Biomass Energy for the OSU-Cascades Campus

PRELIMINARY ANALYSIS

MAY 2017 • BEND, OR

PREPARED FOR

Oregon State University | Cascades

OSU-CASCADES
1500 SW CHANDLER AVE
BEND, OR 97702

FUNDED BY THE US FOREST SERVICE

WISEWOOD ENERGY • Technology in Service of Community and Environment

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Executive Summary

OSU-Cascades (OSU-C) is pursuing the ambitious goal of a net zero energy campus for its planned expansion in Bend, Oregon. Over the last year, this process has been led by a Long Range Development Planning (LRDP) team to craft design standards that will guide campus development through full buildout, including energy efficiency targets and options for renewable heat and power generation on site. The LRDP team has identified five scenarios ranging in energy efficiency, resulting energy demand, and renewable energy technology deployment. Each scenario includes a recommendation for central heating with biomass, and Wisewood Energy has been retained to develop a detailed design of a biomass system to meet the highest (Good scenario) and lowest (Best Plus scenario) energy demand of the campus at full buildout. This document represents Wisewood Energy's preliminary analysis, which will be further refined over the next few months.

Wisewood Energy's preliminary energy model calculated a total (between two boilers at full build out) ideal biomass boiler capacity of 14,000 MBH (4,000 kW) to meet 90% of the heat demand in the Good scenario. In this scenario, the biomass system would require approximately 5,300 green tons (GT) of biomass fuel per year. In the Best Plus scenario, a total ideal biomass boiler capacity of 6,000 MBH (1,600 kW) would meet 70% of the heating load, with the other 30% met by a geoexchange system. This system would require approximately 1,600 GT of biomass fuel per year. In both cases, the biomass system would be specifically designed to utilize hog fuel, a minimally processed wood chip with up to 55% moisture content. This material can be produced from local forest management activities and is the least expensive wood fuel.

The volume of fuel demand projected for both scenarios is small relative to the available biomass fuel in the Central Oregon region. A recent study investigating the availability of biomass in Jefferson, Crook, and Deschutes Counties determined that nearly 280,000 GT of biomass material is economically available each year. Additionally, in dry mixed-conifer, fire-adapted regions such as Central Oregon, restoration activities that generate biomass material as a byproduct contribute to improved forest health and a reduced risk of high-severity wildfire events. In the case of systems such as that proposed for OSU-C, which will utilize fuel generated as a byproduct and sourced from landscapes that benefit from fuel reduction treatments, and with a low volume requirement, carbon impacts are generally considered to be low or even beneficial.

The biomass system proposed for the OSU-C campus features combustion technology that employs dynamic feedback from oxygen and temperature sensors in the combustion chamber and flue gas stream, which optimizes the air-to-fuel ratio and results in optimum (clean) combustion characteristics and high efficiency, even with varying fuel quality. Wisewood Energy has also modelled both a multi-cyclone array and electrostatic precipitator (ESP) to further control particulate emissions to very low levels.

The OSU-C Central Utility Plant (CUP) will house the biomass boiler and related equipment, geoexchange pumps (if applicable), and biomass fuel storage. Wisewood Energy estimates this total footprint to be approximately 11,400 square feet in the Good Scenario or 8,900 square feet in the Best Plus scenario. Fuel deliveries may be once per week in warm months or up to ten times per week in colder weeks in the Good scenario, and three times per week in colder months for the Best Plus scenario. Considering fueling costs of biomass compared to natural gas business-as-usual (excluding costs associated with a geoexchange system), OSU-C is estimated to save approximately $272,000 in year one in the Good Scenario or approximately $77,000 in year one in the Best Plus scenario.

1 Project Background

Over the last year, OSU-Cascades (OSU-C) has been advancing its programmatic vision for the expansion of the OSU-C campus in Bend, Oregon. This has been led by a Long Range Development Planning team (LRDP) comprised of Page, SERA Architects, and PAE Engineers to craft design standards that will guide campus development towards net zero energy use at full buildout. As a part of these efforts, OSU-C has retained Wisewood Energy to work with the LRDP team and conduct a detailed analysis of a potential biomass energy system that would provide central heating to the campus.

The LRDP team has outlined five scenarios that represent increasingly energy efficient building design standards, with corresponding energy demand decreases for the 1.4 million square foot campus. These scenarios range from "Good" to "Best Plus"; the Good scenario represents business-as-usual energy efficiency building standards and campus energy demand, while the Best Plus scenario represents the highest energy efficiency standards and the lowest energy demand. The scenarios also vary in their inclusion of geothermal exchange for supplemental heating and the total square footage of solar photovoltaic development required to meet the campus electricity demand. Each scenario includes a biomass central utility plant (CUP). The Energy Trust of Oregon has determined that of the five scenarios, the standards and infrastructure recommended in the Best Plus scenario provide the most viable pathway to net zero energy usage over full campus buildout. These scenarios are summarized in Table 1.

TABLE 1 Energy scenario comparison adapted from PAE Engineers. Each scenario represents increasingly energy efficient building design standards, as demonstrated by the energy use intensity (EUI) metric measured in kBtu/sf/yr. "Plus" scenarios include geoexchange for supplemental heating and central cooling, and all scenarios include central heating with biomass. Wisewood Energy conducted its biomass analysis using the Good and Best Plus scenarios.

SCENARIO	DESCRIPTION	CAMPUS EUI	GEOTHERMAL	BIOMASS
Good	Biomass central heat Distributed cooling Buildings designed to code	79	No	Yes
Better	Biomass central heat Distributed cooling Buildings exceed code	56	No	Yes
Better Plus	Biomass and geoexchange central heating and cooling Buildings exceed code	49	Yes	Yes
Best	Biomass central heat Distributed cooling Buildings passive as applicable	38	No	Yes
Best Plus	Biomass and geoexchange central heating and cooling Buildings passive as applicable	33	Yes	Yes

To provide a comparison between the highest and lowest energy demand potential of the fully built campus, Wisewood Energy completed a preliminary analysis of a central biomass heating plant based on the Good and Best Plus scenarios. Key outputs from this analysis is provided below and summarized in Table 2 to help inform a group discussion regarding the potential benefits and tradeoffs of the proposed biomass system given the forest health and management, carbon storage, and air quality objectives for the region.

TABLE 2 Summary comparison of modelled Good and Best Plus biomass system scenarios.

	GOOD	BEST PLUS
Boiler Output (MBH)	14,000	6,000
Fuel Consumption (GT/YR*)	5,300	1,600
CUP Footprint**	11,400	8,900
On-Site Storage	196 tons	60 tons
Fuel Deliveries	1 - 10x per week	≤1 - 3x per week

*Assumes 35% moisture content wood fuel
**Footprint includes fuel storage

2 District Energy Model

The OSU-C campus will be developed over a period of a decade or more with clusters of residential, academic, and other facilities constructed in phases. Wisewood Energy's preliminary analysis applies to the anticipated full buildout of the future campus and thus represents the largest biomass energy system required to heat all planned campus buildings. Wisewood Energy's energy model uses key data inputs such as anticipated annual heating energy consumption, an estimate of the efficiency of heating sources, local historical weather data, and, in this case, interaction with a geoexchange system to calculate the biomass heating demand for the campus. The model is used to calculate the optimum biomass boiler size, which is defined as the boiler system that offsets the maximum fossil fuel consumption.

In the Good scenario, biomass provides 90% of central heating energy to the OSU-C campus; in the Best Plus scenario, it is supplemented by a geoexchange system. Geoexchange systems utilize the relatively constant temperature of the earth to supply heating or cooling energy to buildings as required. In cold climates such as Central Oregon, where heating requirements are much higher than cooling requirements, geothermal systems risk creating a net cooling effect on subsurface temperatures by pulling more heat from the earth in the winter than is returned to the earth in the summer. Over time, this can lead to poor heat pump performance and even geofield failure due to freezing.

PAE has recommended that an OSU-C geoexchange system be sized to meet the campus cooling load, which is smaller than the campus heating demand. By doing so, the system is not likely to create a net cooling effect on the geoexchange field. At this size, the geoexchange system will have the capacity to meet approximately 30% of the campus heating demand, while the biomass system will be sized to meet the remaining 70% of the heating demand.

In both the Good and Best Plus scenarios, the system would include a natural gas boiler to supplement the biomass boiler and provide backup. This arrangement would provide a wide range of heat output while maintaining very high efficiency.

2.1 HEAT DEMAND AND BOILER SIZE

To determine the optimum biomass boiler size for the planned OSU-C system, PAE staff provided Wisewood Energy with an estimate of thermal load data for the full campus buildout in both the Good and Best Plus scenarios. This data was calculated based on the programmatic and energy use intensity guidelines developed by the LRDP team.

Wisewood Energy's preliminary energy model calculated a total (between two boilers at full build out) ideal biomass boiler capacity of 14,000 MBH (4,000 kW) to meet 90% of the heat demand in the Good scenario; the remaining 10% is provided by a natural gas boiler. In this scenario, the biomass system would require approximately 5,300 green tons (GT) of biomass fuel per year, assuming 35% moisture content. In the Best Plus scenario, a total (between two boilers at full build out) ideal biomass boiler capacity of 6,000 MBH (1,600 kW) would meet 70% of the heating load, with the other 30% met by a geoexchange system. This system would require approximately 1,600 GT of biomass fuel per year, assuming 35% moisture content.

For the heat pumps planned for heating and cooling distribution within campus buildings, Wisewood Energy's energy model includes an assumed average coefficient of performance (COP) value of 5 – e.g., we assume that very efficient heat pumps will be selected. This is a conservative value for the purposes of the biomass boiler sizing and, if lowered significantly (i.e. the heat pumps selected are less efficient), the biomass boilers could become slightly smaller because the heat pumps themselves would give off more electricity-generated heat (which is more expensive than wood-generated heat). The LRDP and PAE should consider what minimum COP will be recommended as a design standard for the campus before finalizing boiler sizing.

Wisewood Energy's preliminary energy models for the Good and Best Plus OSU-C campus scenarios are included in Appendix A and B, respectively.

3 Fuel Consumption and Supply

3.1 REGIONAL CONTEXT

Central Oregon is home to two USDA Forest Service (USFS) national forests, Bureau of Land Management (BLM) rangelands, Tribal lands, an Oregon state forest, and private forest and rangelands. In the tri-county area of Jefferson, Crook, and Deschutes Counties, 65% of the landscape is federally owned and managed and restoration and wildfire mitigation objectives are prioritized. There is wide agreement that active forest management such as fuel reduction treatments can improve forest health and contribute to a reduced risk of high-severity wildfire in dry mixed-conifer forests similar to those in Central Oregon[1,2]. On the Deschutes National Forest, the Deschutes Collaborative Forest Project (DCFP) is spearheading a collaborative approach to increasing such active management activities and raising awareness around the benefits of doing so. In

[1] Ecological Restoration Institute (ERI). 2013. *The efficacy of hazardous fuel treatments: A rapid assessment of the economic and ecologic consequences of alternative hazardous fuel treatments: A summary document for policy makers.* Northern Arizona University. 28p

[2] Agee, James K. and Carl N. Skinner. 2005. Basic principles of forest fuel reduction treatments. *Forest Ecology and Management* 211(1-2): 83-96

2008, the DCFP was awarded a competitive ten-year contract from the US Forest Service to restore 257,000 acres of forest in Central Oregon, including the current West Bend project.

These types of management activities generate approximately 10 GT of non-merchantable biomass material per treated acre on federal lands, and forest operators are typically able to negotiate whether removing this material is required under their contract. When no market exists, USFS staff will often masticate or pile and burn the remaining biomass to reduce fuel loadings. When markets exist, management costs and emissions from pile burning are reduced.

3.2 FUEL QUALITY

Modern, computer-controlled biomass-fired boilers are available for all levels of thermal outputs, from small-scale systems sized for individual residences to large-scale systems capable of heating entire cities. While each of these systems is able to sustain clean combustion by utilizing automatic controls and continuous emissions monitoring, their respective fuel quality requirements are largely dictated by the size of the system. In general, the smaller the system, the narrower the requirements for fuel quality; the larger the system, the broader the fuel types it can handle.

The wood fuel quality spectrum is defined by particle size, moisture content, and ash content, and has traditionally been bordered on the high end by premium wood pellets suitable for burning in small pellet boilers and stoves and on the low end by "hog fuel," a lightly processed fuel material typically comprised of bark, tops, and limbs from forest activities and other non-marketable woody biomass. To produce hog fuel, pre-commercial woody material generated during forest management or urban tree pruning activities is chipped or ground up, resulting in a range of particle sizes, moisture contents, and ash contents. In contrast, "select" wood chips have been processed to control for particle size and moisture content, and lie on the fuel spectrum between pellets and hog fuel. Because it is minimally processed and requires little-to-no seasoning to reduce moisture content, hog fuel wood chips represent the most readily available and inexpensive biomass fuel.

Types of Biomass Fuels

Wood Pellets Densified sawdust, shavings, chips, and other wood residuals, typically produced as a byproduct of manufacturing.

Clean Chips Whole-tree wood chips that have been processed to a particular size and moisture content, typically free of bark.

Hog Fuel Wood chips produced from low value management byproduct such as bark, limbs, and tops, with no active drying.

The recommended OSU-C boiler system would be specifically designed to efficiently combust a range of wood fuels, including minimally processed hog fuel wood chips. As such, the system will create a demand for material that can be generated directly from forest management and restoration activities for which few markets currently exist, thus helping to offset the cost of forest management in the surrounding area.

3.3 FUEL SUPPLY

A recent report commissioned by the Central Oregon Intergovernmental Council (COIC) examined the availability of biomass in the Central Oregon tri-county area, including from timber harvest residuals, forest restoration and fuels treatments, western juniper removal, forest products manufacturing residuals, urban wood waste, and residential tree trimming and fire safe treatments. According to the report, over 670,000 GT of biomass material (assuming 35% moisture content) is potentially available per year in the studied region, which includes all identified sources and excludes set-aside areas such as wilderness areas. After accounting for steep slopes and other conditions that limit the accessibility of material, over 430,000 GT/year is technically available in the region. Finally, adjusting for existing uses of this material results in over 270,000 GT/year economically available. This information is summarized in Table 3 below. This supply of biomass material is further supported by Deschutes National Forest staff, who reported an average of 81,000 GT of residual biomass produced on the National Forest each year over the last five years.

TABLE 3 Summary of biomass availability in the Jefferson, Crook, and Deschutes tri-county area, assuming 35% moisture content. Adapted from the Central Oregon Biomass Supply Analysis (2016), which was prepared by TSS Consultants for COIC.

SOURCE	POTENTIALLY AVAILABLE (GT/YR)	TECHNICALLY AVAILABLE (GT/YR)	ECONOMICALLY AVAILABLE (GT/YR)
Timber Harvest Residuals	197,941	150,290	90,675
Forest Restoration and Fuel Treatment Residuals	281,538	206,500	146,885
Western Juniper Treatment Residuals	177,769	71,108	40,338
Forest Products Manufacturing Residuals	0	0	0
Construction and Demolition	10,917	7,095	173
Tree Trimming	3,306	2,149	1,440
TOTAL	**671,472**	**437,143**	**279,512**

3.4 CARBON IMPACTS

Energy generated from sustainably-derived biomass is considered carbon neutral in the European Union and under the reporting rules of the United Nations Framework Convention on Climate Change. The European Environment Agency and US EPA do not consider biomass to be carbon neutral *a priori*, although the US EPA has stated it plans to recognize the carbon benefits of biomass feedstocks sourced from waste streams and sustainable forest practices as defined contextually on a state-by-state basis[3]. In general, the carbon impacts of biomass depend on site-specific characteristics such as the feedstock source and management practices, energy technology employed, and the fuel being displaced.

[3] US EPA, Office of Air and Radiation Office of Atmospheric Programs, Climate Change Division. 2014. Framework for Assessing Biogenic CO2 Emissions from Stationary Sources.

A recent literature review on the carbon impacts of biomass energy systems found that systems that utilize the byproduct of management activities, such as the fuels that the proposed OSU-C system would be capable of sourcing, result in greenhouse gas benefits "virtually instantaneously, to within a few years, or a few decades,"[4]. Furthermore, studies that have compared the controlled combustion of biomass in energy systems to open pile burning conclude that emission reduction benefits are realized immediately, both for carbon and other air pollutants. This is important to note, considering the common practice of pile burning biomass that is left after management activities in Central Oregon.

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Incorporating wildfire dynamics in carbon accounting for fire-adapted landscapes such as the dry mixed-conifer forests in Central Oregon has proven to be challenging. Impacts depend on the probability of fire occurrence, fire size, fire severity, the probability of a state change to non-forest cover after fire, and the prescribed treatment for wildfire mitigation. In cases in which management objectives include a return to more historic fire regimes, increasing carbon sequestration may need to be balanced with other regionally-appropriate forest health priorities.

The selected energy conversion technology also influences carbon impacts of biomass energy systems. Thermal-only and combined heat-and-power production technologies provide the highest conversion efficiencies of biomass technologies (greater than 85%), and so offer the quickest carbon benefits relative to displaced fossil fuels.

4 Central Utility Plant

THE LRPD has identified a potential site for the Central Utility Plant (CUP) that will house the biomass boiler(s) and related equipment, geoexchange pumps (if applicable), and primary biomass fuel storage. The final site selection will influence the equipment layout, access for fueling, available fuel storage, and piping routes to connected buildings.) The current footprint of each of Wisewood's preliminary layouts is shown overlaid on the CUP location map provided by the LRDP (see Attachments C and D for the Good and Best Plus scenarios, respectively); some adjustments to the CUP footprint may be required if the CUP site boundaries shown are fixed.

4.1 CENTRAL UTILITY PLANT LAYOUT

In each scenario, the CUP would be built out in two phases while the campus as a whole is developed over several years. To start, the boiler building and one complete boiler system will be installed to serve the initial buildings brought online, including capacity to heat additional buildings in the near-term. In a subsequent phase, once the campus heating demand surpasses the capacity of the phase 1 boiler system, a second complete boiler system will be installed. The current proposed phasing plans include two equally sized biomass boilers in mirror image of each other; as the LRDP team finalizes the campus buildout schedule and

[4] Kittler, B. 2017. Biogenic Carbon Emissions and Bioenergy Systems: A Brief Literature Review. Produced by the Pinchot Institute for Conservation.

the relative size and heating demand of each building is clarified, these boiler sizes may be adjusted to best serve the campus throughout the development period. As discussed in Section 2 above, biomass boilers are most efficient when their size is closely matched to their heat demand; if they are oversized, efficiency is reduced. Wisewood Energy's preliminary plant layouts for the Good and Best Plus scenarios are provided in Attachments E and F respectively.

The estimated CUP footprint, including a fuel storage area for approximately one week of heating during the coldest weather, is approximately 11,400 square feet in the Good scenario and 8,900 square feet in the Best Plus scenario. A small front-end loader will be needed to occasionally push the fuel piles toward the walking floor fuel feed and assist during fuel deliveries to push fuel to either side of the storage area. OSU-C may also wish to have a designated secondary storage site (on- or off-campus) so that additional pre-purchased wood fuel is readily available to reduce overall fuel procurement risk.

To provide the lowest cost fuel (hog fuel), biomass will be delivered using 48-ft trucks with a walking floor trailer, which allows a large volume of chips to be conveyed out of the trailer and into the storage area without the use of a truck tipper. Wisewood estimates that in the Good scenario, fuel deliveries will occur up to ten times per week during the coldest months; in the Best Plus scenario, the maximum frequency of deliveries reduces to up to three times per week during the coldest months. In both scenarios, deliveries will be once or less per week during the warmest months.

4.2 FUELING COSTS

In addition to the positive regional environmental impacts a biomass system can have, the budget impacts can be immediately seen when comparing the relative costs of fossil and wood fuels. Wisewood Energy estimates annual fueling costs to be approximately $232,000 in the Good Scenario and $72,000 in the Best Plus scenario, including biomass fuel, trim natural gas use, and electricity. Hog fuel biomass is estimated to be $25 per GT (assuming 35% moisture content) based on Wisewood's experience in the area. Comparing only the fueling costs of the Good and Best Plus scenarios to natural gas business-as-usual scenarios, in year 1 OSU-C is estimated to save approximately $272,000 in the Good Scenario or $77,000 in the Best Plus scenario. See Table 4 for a summary comparison of business-as-usual and biomass scenarios.

TABLE 4 Summary fueling cost comparison of business-as-usual natural gas systems and proposed biomass systems for both the Good and Best Plus scenarios, rounded to the nearest $1,000. These fueling costs do not include costs of operating a geoexchange system or general maintenance labor.

FUEL SOURCE	NATURAL GAS BAU GOOD SCENARIO	BIOMASS GOOD SCENARIO	NATURAL GAS BAU BEST PLUS SCENARIO	BIOMASS BEST PLUS SCENARIO
Natural Gas	$502,000	$48,000	$148,000	$9,000
Biomass		$134,000		$41,000
Electricity	$2,000	$50,000	$1,000	$22,000
TOTAL	**$504,000**	**$232,000**	**$149,000**	**$72,000**

5 Emissions and Air Quality

Typically, the emission of greatest concern for air quality from biomass energy systems is particulate matter, or fine particles of dust. In general, modern biomass boiler systems have approximately twenty times less particulate emissions than EPA-certified wood stoves. As discussed above, biomass combusted in a controlled boiler system is also significantly cleaner than open pile burning or wildfires, which is particularly relevant in the fire-adapted landscape of Central Oregon. Furthermore, the type of biomass system recommended for the OSU-C campus features additional combustion technology that employs dynamic feedback from oxygen and temperature sensors in the combustion chamber and flue gas stream, which optimizes the air-to-fuel ratio and results in optimum (clean) combustion characteristics and efficiency, even with varying fuel quality.

Regardless of combustion controls, some amount of particulate matter will still be entrained in the flue gas stream and will need to be reduced using a flue gas cleaning system. For both the Good and Best Plus scenarios, Wisewood modelled a flue gas cleaning system that includes two devices: 1) a multi-cyclone array; and 2) an electrostatic precipitator (ESP). A multi-cyclone can achieve an approximate 75% reduction in total particulate matter (TPM) from the flue gas stream, which may be insufficient as a single control device given the public-facing nature of the OSU-C campus. In combination with an ESP, however, the system can achieve a 90-95% reduction in TPM. An ESP functions most efficiently if it is paired with a multi-cyclone, as opposed to serving as the single control device. The resulting flue gas is very clean and, in combination with a properly-sized flue stack, will have little impact on the total particulate load in the ambient air near the OSU-C campus.

Modern biomass boiler systems have ~20x less particulate emissions than EPA-certified wood stoves.

Table 5 includes the estimated air pollutant emissions for the proposed OSU-C biomass system in the Good and Best Plus scenarios. This data is calculated from emission factors produced from a third-party audit of a similarly sized and designed biomass system in Europe, and includes the use of an ESP system to address particulate matter.

TABLE 5 Annual estimated emissions discharge for the Good and Best Plus scenarios. Data is based on emission factors generated by a third-party audit of a similar boiler system in Europe, including an ESP to address particulate matter.

EMISSION	GOOD (TONS/YR)	BEST PLUS (TONS/YR)
Carbon Monoxide (CO)	0.899	0.276
Nitrogen Oxides (NOx)	6.301	1.932
Particulate Matter (PM)	0.281	0.086
Volatile Organic Compounds (VOC)	0.112	0.034
TOTAL	**7.593**	**2.329**

6 Conclusions

OSU-Cascades is pursuing the ambitious goal of net zero energy use for the planned campus expansion in Bend, Oregon. In addition to highly energy efficient campus building standards, selecting the most appropriate renewable energy technology for site heat and power systems will ensure the campus can achieve this goal. The OSU-C LRDP team has recommended that a biomass system provide central heating in each of the five campus buildout scenarios, ranging from Good to Best Plus. While both modeled biomass systems are modest in size, fuel requirements, and emissions, the Best Plus scenario represents an efficient and precise implementation of biomass energy that allows an optimal incorporation of geoexchange sized to provide 100% of cooling and 30% of heating needs, while relying on biomass to provide the additional heating requirements. This avoids overbuilding the geoexchange fields, which can be expensive to construct, and provides energy redundancy. In the Best Plus scenario, new structures are held to aggressive efficiency standards, and biomass is paired with a geoexchange system to optimize the available energy sources at the site. This limits biomass to the minimum size required to efficiently and consistently provide heat without overtaxing geothermal resources. As such, the Best Plus scenario demonstrates a sustainable energy approach that is thoughtful and site-specific, maximizing the local ecologic and economic benefits of biomass development while minimizing potential concerns.

ATTACHMENT A

Energy Model

Good Scenario

OSU Cascades - Good Scenario

Proposed System Analysis

WISEWOOD ENERGY

Location	Bend, Oregon	**Proposed System**	Biomass Boiler Installation	**Contact**	Andrew Haden
Client Contact	Jane Barker	**Proposed System Output (MBH)**	14,000	**Phone**	(503) 706-6187
Date	5/3/17	**Proposed System Fuel Type**	Wood Chips	**Email**	andrew@wisewoodenergy.com

Fuel Prices		**Conversion Factors**		**Proposed System Consumption**	
Natural gas cost [$/MMBtu]	$9.00	Energy per kWh [Btu/kWh]	3,412	Total energy input [MMBtu/yr]	62,710
Electricity demand cost [$/kW]	$6.00	Moisture of biomass [% MC WB]	35%	Cost if 100% heated with natural gas [$/yr]	$627,098
Electricity cost [$/kWh]	$0.08	Energy of bone dry wood [Btu/ton]	16,400,000	Energy from geofield	0%
Biomass fuel cost [$/ton]	$25.00	Energy of actual biomass [Btu/ton]	9,980,720	Energy from geofield [MMBtu/yr]	0

Heat Pump Operations					
Heat pump COP	5	Heat pump electrical consumption [kWh]	3,675,837	Remaining energy input [MMBtu/yr]	50,168
Heat from heat pump losses [MMBtu/yr]	12,542	Heat pump electrical cost [$/yr]	$294,067	Cost if remaining heat from natural gas [$/yr]	$501,678

"Business as Usual" Proposed System Values (Geofield + Natural Gas)					
Boiler efficiency	90%	Heating device nameplate, [MBH]	30,000	Operating hours per day	21
Max. electrical demand [kW]	9.12	Boiler output, low-fire [MBH]	3,750	Total Heat input [MMBtu/HDD]	10.15
Average electrical demand [kW]	2.49	Average boiler output [MBH]	8,181	Non-geofield energy input [MMBtu/HDD]	8.12

Proposed Biomass Boiler Specifications		**Proposed Trim Boiler Specifications**		**Proposed System Values**	
Fuel type	Wood Chips	Fuel type	Natural gas	Load carried by wood, as %	90.4%
Boiler output, high-fire [MBH]	14,000	Boiler output, high-fire [MBH]	30,000	Operating hours per year	6,678
Boiler output, low-fire* [MBH]	1,750	Boiler output, low-fire [MBH]	3,750	Biomass boiler output [% of peak]	45%
Max. electrical demand [kW]	126.5	Max. electrical demand [kW]	9.1		
Average electrical demand [kW]	73.9	Average electrical demand [kW]	1.14		
Boiler efficiency	85%	Boiler efficiency	90%		

Proposed Biomass Boiler Consumption and Cost		**Proposed Trim Boiler Consumption and Cost**		**Proposed Totals**	
Wood fuel consumption [tons/yr]	5,343	Natural gas consumption [MMBtu/yr]	5,374	Total fuel consumption [MMBtu/yr]	53,331
Wood fuel cost [$/yr]	$133,584	Natural gas cost [$/yr]	$48,367	Total fuel cost [$/yr]	$181,952
Electrical consumption [kWh/yr]	493,807	Electrical consumption [kWh/yr]	7,613	Total electrical consumption [kWh/yr]	501,420
Electrical energy cost [$/yr]	$39,505	Electrical use charge [$/yr]	$609	Total electrical use charge [$/yr]	$40,114
Electrical demand charge [$/yr]	$9,111	Electrical demand charge [$/yr]	$657	Total electrical demand charge [$/yr]	$9,767

Month	Heating Degree Days [HDD]	Projected total energy input [MMBtu]	Projected non-geofield energy input [MMBtu]	Projected biomass boiler gross energy consumption [MMBtu]	Projected trim boiler energy consumption [MMBtu]	Projected wood fuel use [tons]
September	245	2,491	1,993	2,119	214	212
October	424	4,308	3,446	3,663	369	367
November	936	9,502	7,601	8,080	814	810
December	971	9,855	7,884	8,381	845	840
January	875	8,887	7,110	7,558	762	757
February	697	7,079	5,663	6,020	607	603
March	620	6,296	5,037	5,355	540	537
April	634	6,437	5,149	5,474	552	548
May	379	3,844	3,075	3,269	329	328
June	141	1,429	1,144	1,216	123	122
July	123	1,253	1,002	1,065	107	107
August	131	1,329	1,063	1,130	114	113
Yearly Total	6,177	62,710	50,168	53,331	5,374	5,343

* Low-fire output includes the use of a 1,000-gallon thermal storage to increase effective boiler turndown

Net fossil energy savings [MMBtu/yr] 57,336

OSU Cascades - Good Scenario

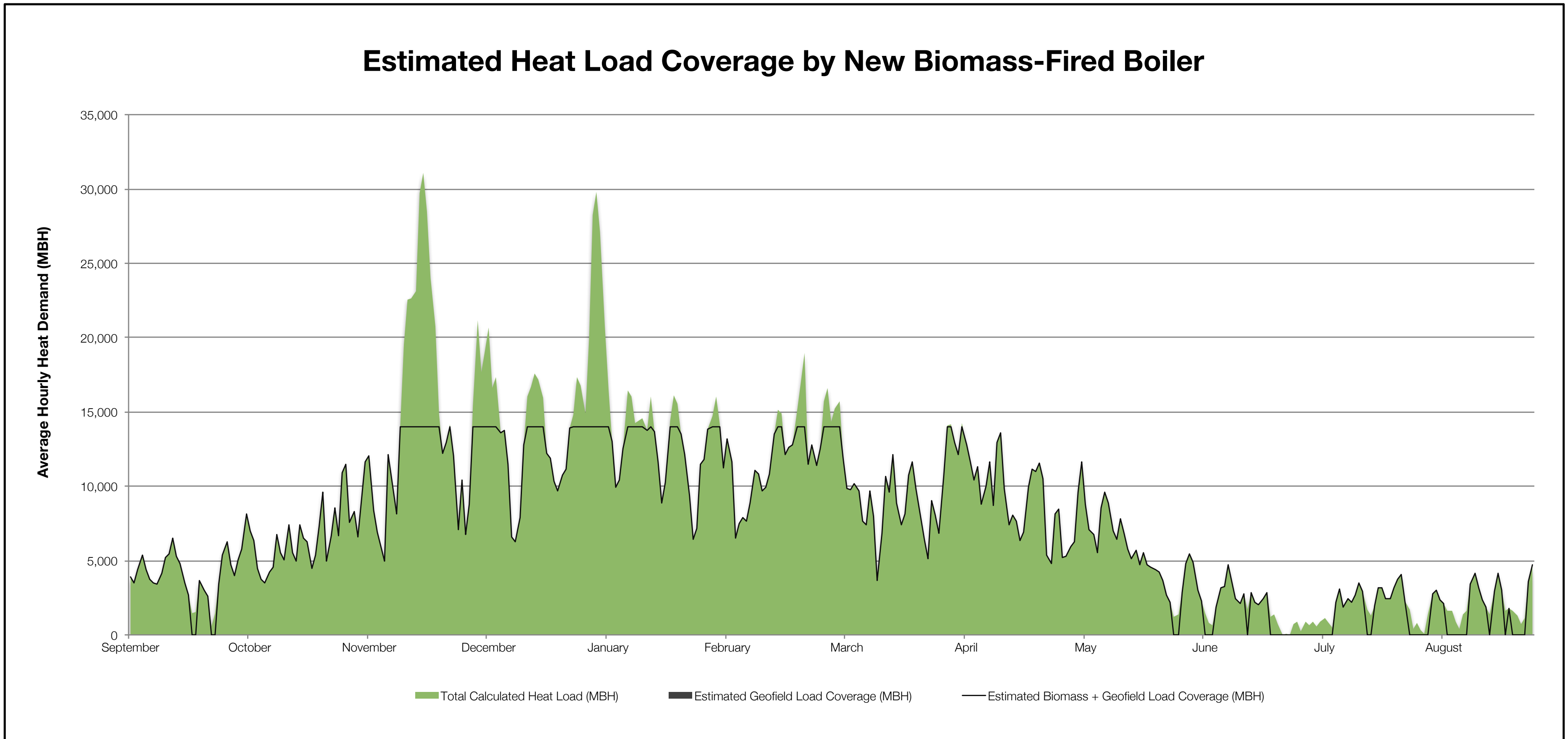
Proposed System Analysis

WISEWOOD ENERGY

Location Bend, Oregon
Client Contact Jane Barker
Date 5/3/17

Proposed System Biomass Boiler Installation
Proposed System Output (MBH) 14,000
Proposed System Fuel Type Wood Chips

Contact Andrew Haden
Phone (503) 706-6187
Email andrew@wisewoodenergy.com



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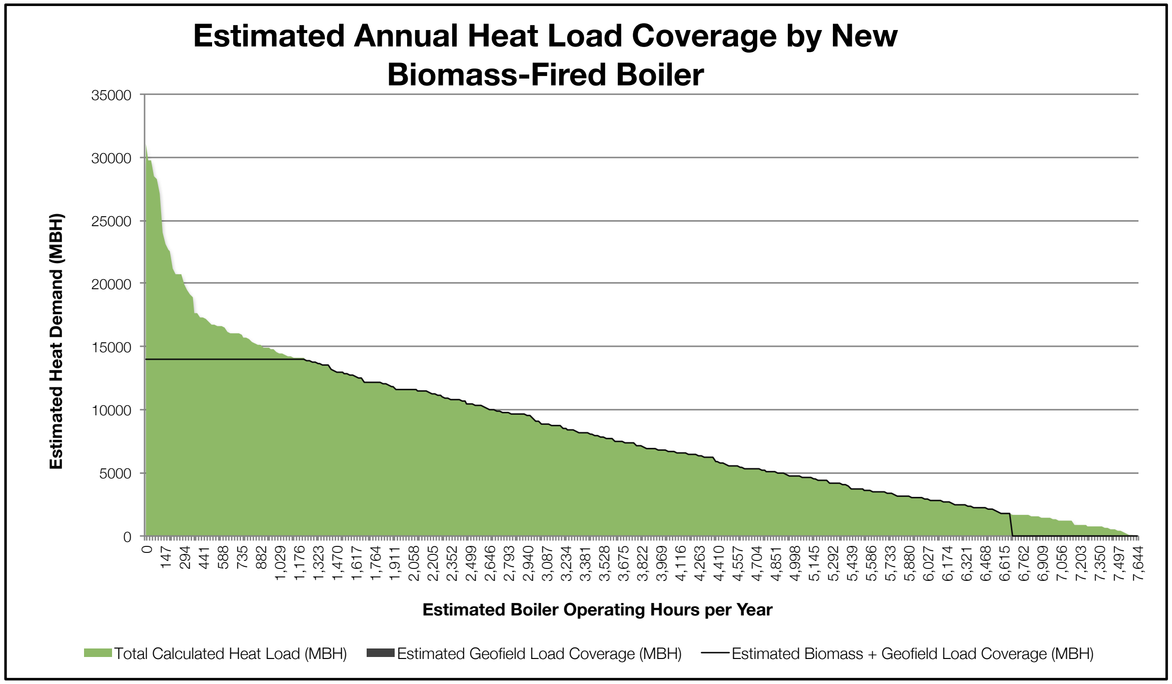

Boiler Output [MBH]	Fossil Fuel Displaced
8,000	69.5%
9,000	74.7%
10,000	79.1%
11,000	83.0%
12,000	86.0%
13,000	88.6%
14,000	90.4%
15,000	91.8%
16,000	93.0%
17,000	93.9%
18,000	94.1%
19,000	94.4%
20,000	94.5%
21,000	94.9%
22,000	95.0%
23,000	94.8%
24,000	94.5%
25,000	94.6%
26,000	94.1%
27,000	94.3%
28,000	93.7%
29,000	93.5%
30,000	93.2%
31,000	92.8%
32,000	92.7%

ATTACHMENT B

Energy Model

Best Plus Scenario

OSU Cascades - Best Plus Scenario

Proposed System Analysis

WISEWOOD ENERGY

Location	Bend, Oregon	**Proposed System**	Biomass Boiler Installation	**Contact**	Andrew Haden
Client Contact	Jane Barker	**Proposed System Output (MBH)**	6,000	**Phone**	(503) 706-6187
Date	5/3/17	**Proposed System Fuel Type**	Wood Chips	**Email**	andrew@wisewoodenergy.com

Fuel Prices		**Conversion Factors**		**Proposed System Consumption**	
Natural gas cost [$/MMBtu]	$9.00	Energy per kWh [Btu/kWh]	3,412	Total energy input [MMBtu/yr]	29,543
Electricity demand cost [$/kW]	$6.00	Moisture of biomass [% MC WB]	35%	Cost if 100% heated with natural gas [$/yr]	$295,433
Electricity cost [$/kWh]	$0.08	Energy of bone dry wood [Btu/ton]	16,400,000	Energy from geofield	30%
Biomass fuel cost [$/ton]	$25.00	Energy of actual biomass [Btu/ton]	9,980,720	Energy from geofield [MMBtu/yr]	8,863

Heat Pump Operations					
Heat pump COP	5	Heat pump electrical consumption [kWh]	1,731,728	Remaining energy input [MMBtu/yr]	14,772
Heat from heat pump losses [MMBtu/yr]	5,909	Heat pump electrical cost [$/yr]	$138,538	Cost if remaining heat from natural gas [$/yr]	$147,716

"Business as Usual" Proposed System Values (Geofield + Natural Gas)					
Boiler efficiency	90%	Heating device nameplate, [MBH]	14,000	Operating hours per day	21
Max. electrical demand [kW]	4.26	Boiler output, low-fire [MBH]	1,750	Total Heat input [MMBtu/HDD]	4.78
Average electrical demand [kW]	1.17	Average boiler output [MBH]	3,854	Non-geofield energy input [MMBtu/HDD]	2.39

Proposed Biomass Boiler Specifications		**Proposed Trim Boiler Specifications**		**Proposed System Values**	
Fuel type	Wood Chips	Fuel type	Natural gas	Non-geofield load carried by wood, as %	94.1%
Boiler output, high-fire [MBH]	6,000	Boiler output, high-fire [MBH]	14,000	Operating hours per year	6,384
Boiler output, low-fire* [MBH]	750	Boiler output, low-fire [MBH]	1,750	Biomass boiler output [% of peak]	41%
Max. electrical demand [kW]	54.2	Max. electrical demand [kW]	4.3		
Average electrical demand [kW]	34.8	Average electrical demand [kW]	0.53		
Boiler efficiency	85%	Boiler efficiency	90%		

Proposed Biomass Boiler Consumption and Cost		**Proposed Trim Boiler Consumption and Cost**		**Proposed Totals**	
Wood fuel consumption [tons/yr]	1,639	Natural gas consumption [MMBtu/yr]	967	Total fuel consumption [MMBtu/yr]	16,354
Wood fuel cost [$/yr]	$40,965	Natural gas cost [$/yr]	$8,704	Total fuel cost [$/yr]	$49,669
Electrical consumption [kWh/yr]	222,396	Electrical consumption [kWh/yr]	3,396	Total electrical consumption [kWh/yr]	225,792
Electrical energy cost [$/yr]	$17,792	Electrical use charge [$/yr]	$272	Total electrical use charge [$/yr]	$18,063
Electrical demand charge [$/yr]	$3,905	Electrical demand charge [$/yr]	$306	Total electrical demand charge [$/yr]	$4,211

Month	Heating Degree Days [HDD]	Projected total energy input [MMBtu]	Projected non-geofield energy input [MMBtu]	Projected biomass boiler gross energy consumption [MMBtu]	Projected trim boiler energy consumption [MMBtu]	Projected wood fuel use [tons]
September	245	1,174	587	650	38	65
October	424	2,029	1,015	1,123	66	113
November	936	4,476	2,238	2,478	147	248
December	971	4,643	2,321	2,570	152	258
January	875	4,187	2,093	2,318	137	232
February	697	3,335	1,668	1,846	109	185
March	620	2,966	1,483	1,642	97	165
April	634	3,032	1,516	1,679	99	168
May	379	1,811	905	1,002	59	100
June	141	673	337	373	22	37
July	123	590	295	327	19	33
August	131	626	313	347	20	35
Yearly Total	6,177	29,543	14,772	16,354	967	1,639

* Low-fire output includes the use of a 1,000-gallon thermal storage to increase effective boiler turndown

Net fossil energy savings [MMBtu/yr]	28,576

OSU Cascades - Best Plus Scenario

Proposed System Analysis

Location Bend, Oregon
Client Contact Jane Barker
Date 5/3/17

Proposed System Biomass Boiler Installation
Proposed System Output (MBH) 6,000
Proposed System Fuel Type Wood Chips

Contact Andrew Haden
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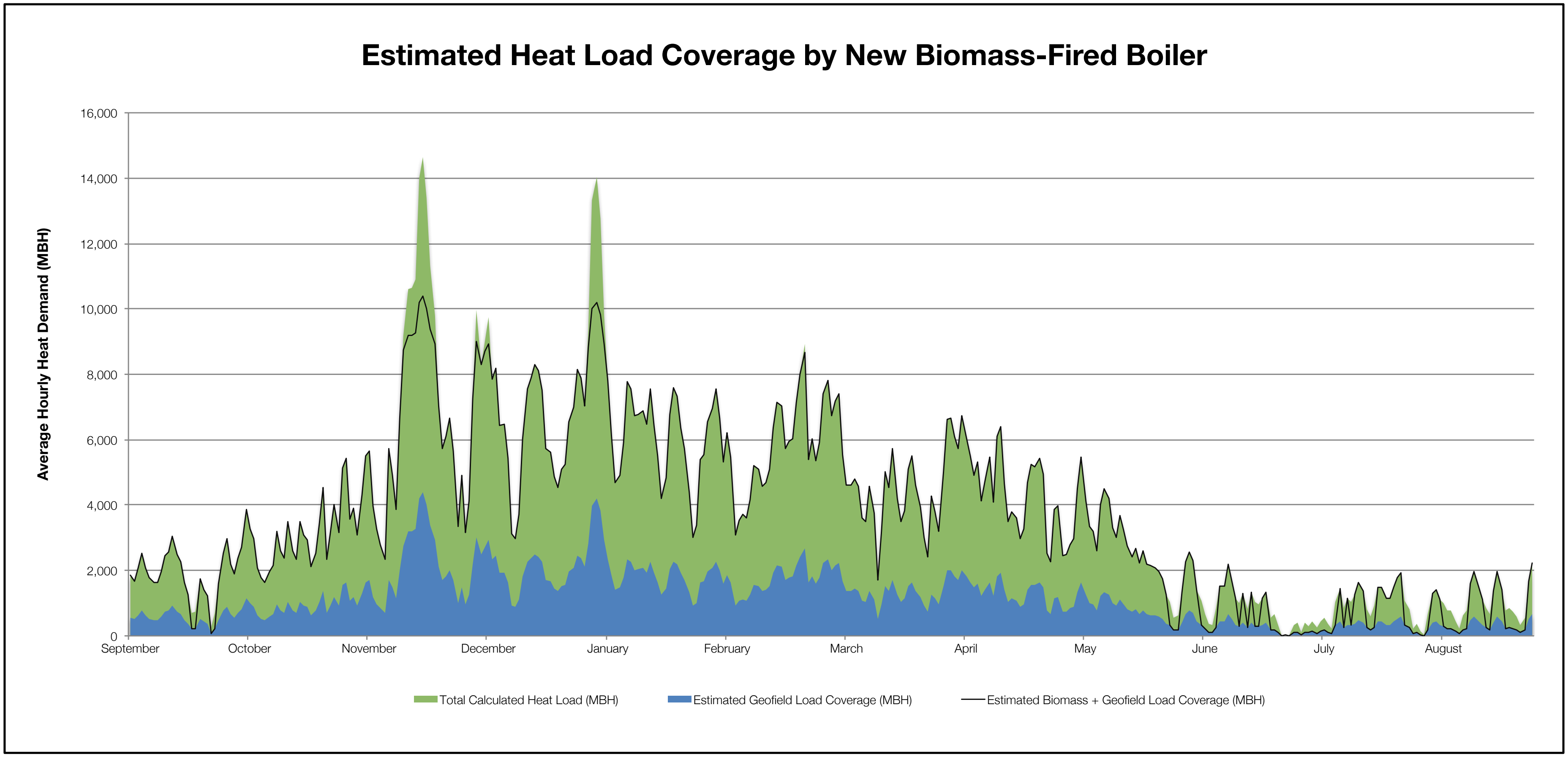
Email andrew@wisewoodenergy.com



OSU Cascades - Best Plus Scenario

Proposed System Analysis

Location Bend, Oregon
Client Contact Jane Barker
Date 5/3/17

Proposed System Biomass Boiler Installation
Proposed System Output (MBH) 6,000
Proposed System Fuel Type Wood Chips

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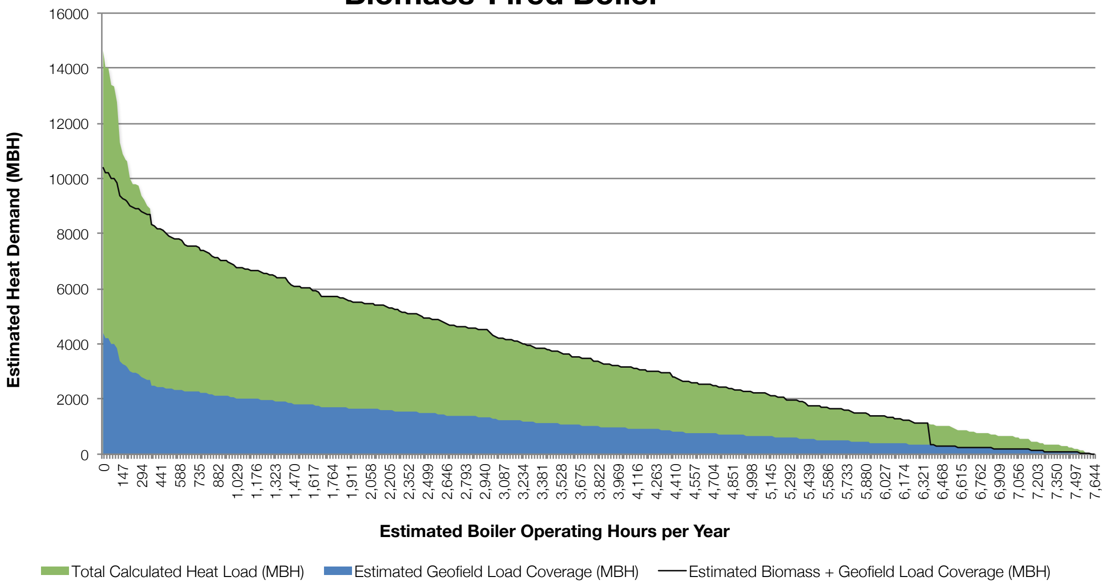
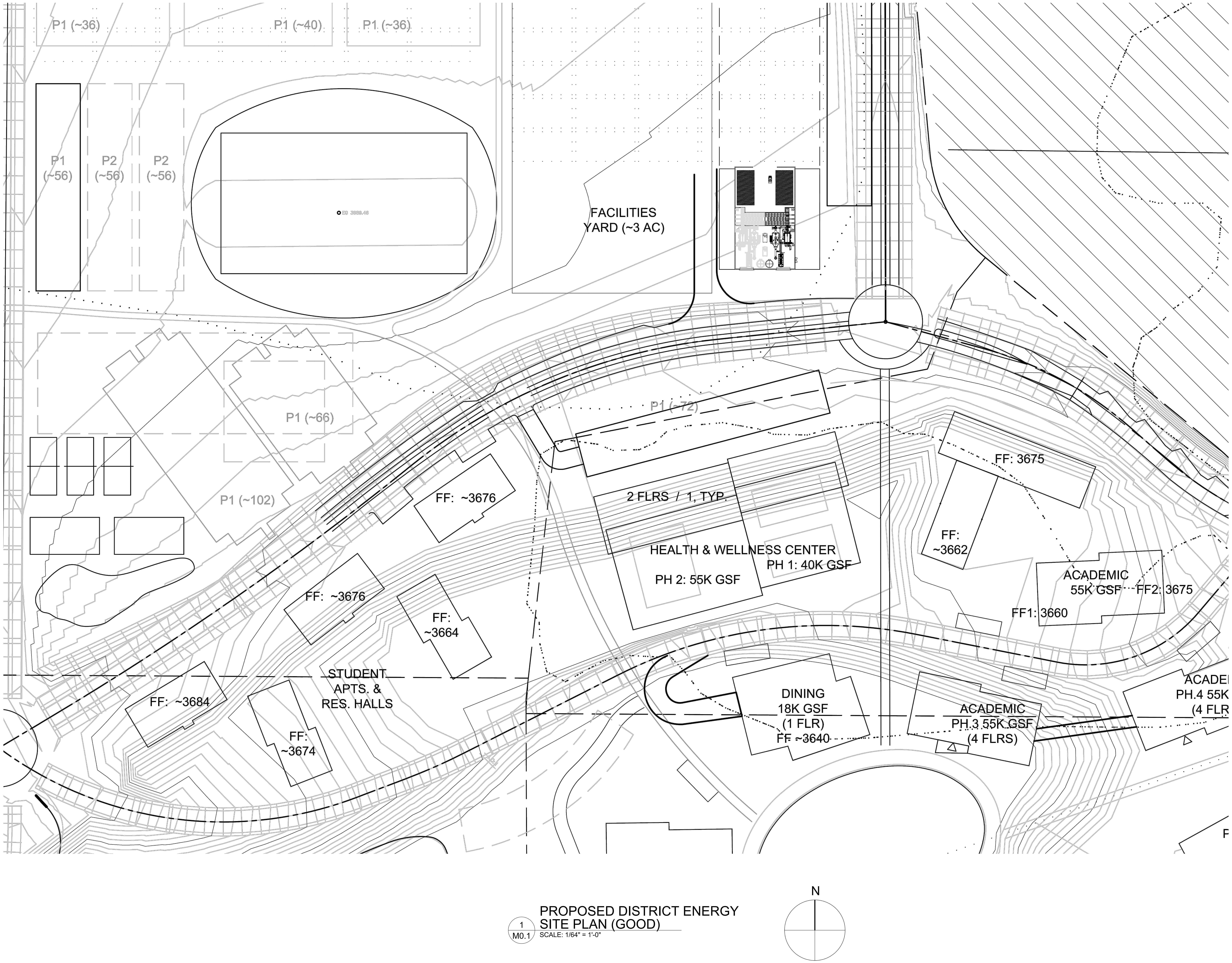


Boiler Output [MBH]	Fossil Fuel Displaced
3,000	75.1%
3,500	81.6%
4,000	86.4%
4,500	89.6%
5,000	92.0%
5,500	93.6%
6,000	94.1%
6,500	94.5%
7,000	95.0%
7,500	94.8%
8,000	94.5%
8,500	94.2%
9,000	94.1%
9,500	93.4%
10,000	92.8%
10,500	92.7%
11,000	92.0%
11,500	91.7%
12,000	90.8%
12,500	89.9%
13,000	89.2%
13,500	88.4%
14,000	87.5%
14,500	86.3%
15,000	85.3%

ATTACHMENT C

Preliminary Site Plan

Good Scenario



1 M0.1 PROPOSED DISTRICT ENERGY SITE PLAN (GOOD)

SCALE: 1/64" = 1'-0"

OWNER

OSU CASCADES

BEND OREGON

PROJECT

BIOMASS BOILER SYSTEM

DESIGN FIRM

WISEWOOD ENERGY
TEL. 503.608.7366
FAX 503.715.0483
INFO@WISEWOODENERGY.COM
WWW.WISEWOODENERGY.COM
2409 N KERBY AVENUE
PORTLAND, OR 97227

DRAWING TITLE

PROPOSED DISTRICT ENERGY SITE PLAN (GOOD)

REV	DESCRIPTION	DATE
A	XX	M/D/YY

PROJECT LOCATION

ENGINEER'S STAMP

PRELIMINARY - FOR REVIEW ONLY - NOT FOR CONSTRUCTION

THIS LINE IS 2 INCHES AT FULL SCALE
IF IT DOES NOT MEASURE 2 INCHES, SCALE ACCORDINGLY

DRAWN: J ABEL
CONTACT: A HADEN
PROJECT: OSUC.20
DATE: 05/03/2017
DRAWING NO.

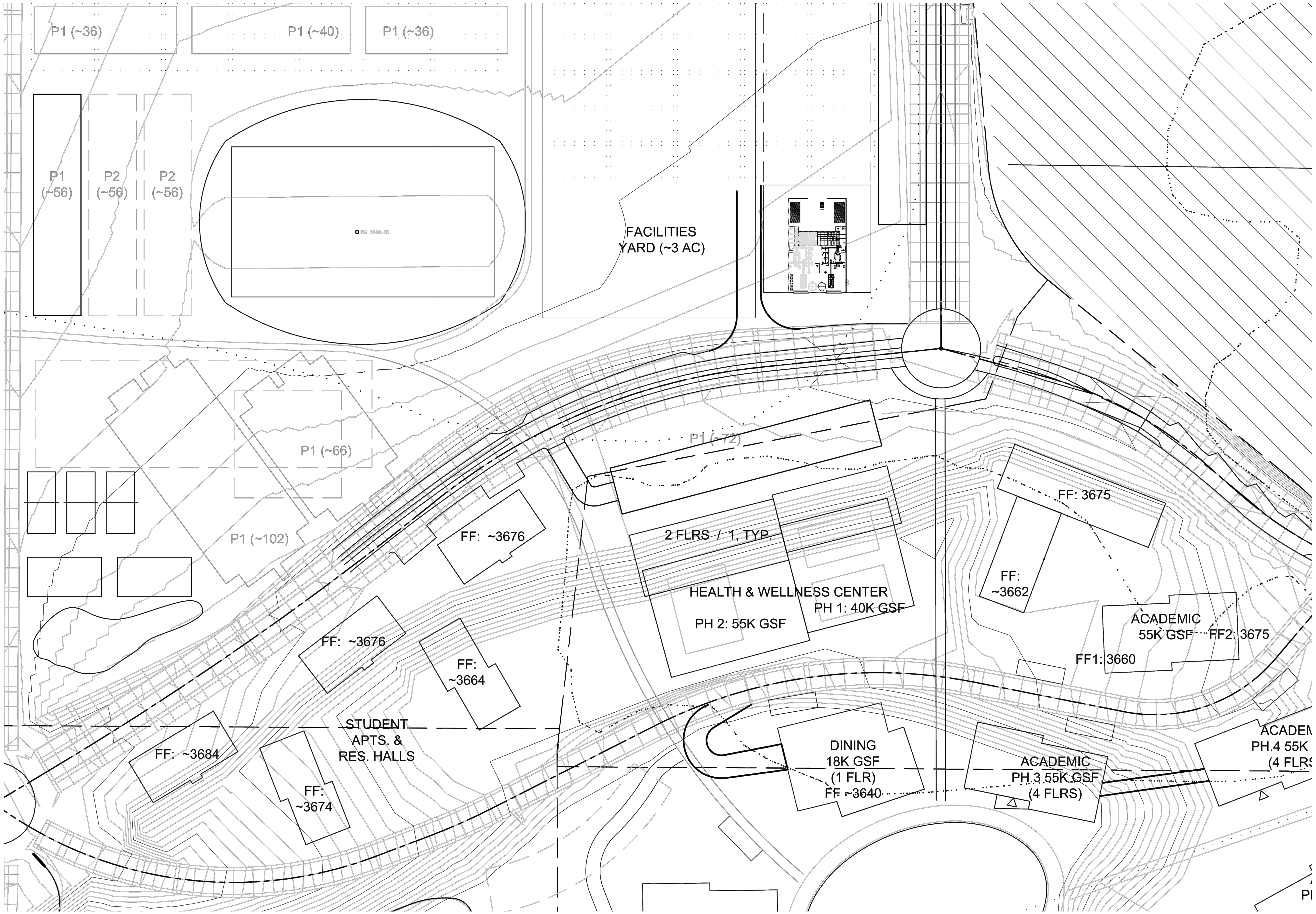
M0.1

SHEET 1 OF 15

ATTACHMENT D

Preliminary Site Plan

Best Plus Scenario



1 / M0.1 PROPOSED DISTRICT ENERGY SITE PLAN (BEST PLUS)

SCALE: 1/64" = 1'-0"

OWNER

OSU CASCADES

BEND OREGON

PROJECT

BIOMASS BOILER SYSTEM

DESIGN FIRM

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PORTLAND, OR 97227

DRAWING TITLE

PROPOSED DISTRICT ENERGY SITE PLAN (BEST PLUS)

REV	DESCRIPTION	DATE
A	XX	M/D/YY

PROJECT LOCATION

ENGINEER'S STAMP

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CONTACT: A HADEN
PROJECT: OSUC.20
DATE: 05/03/2017
DRAWING NO.

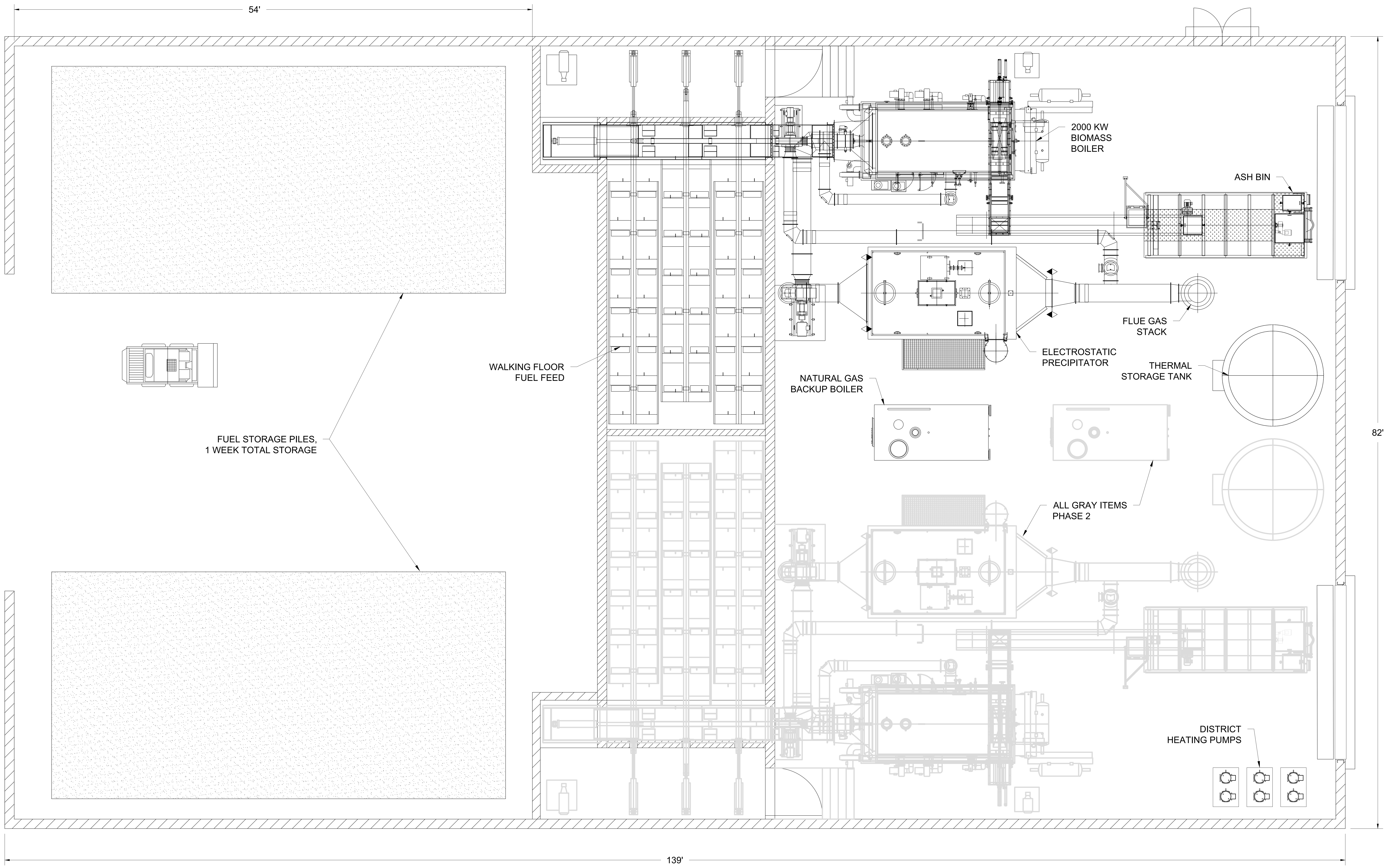
M0.1

SHEET 2 OF 15

ATTACHMENT E

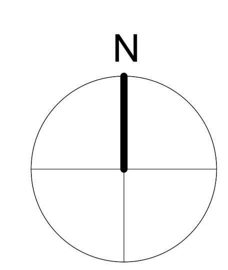
Preliminary Mechanical Layout

Good Scenario



1
M2.0

MECHANICAL PARTIAL PLAN
BIOMASS BOILER BUILDING (GOOD)
SCALE: 3/16" = 1'



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MECHANICAL PARTIAL PLAN BOILER BUILDING (GOOD)

REV	DESCRIPTION	DATE
A	COORDINATION SET	03-07-2017

PROJECT LOCATION

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CONTACT: A HADEN
PROJECT: OSUC.20
DATE: 05/01/2017
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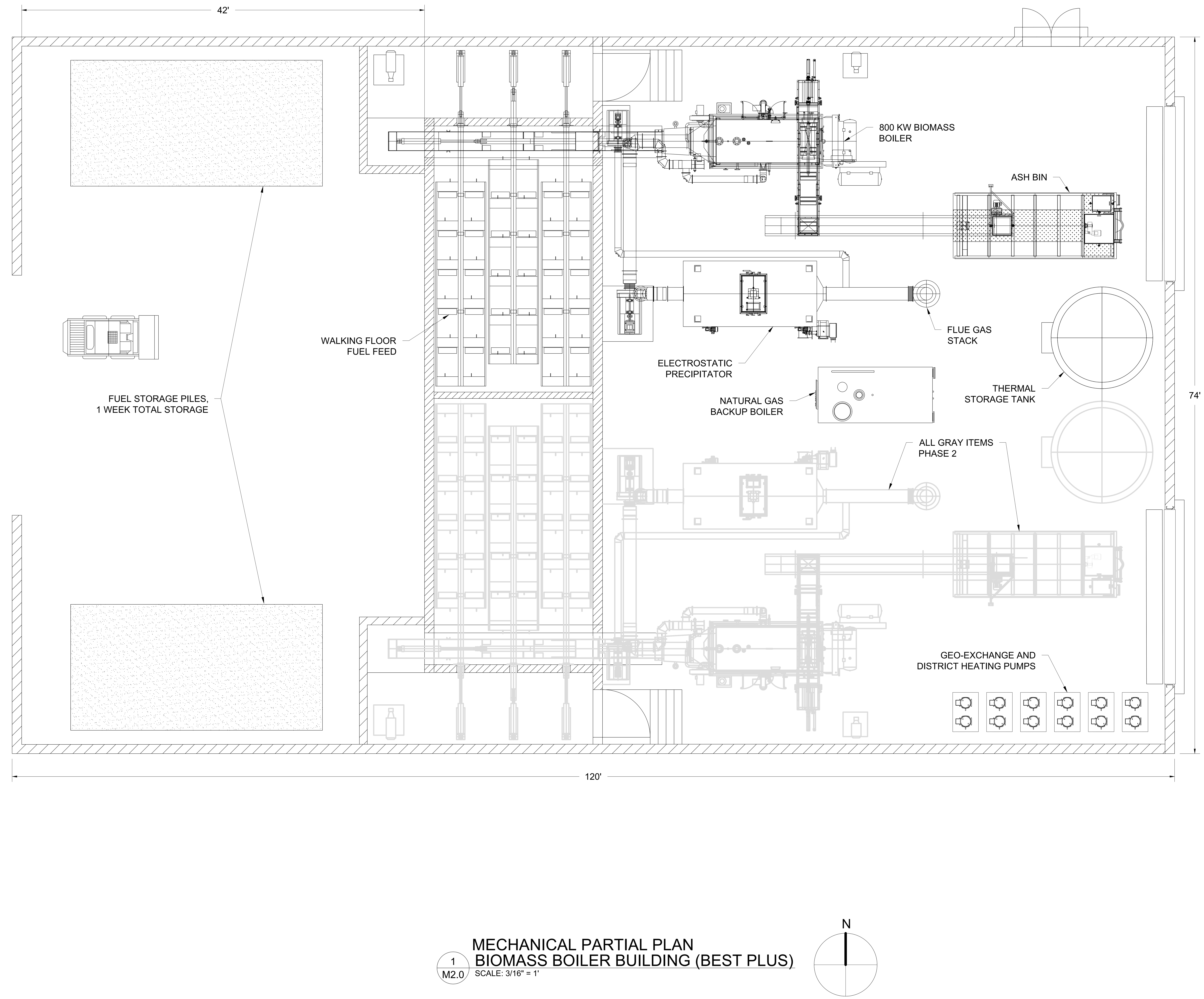
M2.0

SHEET 3 OF 15

ATTACHMENT F

Preliminary Mechanical Layout

Best Plus Scenario



1 M2.0 MECHANICAL PARTIAL PLAN BIOMASS BOILER BUILDING (BEST PLUS)
SCALE: 3/16" = 1'

OWNER

OSU CASCADES

BEND OREGON

PROJECT

BIOMASS BOILER SYSTEM

DESIGN FIRM

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DRAWING TITLE

MECHANICAL PARTIAL PLAN BOILER BUILDING (BEST PLUS)

REV	DESCRIPTION	DATE
A	COORDINATION SET	03-07-2017

PROJECT LOCATION

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DRAWING NO.

M2.0

SHEET 8 OF 15