MEMORANDUM

TO: Jane Barker (OSU-Cascades)

FROM: Meagan Nuss (Wisewood Energy)

CC: Andrew Haden (Wisewood Energy)

DATE: April 11, 2018

RE: Updated biomass energy analysis and phasing

OSU Cascades (OSU-C) has retained Wisewood Energy to develop the preliminary analysis of a potential biomass energy system that would provide central heating to the campus expansion in Bend. The biomass system would be the core component of the campus Central Utility Plant (CUP), complementing a suite of other renewable energy infrastructure that includes geothermal heating and solar photovoltaic power production.

In May 2017 Wisewood completed a first draft of the preliminary analysis, including energy modeling and boiler sizing, an assessment of biomass feedstock available in the area, conceptual layouts of the biomass equipment in the CUP, and a preliminary air quality permitting assessment. This analysis was based on two energy efficiency scenarios projected for the campus by the Long-Range Development Planning (LRDP) team, referred to as "Good" and "Best Plus". These two scenarios represented the lowest and highest efficiency standards that might be adopted by the campus for its future development, which corresponded to the highest and lowest energy input requirements.

Since the May 2017 report, Wisewood consulted with OSU-C to determine which energy efficiency scenario and associated assumptions should be used in the remainder of the biomass system analysis. It was determined that the most realistic option for the campus would be to assume a moderate efficiency standard, deemed the "Better Plus" scenario. OSU-C additionally sought to understand the impact of including the planned Innovations District, an area adjacent to the campus that will be developed by partner organizations and businesses, as part of the CUP district energy loop.

In March 2018, OSU-C provided Wisewood with updated data on the projected campus development for the next 10+ years. Wisewood used this information to update the energy analysis of the proposed biomass system using two new scenarios: Better Plus without the Innovation District (Scenario 1), and Better Plus with the Innovation District

(Scenario 2). These results, in addition to a proposed framework for planning the phasing of the biomass portion of the CUP, are summarized below.

Updated Energy Analysis

The "Better Plus" scenario developed by the LRDP team includes both biomass and geothermal heating and cooling, with efficiency standards that exceed code. Outputs from the LRDP efforts included calculations of total campus heat demand; adding the Innovations District to the Better Plus heat load increases annual heat demand by 47% compared to the same scenario without the Innovations District.

As in the first draft of the preliminary biomass analysis, the geothermal system is sized to meet the campus cooling demand to avoid depleting the subsurface thermal resources; this is equivalent to providing 30% of the campus heating. Biomass is assumed to provide approximately 83% and 85% of the remaining heat demand, after correcting for boiler efficiency (equivalent to 58% and 59% of the overall heat load), without the Innovations District and with it, respectively; in both scenarios a natural gas boiler provides redundancy and peak demand. This complementary approach enables each technology to be optimized for size, long-term functionality, and renewable energy objectives. These and other scenario parameters are summarized in Table 1 below, as well as key results from the biomass energy modeling. Wisewood Energy's preliminary energy models for the two OSU-C campus scenarios are included in Attachments 1 and 2, respectively.

TABLE 1 Summary comparison of Better Plus scenarios at full campus buildout, with associated parameters. Estimated wood fuel demand assumes 35% moisture content.

	SCENARIO 1: BETTER PLUS NO INNOVATIONS DISTRICT	SCENARIO 2: BETTER PLUS WITH INNOVATIONS DISTRICT
Total Campus Heat Demand	48,000 MMBtu/yr	70,500 MMBtu/yr
Biomass Boiler Output	6,500 MBH	10,000 MBH
Estimated Wood Fuel Demand	2,300 tons/yr	4,200 tons/yr
Overall Heat Demand Met by Biomass	58%	59%
Overall Heat Demand Met by Geothermal	30%	30%
Overall Heat Demand Met by Fossil Fuels	12%	11%

Biomass Boiler Phasing

The OSU-C campus will be developed over a period of a decade or more with residential, academic, and other support facilities constructed in phases. The most recent phasing plans for the campus without and with the Innovations District are included in Attachments 3 and 4, respectively (provided to Wisewood in March 2018). According to OSU-C staff, most if not all geothermal infrastructure will be installed in Phases 1 and 2 (2020 - 2028) to take advantage of site prep and road construction activities during that time. The CUP is intended to be constructed in Phase 2 (2024 – 2028), including the biomass system and related equipment.

Like geothermal systems (and unlike most conventional heating systems), a biomass system must be sized appropriately to match the anticipated heat demand so as to ensure efficient operations and a long equipment lifespan. In the case of the OSU-C system, Wisewood Energy recommends two phases of biomass system development: a single boiler installed first to cover existing and near-term heat loads, and a second boiler installed at a later time for future development. Determining the most appropriate size of the first boiler and optimum time to install the second is dependent upon the expected campus heat load (i.e., expected construction schedule) over time. While the actual timing and extent of OSU-C campus development will depend on several factors, the biomass phasing recommendations included here are based on the latest projected development schedule. If construction schedules change substantially from these projections, the optimal size and timing of the boiler installation may change.

Results are included for Scenario 1 and Scenario 2 in the campus phasing tables shown in Attachments 3 and 4, respectively. In Scenario 1, Wisewood Energy recommends a single boiler be installed during Phase 2 with a capacity of 2,700 MBH; in Scenario 2, a first boiler at 3,700 MBH is recommended. At this scale, the biomass system will meet the majority of the total heat demand at that time (excluding what is covered by the geothermal system), while not being oversized such that it will operate sub-optimally. This also allows for new heat loads constructed in the near term to continue to be covered by the biomass system.

The second biomass boiler should be installed once some level of certainty is reached regarding timing of future construction. If development continues as planned, a second biomass boiler is most optimally added during Phase 4A (2031 – 2033). In Scenario 1, the second boiler is estimated to be 3,800 MBH for a total biomass capacity of 6,500 MBH; in Scenario 2 the second boiler is estimated to be 6,300 MBH for a total biomass capacity of 10,000 MBH. Estimated biomass coverage of the total campus heat demand over the course of the projected campus development is provided in Attachments 3 and 4, along with corresponding fossil fuel coverage.

Other Considerations and Next Steps

Because the CUP is not anticipated to be constructed until Phase 2 of campus development, Wisewood Energy recommends that any buildings built before this time be designed with hydronic heating systems; this will enable connection to the future biomass district energy system in a minimally invasive manner. Additionally, Wisewood Energy recommends that OSU-C prioritize advancing the detailed design and engineering of the first biomass system development stage so that buried hot water piping can be installed during other near-term site preparation activities, minimizing future disturbance to new infrastructure. Biomass boiler sizing can also be finalized during detailed design and engineering.

Once OSU-C has confirmed the receipt and approval of this memo, the assumptions included in both scenarios will be used as the basis for air dispersion and carbon accounting models for the biomass system. Wisewood Energy will also update the conceptual layout of the CUP to inform OSU-C's master planning process.

Please let us know if you have any questions about the information provided above.

Attachment 1

Scenario 1 Updated Energy Model – Without Innovations District

OSU Cascades - Better Plus Without Innovations District

Proposed System Analysis

WISEWOOD ENERGY

Location Bend, Oregon
Client Contact Jane Barker
Date 4/9/18

Proposed System Biomass Boiler Installation
Proposed System Output (MBH) 6,500
Proposed System Fuel Type Wood Chips

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

Fuel Prices		Conversion Factors		Proposed System Consumption	
Natural gas cost [$/MMBtu]	$9.00	Energy per kWh [Btu/kWh]	3,412	Total energy input [MMBtu/yr]	48,033
Electricity demand cost [$/kW]	$6.00	Moisture of biomass [% MC WB]	35%	Cost if 100% heated with natural gas [$/yr]	$480,326
Electricity cost [$/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]	14,410

Heat Pump Operations					
Heat pump COP	5	Heat pump electrical consumption [kWh]	2,815,509	Remaining energy input [MMBtu/yr]	24,016
Heat from heat pump losses [MMBtu/yr]	9,607	Heat pump electrical cost [$/yr]	$225,241	Cost if remaining heat from natural gas [$/yr]	$240,163

"Business as Usual" Proposed System Values (Geofield + Natural Gas)					
Boiler efficiency	90%	Heating device nameplate, [MBH]	27,000	Operating hours per day	19
Max. electrical demand [kW]	8.21	Boiler output, low-fire [MBH]	3,375	Total Heat input [MMBtu/HDD]	7.78
Average electrical demand [kW]	2.11	Average boiler output [MBH]	6,938	Non-geofield energy input [MMBtu/HDD]	3.89

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 %	82.8%
Boiler output, high-fire [MBH]	6,500	Boiler output, high-fire [MBH]	27,000	Operating hours per year	6,316
Boiler output, low-fire* [MBH]	813	Boiler output, low-fire [MBH]	3,375	Biomass boiler output [% of peak]	25%
Max. electrical demand [kW]	58.7	Max. electrical demand [kW]	8.2		
Average electrical demand [kW]	62.7	Average electrical demand [kW]	1.03		
Boiler efficiency	85%	Boiler efficiency	90%		

Proposed Biomass Boiler Consumption and Cost		Proposed Trim Boiler Consumption and Cost		Proposed Boiler Plant Totals	
Wood fuel consumption [tons/yr]	2,344	Natural gas consumption [MMBtu/yr]	4,593	Total fuel consumption [MMBtu/yr]	27,984
Wood fuel cost [$/yr]	$58,590	Natural gas cost [$/yr]	$41,340	Total fuel cost [$/yr]	$99,930
Electrical consumption [kWh/yr]	396,073	Electrical consumption [kWh/yr]	6,481	Total electrical consumption [kWh/yr]	402,553
Electrical energy cost [$/yr]	$31,686	Electrical use charge [$/yr]	$518	Total electrical use charge [$/yr]	$32,204
Electrical demand charge [$/yr]	$4,230	Electrical demand charge [$/yr]	$591	Total electrical demand charge [$/yr]	$4,821

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	1,908	954	929	182	93
October	424	3,299	1,650	1,607	316	161
November	936	7,278	3,639	3,544	696	355
December	971	7,548	3,774	3,676	722	368
January	875	6,807	3,404	3,315	651	332
February	697	5,422	2,711	2,641	519	265
March	620	4,823	2,411	2,349	461	235
April	634	4,930	2,465	2,401	471	241
May	379	2,944	1,472	1,434	282	144
June	141	1,095	547	533	105	53
July	123	960	480	467	92	47
August	131	1,018	509	496	97	50
Yearly Total	6,177	48,033	24,016	23,391	4,593	2,344

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

Net fossil energy savings [MMBtu/yr] 43,439

OSU Cascades - Better Plus Without Innovations District

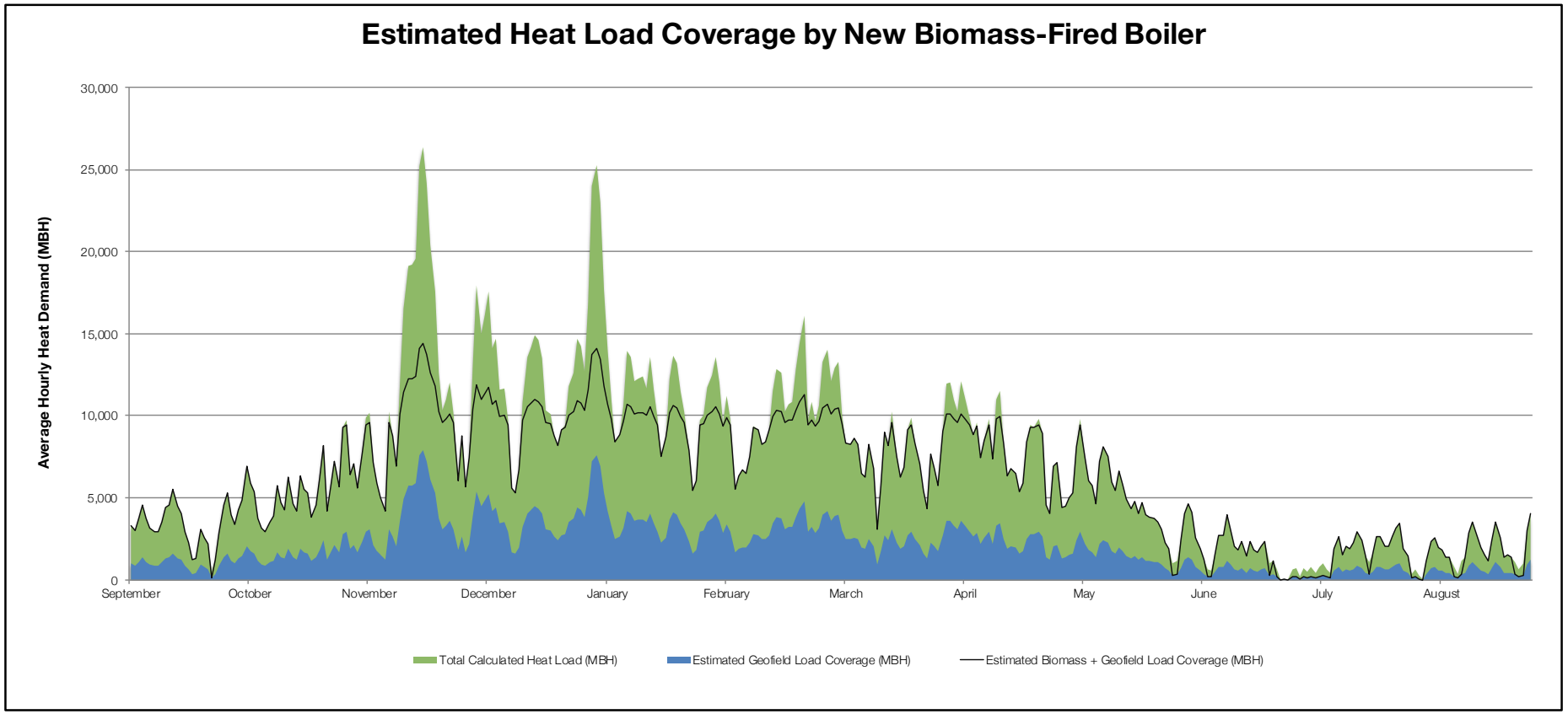
Proposed System Analysis

WISEWOOD ENERGY

Location Bend, Oregon
Client Contact Jane Barker
Date 4/9/18

Proposed System Biomass Boiler Installation
Proposed System Output (MBH) 6,500
Proposed System Fuel Type Wood Chips

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



OSU Cascades - Better Plus Without Innovations District

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WISEWOOD ENERGY

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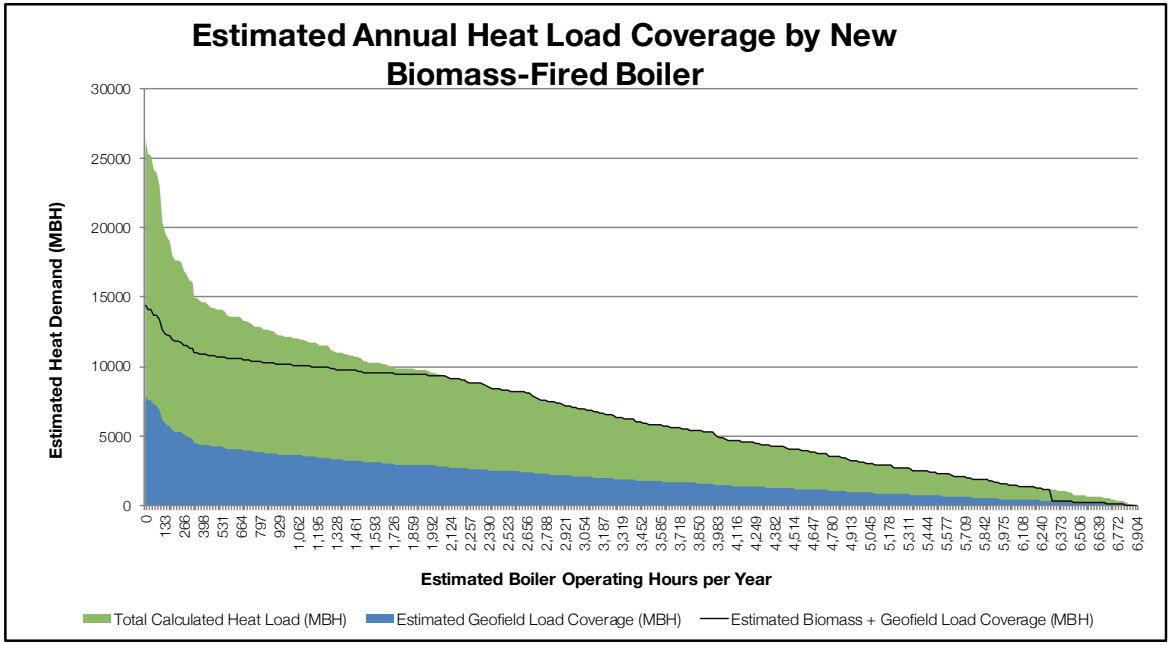

Boiler Output [MBH]	Fossil Fuel Displaced
3,000	50.4%
3,500	56.5%
4,000	62.1%
4,500	67.1%
5,000	71.7%
5,500	75.9%
6,000	79.5%
6,500	82.8%
7,000	85.5%
7,500	87.7%
8,000	89.4%
8,500	90.9%
9,000	92.0%
9,500	93.0%
10,000	93.8%
10,500	94.2%
11,000	94.3%
11,500	94.3%
12,000	94.6%
12,500	94.9%
13,000	94.9%
13,500	94.8%
14,000	94.8%
14,500	94.5%
15,000	94.2%

Attachment 2

Scenario 2 Updated Energy Model – With Innovations District

OSU Cascades - Better Plus With Innovations District

Proposed System Analysis

WISEWOOD ENERGY

Location Bend, Oregon
Client Contact Jane Barker
Date 4/9/18

Proposed System Biomass Boiler Installation
Proposed System Output (MBH) 10,000
Proposed System Fuel Type Wood Chips

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

Fuel Prices		Conversion Factors		Proposed System Consumption	
Natural gas cost [$/MMBtu]	$9.00	Energy per kWh [Btu/kWh]	3,412	Total energy input [MMBtu/yr]	70,554
Electricity demand cost [$/kW]	$6.00	Moisture of biomass [% MC WB]	35%	Cost if 100% heated with natural gas [$/yr]	$705,539
Electricity cost [$/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]	14,410

Heat Pump Operations					
Heat pump COP	5	Heat pump electrical consumption [kWh]	4,135,632	Remaining energy input [MMBtu/yr]	42,033
Heat from heat pump losses [MMBtu/yr]	14,111	Heat pump electrical cost [$/yr]	$330,851	Cost if remaining heat from natural gas [$/yr]	$420,333

"Business as Usual" Proposed System Values (Geofield + Natural Gas)					
Boiler efficiency	90%	Heating device nameplate, [MBH]	40,000	Operating hours per day	19
Max. electrical demand [kW]	12.16	Boiler output, low-fire [MBH]	5,000	Total Heat input [MMBtu/HDD]	11.42
Average electrical demand [kW]	3.10	Average boiler output [MBH]	10,193	Non-geofield energy input [MMBtu/HDD]	6.80

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 %	84.5%
Boiler output, high-fire [MBH]	10,000	Boiler output, high-fire [MBH]	40,000	Operating hours per year	6,258
Boiler output, low-fire* [MBH]	1,250	Boiler output, low-fire [MBH]	5,000	Biomass boiler output [% of peak]	26%
Max. electrical demand [kW]	90.4	Max. electrical demand [kW]	12.2		
Average electrical demand [kW]	92.1	Average electrical demand [kW]	1.52		
Boiler efficiency	85%	Boiler efficiency	90%		

Proposed Biomass Boiler Consumption and Cost		Proposed Trim Boiler Consumption and Cost		Proposed Boiler Plant Totals	
Wood fuel consumption [tons/yr]	4,187	Natural gas consumption [MMBtu/yr]	7,240	Total fuel consumption [MMBtu/yr]	49,025
Wood fuel cost [$/yr]	$104,664	Natural gas cost [$/yr]	$65,162	Total fuel cost [$/yr]	$169,826
Electrical consumption [kWh/yr]	576,541	Electrical consumption [kWh/yr]	9,513	Total electrical consumption [kWh/yr]	586,053
Electrical energy cost [$/yr]	$46,123	Electrical use charge [$/yr]	$761	Total electrical use charge [$/yr]	$46,884
Electrical demand charge [$/yr]	$6,508	Electrical demand charge [$/yr]	$876	Total electrical demand charge [$/yr]	$7,383

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	2,803	1,670	1,660	288	166
October	424	4,846	2,887	2,870	497	288
November	936	10,690	6,369	6,331	1,097	634
December	971	11,088	6,606	6,566	1,138	658
January	875	9,999	5,957	5,922	1,026	593
February	697	7,965	4,745	4,717	817	473
March	620	7,084	4,220	4,195	727	420
April	634	7,242	4,314	4,289	743	430
May	379	4,324	2,576	2,561	444	257
June	141	1,608	958	952	165	95
July	123	1,410	840	835	145	84
August	131	1,495	891	885	153	89
Yearly Total	6,177	70,554	42,033	41,785	7,240	4,187

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

Net fossil energy savings [MMBtu/yr] 63,314

OSU Cascades - Better Plus With Innovations District

Proposed System Analysis

WISEWOOD ENERGY

Location Bend, Oregon
Client Contact Jane Barker
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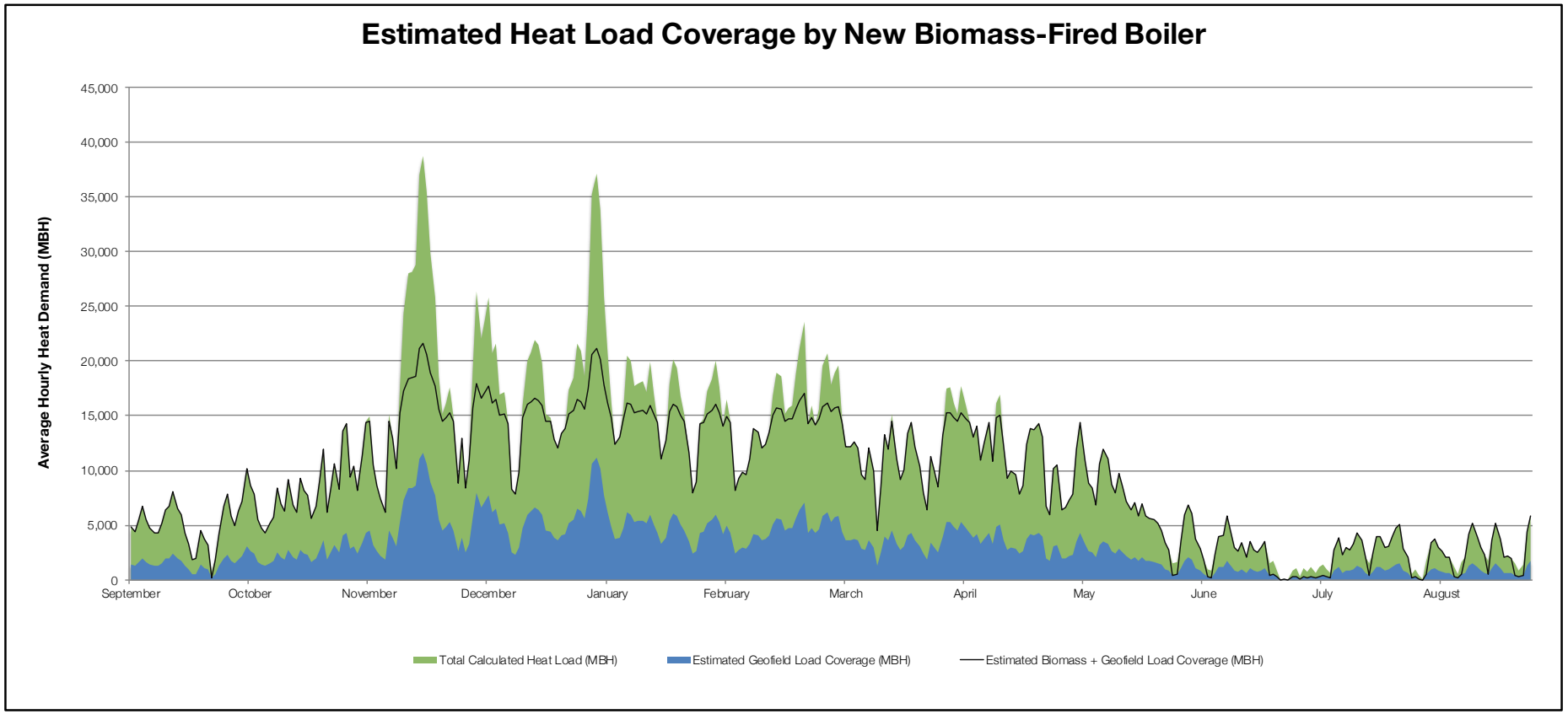

OSU Cascades - Better Plus With Innovations District

Proposed System Analysis

WISEWOOD ENERGY

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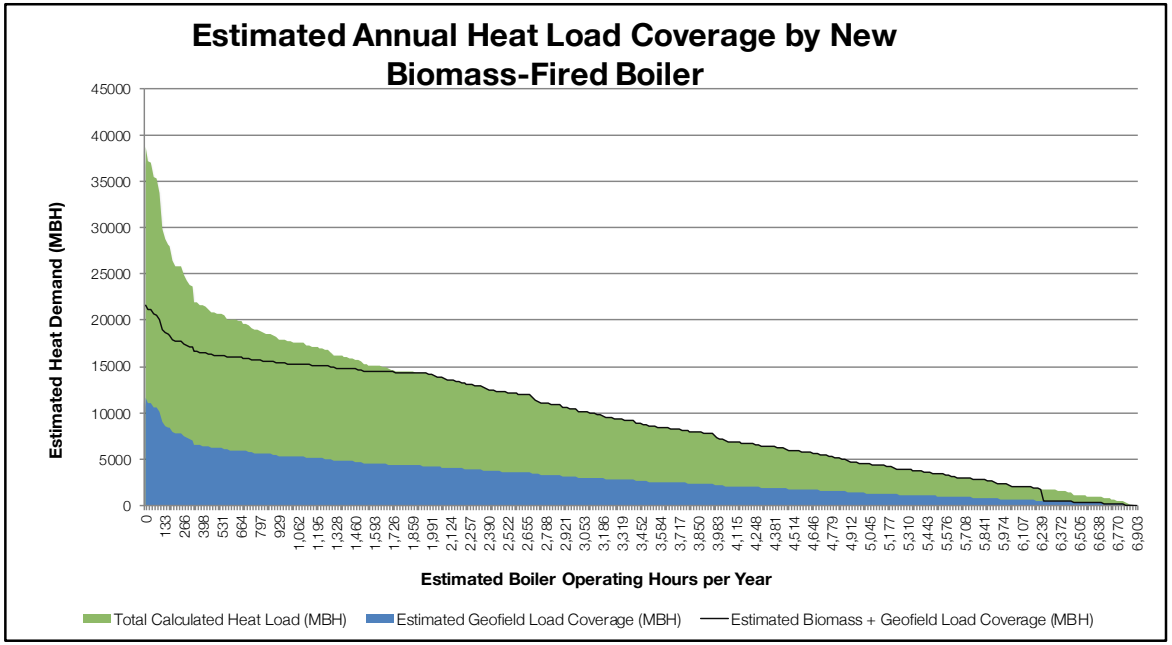

Boiler Output [MBH]	Fossil Fuel Displaced
5,000	55.4%
6,000	63.0%
7,000	69.6%
8,000	75.5%
9,000	80.4%
10,000	84.5%
11,000	87.6%
12,000	89.9%
13,000	91.7%
14,000	93.1%
15,000	93.9%
16,000	94.2%
17,000	94.4%
18,000	94.8%
19,000	94.9%
20,000	94.8%
21,000	94.5%
22,000	94.2%
23,000	94.2%
24,000	94.1%
25,000	93.4%
26,000	93.2%
27,000	92.8%
28,000	92.6%
29,000	92.4%

Attachment 3

Scenario 1 OSU-C Campus Development and Biomass Boiler Phasing – Without Innovations District

WITHOUT INNOVATIONS DISTRICT	EXISTING 10 ACRES (2018-2020)	PHASE 1 (2020-2024)	PHASE 2 (2024-2028)	PHASE 3 (2028-2031)	PHASE 4A (2031-2034)	PHASE 4B (2034-2036)	FULL CAMPUS BUILDOUT
Academic (gsf)	58,500	55,000	55,000	110,000	110,000	30,000	418,500
Campus Life (gsf)	13,500	22,500	80,000	18,000	90,000	-	224,000
Campus Residence (gsf)	87,000	63,000	94,500	97,500	235,000	111,000	688,000
Campus Support CUP (gsf)	-	-	17,000	-	-	-	17,000
Total Bldg Area (gsf)	159,000	299,500	546,000	771,500	1,206,500	1,347,500	1,347,500
% of Full Buildout	12%	22%	41%	57%	90%	100%	100%
Total Biomass Boiler Installed Capacity	-	-	1 Boiler 2,700 MBH	1 Boiler 2,700 MBH	2 Boilers 6,500 MBH	2 Boilers 6,500 MBH	2 Boilers 6,500 MBH
Biomass Coverage of Total Load by End of Phase	0%	0%	61%	43%	67%	59%	59%
Fossil Fuel Coverage of Total Load by End of Phase	70%	70%	9%	27%	4%	11%	11%

Note: Table adapted from OSU-Cascades Campus Phasing Projections sent to Wisewood Energy 3/20/18. Should campus construction schedule change substantially, boiler sizing and optimum installation timing may also change. Biomass and fossil fuel coverage is corrected for efficiency, and assumes geothermal system provides 30% of total campus heat load.

Attachment 4

Scenario 2 OSU-C Campus Development and Biomass Boiler Phasing – With Innovations District

WITH INNOVATIONS DISTRICT	EXISTING 10 ACRES (2018-2020)	PHASE 1 (2020-2024)	PHASE 2 (2024-2028)	PHASE 3 (2028-2031)	PHASE 4A (2031-2034)	PHASE 4B (2034-2036)	FULL CAMPUS BUILDOUT
Academic (gsf)	58,500	55,000	55,000	110,000	110,000	30,000	418,500
Campus Life (gsf)	13,500	22,500	80,000	18,000	90,000	-	224,000
Campus Residence (gsf)	87,000	63,000	94,500	97,500	235,000	111,000	688,000
Campus Support CUP (gsf)	-	-	17,000	-	-	-	17,000
Innovations Partners (gsf)	-	55,000	142,000	42,000	141,000	-	380,000
ELC (gsf)	-	-	-	52,800	-	-	52,800
Middle Market Housing (gsf)	-	-	57,954	33,806	150,519	36,221	278,500
Total Bldg Area (gsf)	159,000	354,500	800,954	1,155,060	1,881,579	2,058,800	2,058,800
% of Full Buildout	8%	17%	39%	56%	91%	100%	100%
Total Biomass Boiler Installed Capacity	-	-	1 Boiler 3,700 MBH	1 Boiler 3,700 MBH	2 Boilers 10,000 MBH	2 Boilers 10,000 MBH	2 Boilers 10,000 MBH
Biomass Coverage of Total Load by End of Phase	0%	0%	57%	39%	65%	59%	59%
Fossil Fuel Coverage of Total Load by End of Phase	70%	70%	13%	31%	5%	11%	11%

Note: Table adapted from OSU-Cascades Campus Phasing Projections sent to Wisewood Energy 3/20/18. Should campus construction schedule change substantially, boiler sizing and optimum installation timing may also change. Biomass and fossil fuel coverage is corrected for efficiency, and assumes geothermal system provides 30% of total campus heat load.