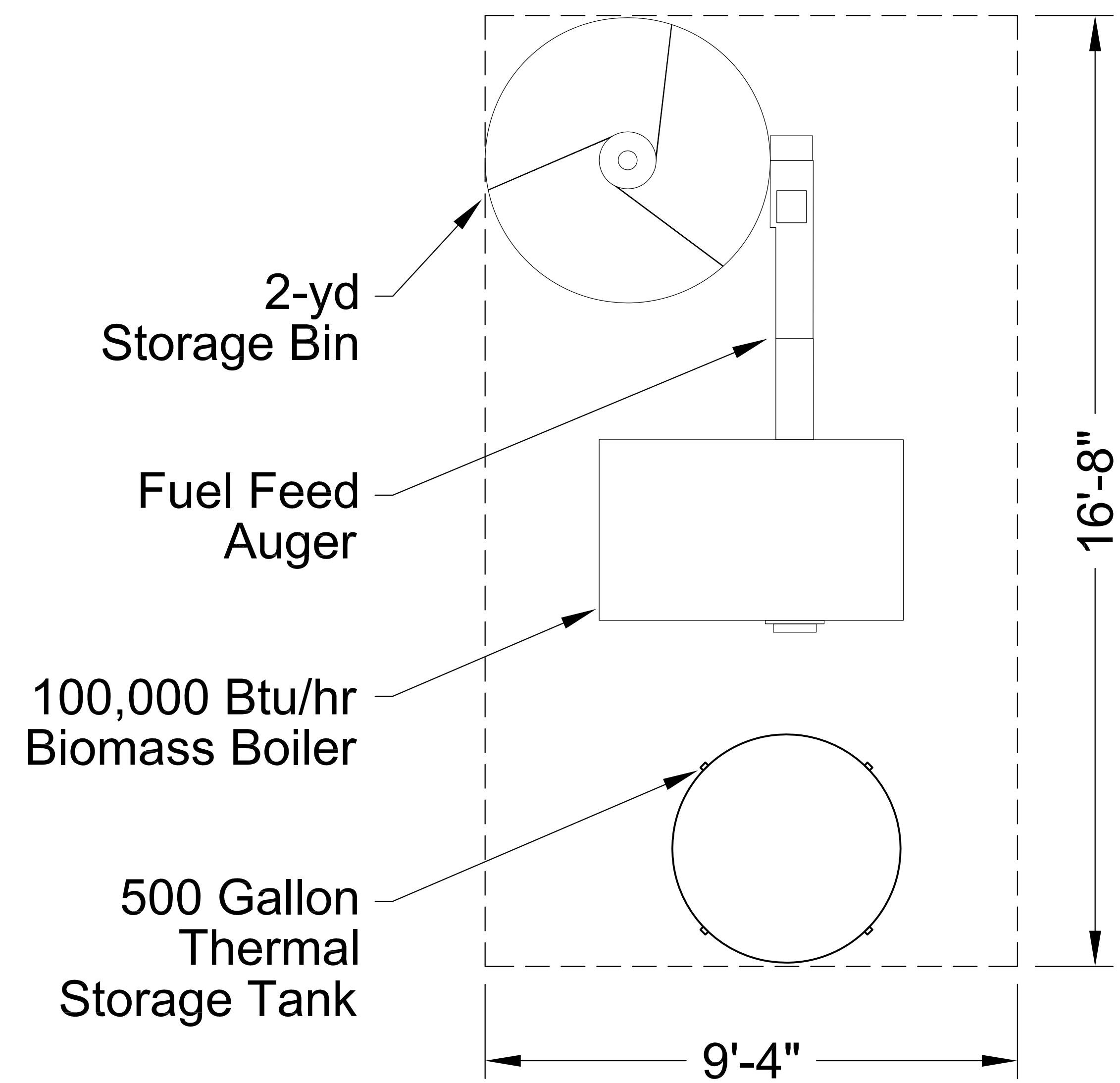
- Diversification of fuels used at NRRI,
- Reduction in operating budget volatility due to wide fluctuations in fossil energy pricing,
- Creating markets for low-value woody biomass to enhance opportunities for forest management activities to reduce pests and disease, prevent fires, and manage for ecological diversity, soil health, and water quality.

Should the NRRI be interested in pursuing a biomass option at its greenhouse, WES recommends that staff visit modern biomass boiler installations to develop a detailed understanding of the equipment and its capabilities. The MN SWET is available to assist in arranging tours of existing facilities. As the NRRI continues to pursue renewable biomass energy options, WES recommends that the next level of evaluation includes detailed consideration of the following items:

- Work with the MN SWET to identify alternative funding sources (low interest loans, grants, and incentives).
- Perform site investigations for the installation of a boiler system in the existing garage/storage area and further develop layout and capital costs based on investigation results.
- Continue to evaluate the wood and paper residuals streams generated on-site

Appendix A – Drawings

- A.1 Site and Biomass System Layout
- A.2 Option 1 – Biomass System Schematic
- A.3 Option 2 – Biomass System Schematic
- A.4 Option 2 – Radiant Floor Layout



Biomass Boiler Layout

Designed	SFK	12/12/16
Drawn	SFK	12/12/16
Checked		

Approved — Date —
Title — Job Class —

NRRI Greenhouse
Duluth, MN

Site & Biomass System Layout

WERC
Wood Education and Resource Center
United States Forest Service
United States Department of Agriculture

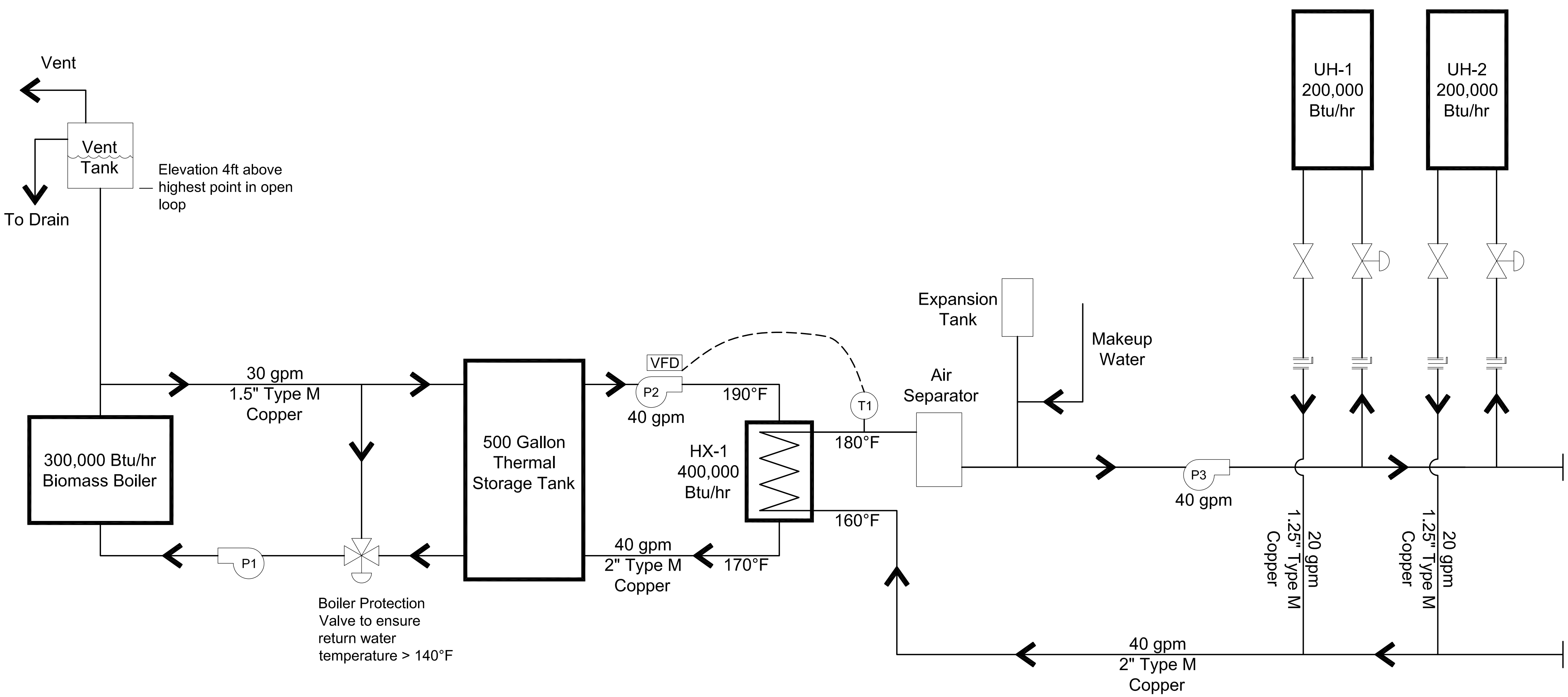
REVISIONS

Date	Description	Approved

A.1

Sequence of Operations:

1. The 300,000 Btu/hr biomass boiler will be controlled to maintain a 190°F supply water temperature to the thermal storage tank. A thermostatic mixing valve allows supply water from the cordwood boilers to bypass the thermal storage, in order to maintain a return water temperature of at least 140°F to prevent flue gas condensation. This is mainly a concern during boiler startup and at times of heavy load.
2. P2 will modulate to maintain T1 at its set-point temperature. The set-point is set based on an outdoor reset schedule.
3. UH-1 and UH-2 will each be controlled by a thermostat in their respective zones set to maintain 55°F. When the temperature of either zone falls below its set-point, P3 and the UH fan will be energized.



Legend

- Shutoff Valve
- Valve
- Control Valve
- Three Way Mixing Valve
- Pump
- (T) Temperature Transmitter
- VFD Variable Frequency Drive

Notes:

1. This drawing is a conceptual layout for the purposes of showing biomass system options.
2. Final design and layout will change based on equipment selected, designer, and site conditions.

Option 1 - Biomass System Schematic

Designed	SFK	11/28/16
Drawn	SFK	11/28/16
Checked		

Approved ____ Date ____

Title ____ Job Class ____

NRRI Greenhouse

Duluth, MN

Biomass Boiler System Schematic

WES

Wilson Engineering Services, PC
www.wilsonengineeringservices.com
902 Market St. Meadville, PA 16335

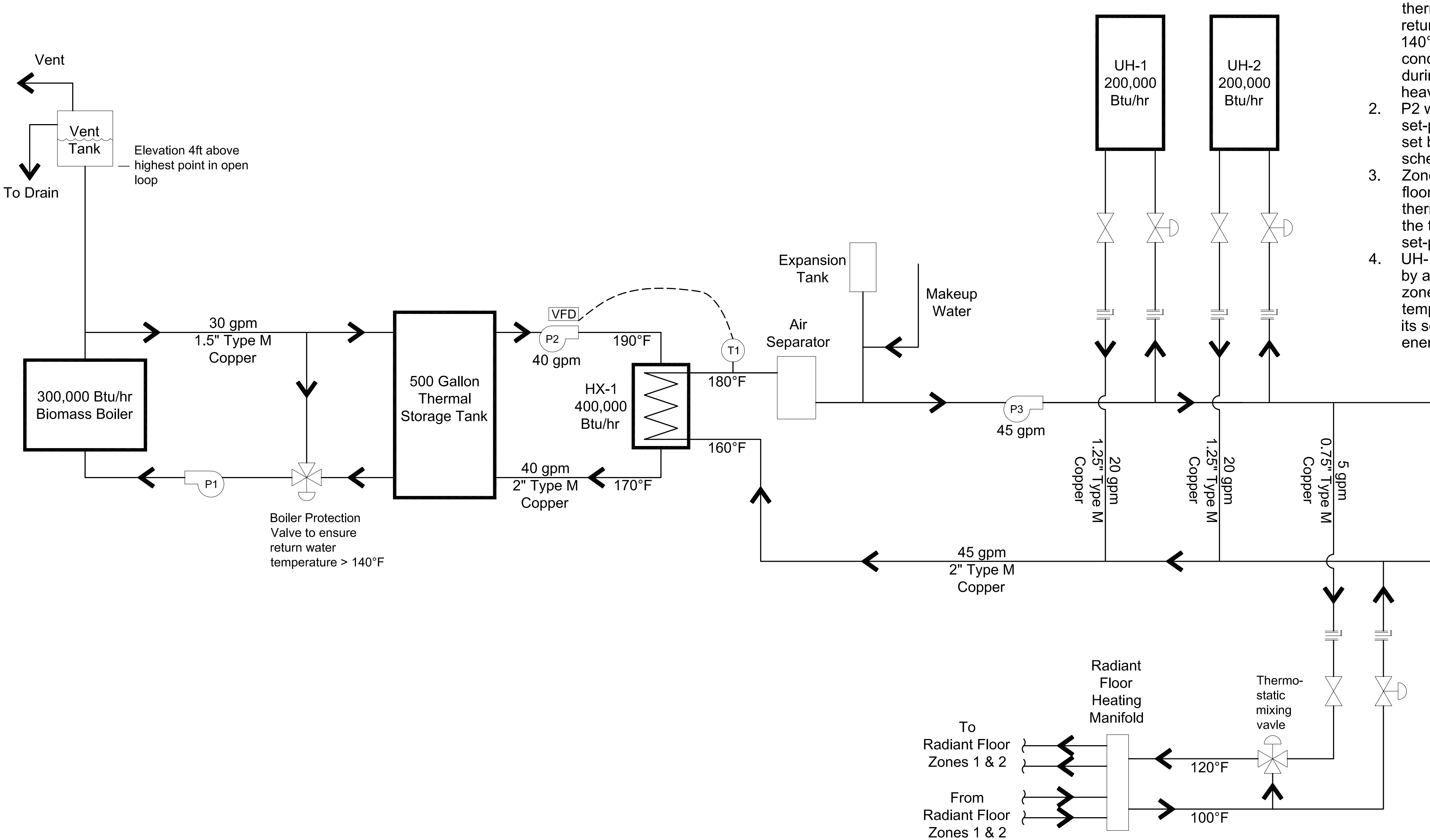
REVISIONS

Date	Description	Approved

A.2

Sequence of Operations:

1. The 300,000 Btu/hr biomass boiler will be controlled to maintain a 190°F supply water temperature to the thermal storage tank. A thermostatic mixing valve allows supply water from the cordwood boilers to bypass the thermal storage, in order to maintain a return water temperature of at least 140°F to prevent flue gas condensation. This is mainly a concern during boiler startup and at times of heavy load.
2. P2 will modulate to maintain T1 at its set-point temperature. The set-point is set based on an outdoor reset schedule.
3. Zone circulator pumps for the radiant floor system will be controlled by thermostat set to maintain 60°F. When the temperautre falls below its set-point, the pumps will be energized.
4. UH-1 and UH-2 will each be controlled by a thermostat in their respective zones set to maintain 50°F. When the temperature of either zone falls below its set-point, P3 and the UH fan will be energized.



Legend

- Shutoff Valve
- Valve
- Control Valve
- Three Way Mixing Valve
- Pump
- (T) Temperature Transmitter
- VFD Variable Frequency Drive

Notes:

1. This drawing is a conceptual layout for the purposes of showing biomass system options.
2. Final design and layout will change based on equipment selected, designer, and site conditions.

Option 2 - Biomass System Schematic

Designed	SFK	12/12/16
Drawn	SFK	12/12/16
Checked		

Approved ____ Date ____

Title ____ Job Class ____

NRRI Greenhouse

Duluth, MN

Option 2 - Biomass System Schematic

WES

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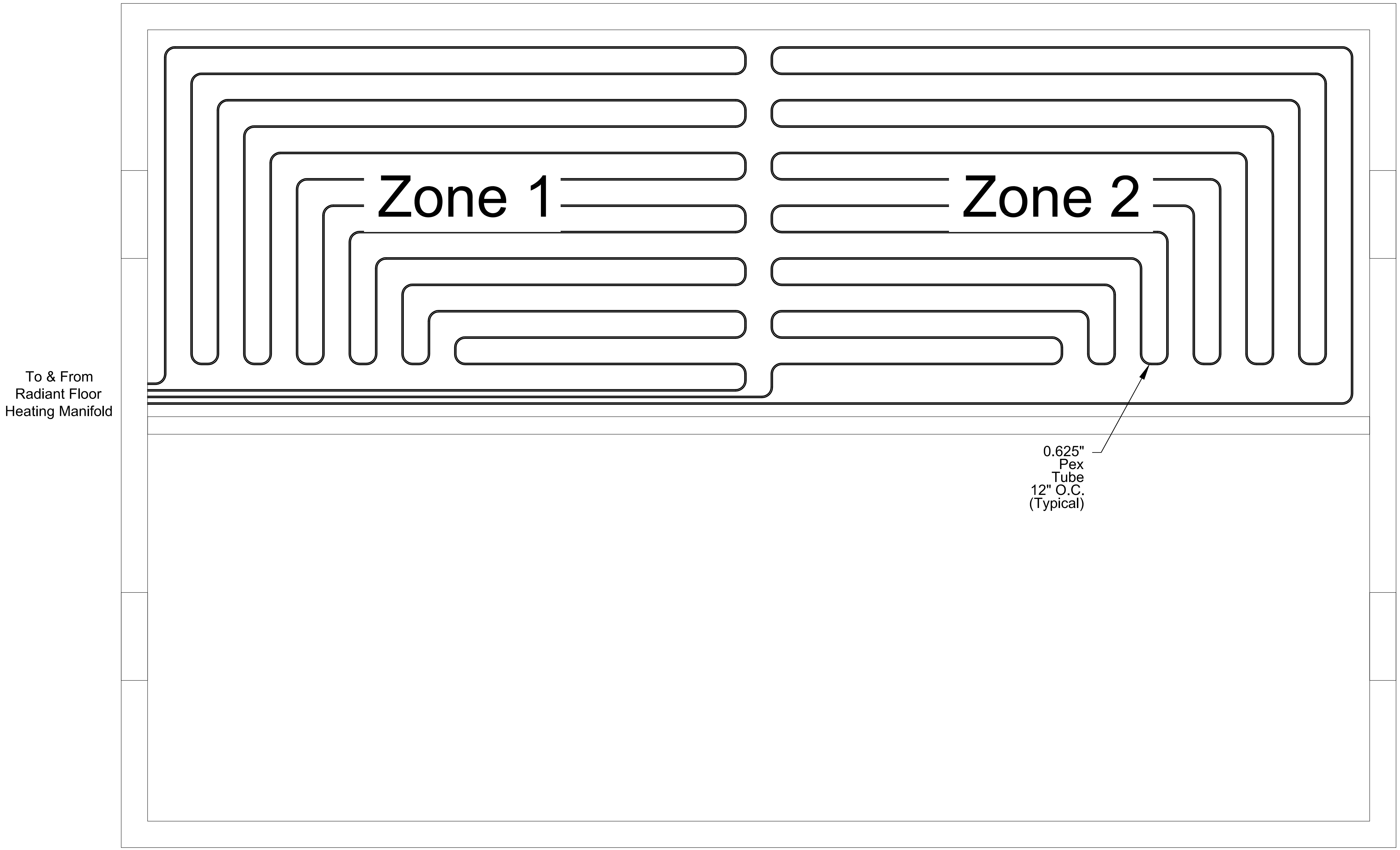
REVISIONS

Date	Description	Approved



Option 2 - Radiant Floor Layout

Designed	SFK	12/12/16
Drawn	SFK	12/12/16
Checked		

Approved ____ Date ____
Title ____ Job Class ____

NRRI Greenhouse
Duluth, MN

Option 2 - Radiant Floor Layout

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REVISIONS

Date	Description	Approved

Appendix B – Capital Cost Estimates

Option 1 - Biomass System Capital Cost Estimate

Biomass Boiler Manufacturer Contract[1]

Line Item		Cost
100,000 Btu/hr biomass boiler, non-pressurized, shipped	$	14,000
500 gallon thermal storage tank, non-pressurized	$	2,000
2 cubic yard fuel hopper & fuel handling	$	2,200
Freight	$	1,500
Total Boiler Manufacturer Contract	**$**	**19,700**

General Contract

Line Item		Cost
200,000 Btu/hr hydronic unit heaters	$	4,000
Pumps, valves, heat exchanger, and piping	$	5,000
Mechanical	$	5,000
Electrical	$	2,000
Sub-Total	$	16,000
Contractor profit, overhead, and insurance 16%	*$*	*2,560*
Total General Contract Building and Site[2]	**$**	**18,560**

Total Project Cost

Line Item		Cost
Project Sub-Total (Boiler, General Contract, Additional Items)	$	38,260
Professional Services[3] 10%	*$*	*3,826*
Contingency 15%	*$*	*5,739*
Total Project Cost	**$**	**47,825**

Notes:
1 - Assumes that biomass boiler and general contract are bid separately.
2 - Costs are approximate. Estimate is based on competitive bidding.
3 - Professional Services includes engineering, permitting, legal, and project management.

Option 2 - Biomass System Capital Cost Estimate

Biomass Boiler Manufacturer Contract[1]

Line Item	Cost
100,000 Btu/hr biomass boiler, non-pressurized	$ 14,000
500 gallon thermal storage tank, non-pressurized	$ 2,000
2 cubic yard fuel hopper & fuel handling	$ 2,200
Freight	$ 1,500
Total Boiler Manufacturer Contract	**$ 19,700**

General Contract

Line Item	Cost
200,000 Btu/hr hydronic unit heaters	$ 4,000
Pumps, valves, heat exchanger, and piping	$ 5,000
Radiant floor system, with gravel overlay	$ 5,600
Mechanical	$ 6,000
Electrical	$ 2,000
Sub-Total	$ 22,600
Contractor profit, overhead, and insurance 16%	*$ 3,616*
Total General Contract Building and Site[2]	**$ 26,216**

Total Project Cost

Line Item	Cost
Project Sub-Total (Boiler, General Contract, Additional Items)	$ 45,916
Professional Services[3] 10%	*$ 4,592*
Contingency 15%	*$ 6,887*
Total Project Cost	**$ 57,395**

Notes:
1 - Assumes that biomass boiler and general contract are bid separately.
2 - Costs are approximate. Estimate is based on competitive bidding.
3 - Professional Services includes engineering, permitting, legal, and project management.

Appendix C –
UMN Extension By-Products Program Brochure

Why Recycle?

- Provide a beneficial use for products that were previously discarded in landfills
- Reduce landfill costs to government and industry and improve environmental quality by removing large volumes of by-products from concentrated landfill disposal
- Improve farm profitability by reducing fertilizer and lime costs
- Contribute to environmental quality and soil conservation by improving the economics of perennial forage crops as an alternative to row crops on more sensitive sites

Before any by-products are delivered to a field, the following requirements must be met:

1. Farmer must sign and follow Best Management Practices (BMP's)
2. Develop a farm plan, which includes crop rotation
3. Mapping and soil sampling of fields
4. Lease agreement signed if field is rented
5. Notification to township officers prior to hauling to site

If interested in receiving any of these by-products, contact the University of Minnesota Extension Service: Carlton County, P.O. Box 307, Carlton, MN (218) 384-3511 or 1-800-862-3760, ext. 223.

UNIVERSITY OF MINNESOTA
Extension
SERVICE

Carlton County

By-products Program

By-products Program

Wood Ash
Bio-Solids
Lime

By-product Program Resources

Troy Salzer
Extension Educator, Agriculture

Dr. Carl Rosen
Soil Scientist – Fertility

Dr. Tom Halbach
Water quality & Waste Mgmt

Russ Mathison
Forage Specialist

Bob Olen
Extension Educator, Horticulture

Dr. George Rehm
U of M Soil Scientist

Paul Peterson
Forage Specialist

MPCA
University Testing Labs
Forestry Specialists
Animal Science Specialists
University Dept on GIS/ Global Positioning

Wood Ash

Recycling wood ash saves valuable landfill space and provides farmers with an excellent liming source, as well as many of the nutrients needed to increase soil fertility. Wood ash increases soil pH and adds elements to the soil, which includes potassium, phosphorus, boron, and sulfur. Wood ash is delivered at no cost, but the farmer is responsible for spreading and incorporation.

There are eight local companies supplying wood ash. Listed below are the companies and the approximate amount of wood ash delivered annually.

	Tons	Acres
Minnesota Power	10,000	800
Georgia-Pacific, Duluth	400	50
Ainsworth, Bemidji	10,400	1,340
Trus Joist	1,300	220
Jardon Home Brands	125	15
Sappi Cloquet LLC	20,000	2,800
Potlatch, Bemidji	400	40
DNR Fisheries	30	10
TOTALS	42,280	5,285

Bio-Solids

Bio-solids are rich in organic matter and will provide nitrogen, along with small amounts of phosphorus, potassium, and lime. Additional commercial fertilizer may be needed to meet soil test recommendations. Each site for bio-solids must be approved by the Minnesota Pollution Control Agency.

However, not all fields qualify for bio-solids application due to soil pH, water table level, or slope. Records are kept to ensure that Best Management Practices are followed. Crops that would respond to the nitrogen in bio-solids are corn, grasses, legumes, and small grains.

Bio-solids are provided by the Western Lake Superior Sanitary District in Duluth, and are hauled, spread, and incorporated at no charge to the farmer.

Lime

We currently have three sources for by-product ag lime. The largest source is from Sappi Fine Paper of North America who delivers and spreads their lime at no cost to the farmers. This lime is made available as they produce it. The product is only produced during scheduled and unscheduled maintenance of the reclaiming kiln. The Effective Neutralizing Power (ENP) of this lime is 1300.

Cutler-Magner in Superior, WI has been the first source of by-product ag lime. The ENP of this lime is 1840. Loads are delivered with a semi-end dump with loads averaging 23 tons per load. The lime is free and the price farmers pay is based on distance from the plant.

Another source of by-product lime in Northeast Minnesota is from Specialty Minerals, Inc. in Cloquet. The ENP of this lime is 1600. This lime is a wet product that's good for certain applications. The lime and trucking are free to the farmer.

Benefits to participating in the By-products Program:

- Proven track record with over a decade of beneficial reuse of by-products
- University research used for application recommendations
- Education programs and field days for both industries and producers to share current research data and cropping improvement technologies
- Unbiased 3rd party involvement
- Provide educational programming to local decision makers/residents describing the research on the re-use benefits of these products.
- Assisting producers in developing environmentally sound crop management systems including the use of industrial by-products as soil amendments.
- Develop packets for individual fields including information about land ownership, soil types, soil analysis, and determine application rates based on crop type and soil analysis.
- Develop, research and secure funding for new potential uses for by-products.