WESTERN WASHINGTON UNIVERSITY

UTILITIES MASTER PLAN UPDATE
Bellingham Main Campus

SP045

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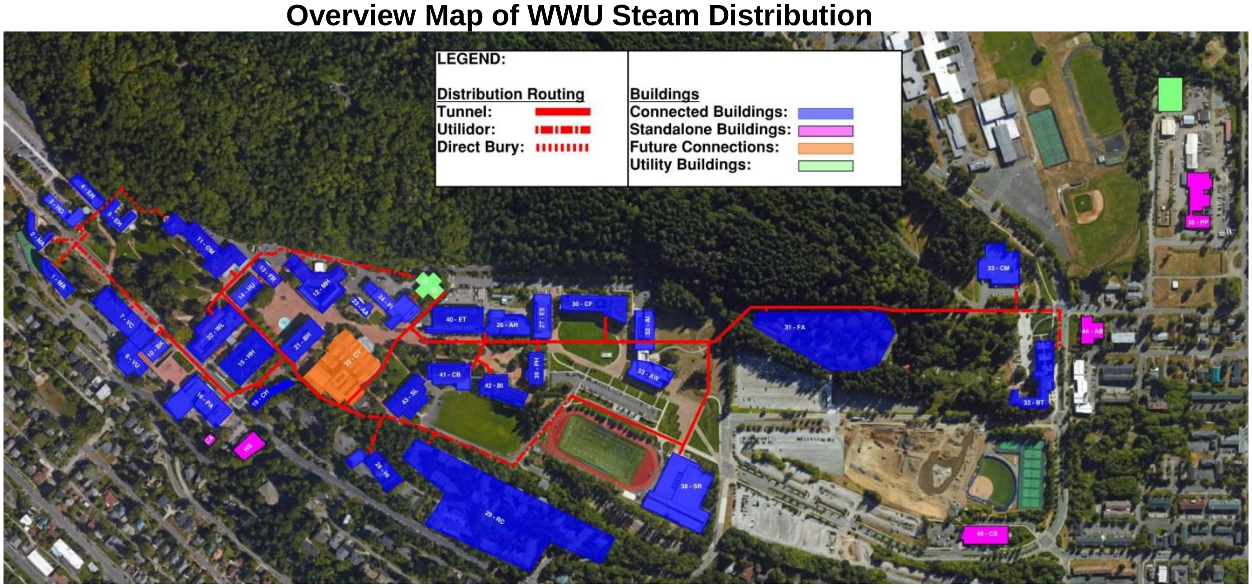
Wilson
SURVEY / ENGINEERING

5. DISTRICT HEATING SYSTEM

5.1. Existing System Overview and Evaluation

The district heating system serving Western Washington University (WWU) is comprised of a central steam production plant and a steam distribution system that serves a majority of the campus facilities through a large utility tunnel system. Steam is provided to 43 of 51 buildings on campus, primarily for heating purposes. Most buildings convert this steam to hot water that is then used for space heating and domestic water needs. Fraser Hall and the Bookstore buildings currently utilize direct steam for all heating needs. There are also a few locations where steam is used for process requirements, primarily in science buildings for lab use, and in buildings for space humidification. The map below provides an overview of the current steam distribution system.

Overview Map of WWU Steam Distribution



Overview of Campus District Energy

The WWU campus benefits from its continued investment in district energy, as it provides an economical and efficient way to heat multiple buildings in a campus setting from a central location. As opposed to distributed generation which requires heating generation equipment at each building, district energy systems use a network of distribution pipes (often underground) to deliver heating/cooling media to multiple buildings in an area such as a downtown district, college, hospital, or other campus setting. This consolidation of thermal loads into a centralized plant provides the ability to reduce energy usage through enhanced production efficiency, reduction in losses, and ability to recover sources of waste heat that would be lost in a distributed generation system. This consolidation also reduces costs associated with renewal and maintenance due to fewer pieces of equipment required as opposed to a distributed system. It also provides the ability to incorporate and transition to renewable sources as they become economically and technically viable in an effective and efficiency manner.

5.1.1. Heating Production Plant Overview

The existing Steam Production Plant was originally constructed in 1946 and is centrally located on the east side of the campus next to the Arboretum Forest. The building is two story and covers 11,000 sq. ft. In 1969 a major building expansion added space for boilers #5, #6, and a chilled water plant with an outdoor cooling tower. The chilled water equipment has since been removed and the space is used for the facility repair shop and district compressed air system. District compressed air is distributed to various buildings throughout campus for controls and process usage.

Existing Plant Equipment

The Steam Production Plant produces steam utilizing five water tube boilers of various sizes. The total installed steam capacity is 260,000 lb/hr. Each boiler has a single stage economizer that utilizes waste heat from the stack exhaust gas to preheat boiler feed water.

Steam Production Plant – Installed Capacity

Name	Year Installed	Nominal Output (lb/hr)	Fuel Type
Boiler #2	1946	15,000	N. Gas/Oil
Boiler #3	1959	25,000	N. Gas/Oil
Boiler #4	1966	40,000	N. Gas/Oil
Boiler #5	1970	100,000	N. Gas/Oil
Boiler #6	1995	75,000	N. Gas

Most of the boilers have duel fuel capability. The primary fuel used for the boilers is natural gas. A 6” natural gas line at 45psig is supplied to the building for use. Fuel oil can also be used in all of the boilers except for #6. Fuel oil is stored outside of the building in four underground tanks: (2) at 44,000 gallons and (2) at 19,000 gallons. The 19,000 gallon tanks were installed in 1946 when the original building was constructed and the 44,000 tanks were installed in 1970 when Boiler #5 was installed.

Boilers #4,5,6 have a fully digital control system. This control system is interfaced into the Campus Apogee control system for monitoring only. Boilers #2,3 currently use pneumatic controls for a majority of the boiler functions.

Boilers #2 and #6 are the only boilers that are currently connected to the emergency generator. As such, these boilers are the only available boilers that can be used during a power outage. The total installed capacity of these boilers is 90,000 lb/hr.

Each boiler has an indirect draft fan located on the cat walk level. Boilers #2,3,4 also have an induced draft fan in addition to the forced draft fan. Boiler #5 has a “MagnaDrive” and Boiler #6 has a variable frequency drive (VFD) on its fan to allow for turndown at part load on the boilers.

Two deaerator tanks are located in the Steam Plant: one sized at 100,000 lb/hr installed in 1946 and 200,000 lb/hr installed in 1970. Each deaerator tank takes steam at 5psig and condensate return at ~180F. The condensate is heated to ~228F to remove a majority of the dissolved air in the water to prevent corrosion in the piping due to carbonic acid formation. Once the water leaves the deaerators it is considered feed water and is pumped to the boilers by five pumps of various sizes at 175 psi. The feed water is pumped through a single stage economizer directly before entering the boiler and has a typical boiler input temperature of ~260F.

When condensate is returned to the Steam Plant it is collected in an approximately 3,500 gallon receiver tank or can directly supply the deaerator if needed. Makeup water can be added either to the condensate receiver or to the deaerator tanks via an emergency bypass. The system appears to be capable of providing 85,000 lb/hr of makeup water if required at the worst assumed condition.

The following table provides an overview of the major Steam Production Plant production equipment aside from the boilers.

Steam Plant Major Equipment list

Equipment Tag	Description
DA-1	100,000 lb/hr Deaerator Tank
DA-2	200,000 lb/hr Deaerator Tank
CR-1	3,500 Gallon Condensate Receiver
P-1,2,3	Boiler Feed Pumps. 178 gpm, 365 TDH
P-4	Boiler Feed Pump. 80 gpm, 355 TDH, 20 HP
P-5	Boiler Feed Pump. 220 gpm, Steam Driven

A schematic diagram showing the current steam production plant layout can be found in the Appendix.

Steam System Operating Parameters

Saturated steam is produced at 100-110 psig for distribution to the campus district steam system. Throughout the distribution system and at the building level, steam is condensed and the condensate is sent back to the Steam Plant to complete the cycle. It has been reported by boiler operation staff that 90-95% of condensate is returned to the Steam Plant with a return temperature ranging between 160F to 180F.

The boilers operate with a variable percent excess air in the exhaust stream.

5.1.2. Heating Production Plant Conditions Evaluation

Overview

The overall appearance of Steam Plant heating system is that it is well maintained. Pipe insulation appears tight with no visible fraying or noticeable missing sections, equipment looks clean with no indication of oil leaks, and there were no indications of water/steam leaks.

Example Photo of Steam Plant Interior

Preventive maintenance is routinely completed and well documented. Detailed logs describing the typical regular maintenance completed for the various equipment of the plant was provided for the past 6 years. The list of regular maintenance items appears to be sufficiently complete to ensure all plant equipment is well taken care of.

Safety Concerns

Plant staff reported no safety issues at the Steam Plant. There are however, noted instances of asbestos insulation that remains in the plant but is still fully contained at this point. Plant staff also reported that there are no regular water hammer concerns with the steam system. There was one anecdotal report of a water hammer incident due to a safety valve closing, but this is not something that is an ongoing issue.

Equipment Conditions

Overall, the boilers appear to be in good shape given the age and typical life expectancy. Conversations with boiler operation staff noted no major issues with the operating condition of the boilers themselves. However, upon the last inspection, boilers #2 and #3 may potentially have a light amount of scale in some tube sections. It must be noted, that with the advanced age of these boilers (with the newest boiler being 22 years old), that a short and long term plan should be put in place to deal with equipment renewal and replacement. For reference, ASHRAE lists that the median service life for steam water tube boilers is 30 years, boiler burners is 21 years, pneumatic controls is 20 years, and condensate pumps is 15 years.

There is some concern over the ongoing ability to cost effectively maintain and operate the aging production equipment. Boilers #2,3,4,5 have obsolete components that will make it difficult to locate and obtain replacement parts in the coming years. Some additional concerns with the future operations and maintenance of the boilers is as follows:

- Boiler #2: Boiler is currently 71 years old and the control system is completely pneumatic. Concern with availability of replacement parts.
- Boiler #3: Boiler is currently 58 years old and the control system is completely pneumatic. Concern with availability of replacement parts.
- Boiler #4: Boiler is currently 51 years old. Concern with availability of replacement parts.
- Boiler #5: Boiler is currently 47 years old. Concern with boiler refractory material and availability of replacement parts. Per boiler operation staff, repairs to the refractory material will be needed within 10 years.

Other Items of Note

Additional concern was noted about the existing diesel storage tanks. Plant personnel expressed apprehension over the lack of full knowledge of the type and condition of the existing tanks. It is currently unknown if the older installed tanks are double wall containment tanks or not. If not, this could indicate a possible future environmental leak hazard. If future concern grows regarding the condition of the tank, it has been noted that a scan of the tank/area by the geology department is a potential option.

5.1.3. Heating Distribution Overview

The majority of buildings are connected to the Steam Plant by way of a walk-able tunnel system. There are also sections of buried trench (referred to as “utilidor” in this document) that are used to protect steam and condensate piping; some of which have since been abandoned. The age of the tunnel and piping vary, however a majority of the existing tunnel system had been established by 1970.

There are entry points to the tunnel at each building and via doorways distributed throughout the tunnel system. The tunnel is ventilated with several intake and exhaust fans located throughout the distribution system.

Steam, condensate, compressed air, and sections of abandoned chilled water piping (installed in 1969) are located throughout the tunnel. Abandoned chilled water piping runs from the Steam Plant to roughly the Performing Arts Building. Power, data, and communication lines are also located throughout the tunnel. There are several sections of the chilled water piping that have been re-appropriated for running data and communication lines.

The typical dimensions of the tunnel vary but are sufficiently large enough to house the existing piping and cabling while providing adequate walk/work space.

The tunnel typically supports pipes using support roller supports spaced roughly every 10 ft. Steam pipe expansion is accommodated by a mix of ball and bellows types expansion joints, located in most node areas.

The high pressure steam (HPS) line has approximately 3” thick insulation with an aluminum jacket on all pipe sizes and the pumped condensate (PC) has approximately 2” thick insulation with an aluminum jacket on all pipe sizes. Asbestos insulation can still be found on sections of piping throughout the tunnel system. Removal of asbestos has been sporadic over the years as repairs have demanded. Following each abatement project, the piping is typically marked with blue bands to indicate it is asbestos free.

Overview of Existing Buildings' Heating Requirements

The following table provides an overview of the buildings on the WWU campus.

General			Heating					Domestic Hot		
Building	Abbrev.	Sq. Ft	Total Steam Req. (Lb/hr)	Bldg. Heating Type	Total Heating (Lb/hr)	Steam Coils (Lb/hr)	HW Converter (Lb/hr)	Domestic Heating Type	Domestic Load (BTU/h)	Domestic Steam (Lb/hr)
ARNTZEN	AH	99,337	9,220	Steam/HW	7,220	620	6,600	Steam	2,000,000	2,000
BIOLOGY BUILDING	BI	81,120	12,791	Steam/HW	12,791	8,591	4,200	Steam/ Electric Booster		
BOND HALL	BH	89,591	4,621	HW Only	4,233	0	4,233	Steam	366,667	388
CARVER GYM	CV	110,700	12,500	Steam/HW	8,500	0	8,500	Steam	3,750,000	4,000
CHEMISTRY BUILDING	CB	72,574	12,152	Steam/HW	11,752	5,152	6,600	Steam		
COLLEGE HALL	CH	32,917	720	Steam/HW	720		720	Steam		
COMMISSARY	CM	37,121	100	Steam/HW	100		100			
COMMUNICATIONS FACILITY	CF	131,365	5,207	HW Only	4,561		4,561	Steam	600,000	646
ENGINEERING TECH	ET	77,592	4,679	Steam/HW	3,779	2,529	1,250	Steam		900
ENVIRONMENTAL STUDIES	ES	111,145	5,468	Steam/HW	4,200	600	3,600	Steam	1,240,000	1,240
ACADEMIC INSTRUCTION CENTER	AI	83,652	5,611	Steam/HW	5,611	1,200	4,411	Electric	848,940	0
ACADEMIC INSTRUCTION WEST	AW	46,997		HW Only						
FAIRHAVEN COLLEGE (ACADEMIC AND DINING)	FA	51,529		Steam/HW				Steam		
FINE ARTS	FI	74,866	2,529	Steam/HW	2,404	2,196	207	Steam	25,000	0
FRASER HALL	FR	13,562	991	Steam Only	991	991	0	Electric - POU	55,277	0
HAGGARD HALL	HH	107,971	4,217	HW Only	3,792	0	3,792	Steam	400,000	425
HUMANITIES BUILDING	HU	33,342	1,170	HW Only	450	0	450	Steam	720,000	720
MILLER HALL	MH	133,117	5,200	HW Only	5,200	0	5,200	Electric	121,131	0
OLD MAIN	OM	145,474	8,654	Steam/HW	6,154		6,154	Steam/Electric	2,684,256	2,500
PARKS HALL	PH	56,109	1,100	HW Only	1,100	0	1,100	Steam		
PERFORMING ARTS CENTER	PA	128,649	4,339	HW Only	3,704	0	3,704	Steam	600,000	635
SMATE (SCI/MATH/TECH EDUCATION)	SL	40,144	4,550	HW Only	4,550	0	4,550	Electric	51,182	0
WILSON LIBRARY	WL	141,027	3,767	Steam/HW	3,767		3,767	Electric	6,824	0

Continued....

General			Heating					Domestic Hot		
Building	Abbrev.	Sq. Ft	Total Steam Req. (Lb/hr)	Bldg. Heating Type	Total Heating (Lb/hr)	Steam Coils (Lb/hr)	HW Converter (Lb/hr)	Domestic Heating Type	Domestic Load (BTU/h)	Domestic Steam (Lb/hr)
BUCHANAN TOWERS COMPLEX	BT	101,095	7,871	HW Only	3,300	0	3,300	Steam	4,320,000	4,571
EDENS NORTH	EN	26,432	950	HW Only	950	0	950	Steam		
EDENS SOUTH	EH	63,662	5,350	HW Only	1,450	0	1,450	Steam	3,640,000	3,900
FAIRHAVEN TOWERS (RESIDENTIAL)	FT	123,231	0	HW Only	0			Steam		
HIGGINSON HALL (RESIDENCE)	HG	47,241	2,960	HW Only	730	0	730	Steam	2,450,000	2,230
HIGHLAND I & II (RESIDENCE)	HI	21,984	2,143	Steam/HW	810		810	Steam	1,260,000	1,333
MATHES HALL (RESIDENCE)	MA	75,381	3,798	Steam/HW	2,496	696	1,800	Steam	1,250,000	1,302
NASH HALL (RESIDENCE)	NA	76,891	3,920	Steam/HW	2,618	504	2,115	Steam	1,250,000	1,302
RDG ALPHA	RA	21,109	2,000	HW Only	2,000	0	2,000	Steam		
RDG BETA	RB	35,857	0	HW Only	0	0		Steam		
RDG DELTA	RD	22,513	3,200	HW Only	700	0	700	Steam	2,000,000	2,500
RDG GAMMA	RG	32,853	0	HW Only	0	0		Steam		
RDG KAPPA	RK	38,529	0	HW Only	0	0		Steam		
RDG OMEGA	RO	48,577	0	HW Only	0	0		Steam		
RDG SIGMA	RS	20,693	0	HW Only	0	0		Steam		
RIDGEWAY COMPLEX (DINING)	RC	20,471	1,087	Steam Only	1,087	1,087	0	Steam		
VIKING COMMONS	VC	30,739	3,560	Steam/HW	2,660	2,209	451	Steam		900
VIKING UNION	VU	65,342	1,100	Steam/HW			8,600	Steam	1,050,000	1,100
BOOKSTORE	BK	17,896	175	HW Only	0		NA	Steam	166,667	175
STUDENT RECREATION	SV	98,300	9,071	Steam/HW	5,470	500	4,970	Steam/Electric (Summer Use)	2,600,000	3,601
Building Totals		**2,888,697**	**156,769**		**119,847**	**26,874**	**101,574**		**33,455,943**	**36,369**

This table was developed by referencing the drawings located on WWU's online drawing vault. Blank cells indicate information that is currently missing and is in need of field verification for completion. In its current state, the table shows that the aggregate building connected load capacity for steam is 156,000 lb/hr consisting of roughly 120,000 for heating and process loads and 36,000 for domestic hot water production. Of this reported 120,000 for heating and process loads, 53,000 is used in buildings that utilize hot water for in-building distribution. It is important to note that this does not represent the expected diversified peak that would be required to be served by the Steam Plant. As a district system, with inherent operating diversity and design safety factors, the actual system coincident peak is often 50% to 75% of the connected load.

5.1.4. Heating Distribution Conditions Evaluation

Overview

The overall appearance of the distribution systems is that it is well maintained. Pipe insulation appears tight with no visible fraying or noticeable missing sections, there is no indication of water/steam leaks, and there is no indication of water infiltration into the tunnel.

Example Photo of Steam Distribution Interior

Tunnel, Piping, and Equipment Conditions

Overall, the tunnel and associated piping/equipment are reported to be in good shape. There is a segment of steam/condensate piping serving the Ridgeway residence halls that is slated for repair and replacement. These segments include the southern half of the complex near the Kappa building and Beta to Gamma buildings.

Life expectancy of steam and condensate pipe varies greatly depending on system conditions. Typical life expectancies are approximately 60 years for steam piping and 30 years for condensate piping. Steam piping typically experiences a longer life than condensate piping because the steam lines are typically at a relatively constant pressure/temperature and has little to no oxygen content. Condensate piping on the other hand sees much more degradation due to carbonic acid formation and potential steam flashing from hot condensate (and it is for this reason why condensate piping is typically schedule 80 as opposed to steam at schedule 40).

With the varying age of the steam and condensate piping a long term plan should be implemented to monitor the condition of the piping system and prepare for renewal and replacement.

Safety Concerns

WWU Staff reported no safety issues with the steam distribution system. There was however, noted instances of asbestos insulation that remains in portions of the distribution system.

Other Items of Note

The tunnel appears to be well ventilated by means of intake/exhaust fans located at most “node” areas in the tunnel system. This intake air is typically introduced to the tunnel from ground level of the main campus. Care should be exercised to ensure vehicles and other equipment are not placed near these intake areas to ensure proper air quality for the tunnel.

It was also noticed that there was a condenser unit located in the tunnel system. While this unit doesn’t appear to have a refrigerant charge large enough to be dangerous to the tunnel air quality, care should be exercised if additional refrigerant containing equipment is installed in the tunnel system.

Another item to note is the tunnel ambient temperature. Tunnel temperatures vary from roughly 70F to 100F depending on location. During a site visit tunnel temperatures were measured in excess of 100F in multiple locations near the Steam Plant. The ambient outdoor temperature during these measurements was ~45F in November. This can make the tunnel a potential heat related illness hazard if work is to be performed in the tunnel for extended periods of time.

While these issue appear to be mitigated due to tunnel entry/exit procedures it is still something of which to be aware.

5.1.5. Historic Steam Production and Energy Consumption

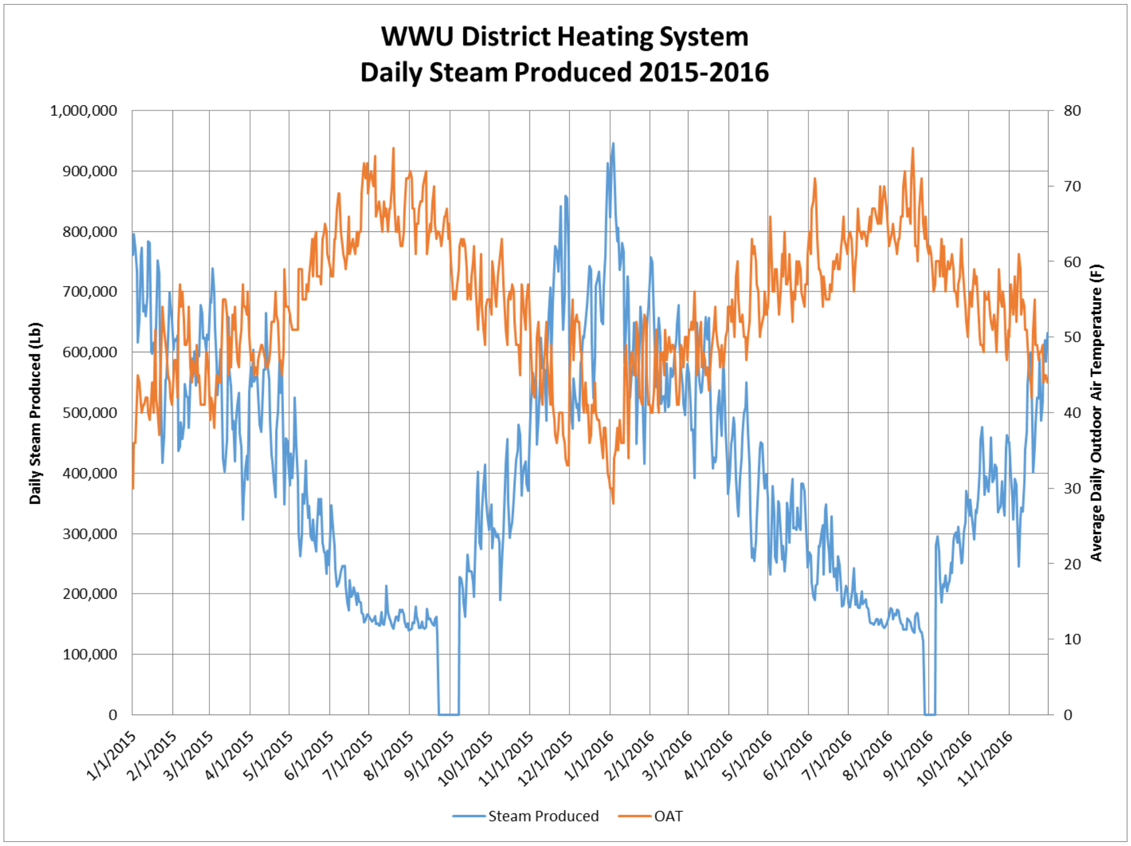
Western Washington University is a large user of energy for both natural gas and electricity. Typical natural gas usage has averaged 2,100,000 therms and electricity usage has averaged 33,000,000 kWh over the last five years for the entire campus.

The last two years of data is shown in the tables below for reference to the magnitude of energy usage and cost for both the steam plant and the WWU main campus.

Year	Month	Steam Plant N. Gas & Electricity Usage					Total Campus N. Gas & Electricity Usage				
		Natural Gas Usage	**Natural Gas Cost**	**Steam Produced**	**Electricity Usage**	**Electrical Cost**	**Total Campus N. Gas Usage**	**Natural Gas Cost**	**Total Campus Electricty Usage**	**Electricity Cost**	**Total Campus Carbon**
		Therms	$	Lb	kWh	$	Therms	$	kWh	$	Mtons
2015	January	255,380	$139,477	20,369,463	66,841	$4,705	261,958	$146,230	2,926,711	$206,028	2,597
	February	199,230	$116,925	15,897,321	60,157	$4,267	204,940	$123,428	2,721,935	$193,054	2,210
	March	198,574	$110,224	16,007,381	64,536	$4,625	204,256	$116,361	2,813,355	$201,619	2,244
	April	186,843	$91,860	15,162,075	62,152	$4,448	191,995	$97,165	2,842,404	$203,416	2,190
	May	128,607	$68,552	10,444,719	59,239	$4,345	133,660	$73,753	2,888,887	$211,905	1,900
	June	79,394	$46,784	6,449,780	50,637	$3,821	82,091	$49,603	2,566,188	$193,645	1,493
	July	63,540	$31,584	4,924,684	49,533	$3,737	64,946	$33,085	2,571,509	$193,989	1,404
	August	43,670	$24,484	3,354,489	46,149	$3,506	44,848	$25,708	2,452,264	$186,274	1,248
	September	83,240	$42,757	6,374,203	50,728	$3,865	85,777	$45,018	2,374,339	$180,924	1,433
	October	142,200	$72,378	10,958,900	64,353	$4,775	145,693	$76,271	2,877,178	$213,504	1,959
	November	239,760	$110,247	19,369,939	66,397	$4,943	245,942	$115,971	2,740,452	$204,012	2,435
	December	245,880	$123,822	20,034,694	63,789	$4,806	253,142	$130,046	2,502,202	$188,512	2,375
	Totals	**1,866,318**	**$979,093**	**149,347,648**	**704,511**	**$51,843**	**1,919,249**	**$1,032,638**	**32,277,424**	**$2,376,882**	**23,487**

Year	Month	Steam Plant N. Gas & Electricity Usage					Total Campus N. Gas & Electricity Usage				
		Natural Gas Usage	**Natural Gas Cost**	**Steam Produced**	**Electricity Usage**	**Electrical Cost**	**Total Campus N. Gas Usage**	**Natural Gas Cost**	**Total Campus Electricty Usage**	**Electricity Cost**	**Total Campus Carbon**
		Therms	$	Lb	kWh	$	Therms	$	kWh	$	Mtons
2016	January	257,360	$126,355	21,066,067	65,059	$4,756	264,565	$132,535	2,870,753	$209,853	2,588
	February	206,625	$102,056	17,018,202	65,328	$4,799	213,105	$107,621	2,736,639	$201,034	2,259
	March	195,721	$86,663	16,060,060	63,031	$4,696	201,375	$91,517	2,704,829	$201,506	2,184
	April	146,440	$67,872	12,028,757	62,824	$4,676	151,266	$72,025	2,722,075	$202,622	1,925
	May	116,866	$53,000	9,644,016	59,668	$4,389	121,242	$56,754	2,829,561	$208,137	1,809
	June	90,321	$42,083	7,395,782	51,425	$3,818	92,630	$44,109	2,380,849	$179,333	1,473
	July	66,550	$32,924	5,327,899	50,064	$3,776	67,713	$33,977	2,360,749	$178,042	1,332
	August	53,758	$28,480	4,166,706	45,532	$3,423	54,488	$29,148	2,410,645	$181,245	1,282
	September	87,089	$46,907	6,656,503	48,636	$3,681	89,618	$48,898	2,304,580	$174,437	1,425
	October	152,310	$77,161	11,823,113	57,413	$4,224	156,980	$80,812	2,820,940	$207,544	1,996
	November	175,390	$94,147	13,863,463	58,458	$4,261	181,504	$98,919	2,714,689	$197,869	2,082
	December						325,670	$164,257	2,535,186	$182,852	2,774
	Totals	**1,548,430**	**$757,648**	**125,050,568**	**627,438**	**$46,499**	**1,920,155**	**$960,572**	**31,391,495**	**$2,324,475**	**23,127**

The last two years of daily steam production and daily average outdoor air temperature is shown on the graph below.



5.1.6. Heating System Efficiency Evaluation

Boiler logs detailing boiler operation, metered data regarding building steam usage, and utility billings from WWU's Energy Center website were provided and analyzed to determine overall system efficiency.

Heating System Efficiency Overview

Year	Heating Degree Day HDD	Total Steam Produced Lb	Total Steam Energy Mbtu	Natural Gas Usage Therms	Natural Gas Energy Mbtu	Overall Boiler Energy Loss Mbtu	Overall Boiler Efficiency %	Distribution Energy Loss Mbtu	Useful Steam Energy Mbtu	Distribution Efficiency %	Total Net System Efficiency %
2012	5,419	179,836,374	187,569,338	2,245,075	224,507,500	36,938,162	83.5%	42,096,925	135,906,377	72.5%	60.5%
2013	5,185	178,687,601	186,371,168	2,196,761	219,676,100	33,304,932	84.8%	51,979,257	124,886,982	67.0%	56.9%
2014	4,628	163,238,183	170,257,425	2,033,226	203,322,600	33,065,175	83.7%	46,435,795	115,138,501	67.6%	56.6%
2015	4,437	149,347,648	155,769,597	1,866,318	186,631,800	30,862,203	83.5%	47,052,556	100,772,792	64.7%	54.0%
2016	3,544	125,050,568	130,427,742	1,548,430	154,843,000	24,415,258	84.2%	41,644,885	82,131,043	63.0%	53.0%
Average	**4,643**	**159,232,075**	**166,079,054**	**1,977,962**	**197,796,200**	**31,717,146**	**84.0%**	**45,841,883**	**111,767,139**	**67.3%**	**56.5%**

The above table details yearly usage for the past five years with the five year average values. The five year average system efficiency is 56.5% defined as the useful steam consumed by the buildings by the energy consumed by the boilers. Please note that the data for 2016 does not include steam production information for the month of December. This affects the total Heating Degree Days, amount of steam produced, and natural gas consumed. The percentage of efficiencies are relatively unaffected by this missing data as it accounts for only one month of the year.

The following definitions were used in calculating the system efficiency:

- ***Heating Degree Day (HDD):*** Is an indicator of the relative amount of heating required in a given year. HDD is defined by the sum of a base temperate minus the daily average outdoor air temperature for all days where outdoor air temperature is less than the base temperature (all positive values). The base temperature is representative of the outdoor air temperature where it is expected a building does not require additional heat input. This value is typically 65F for office/retail buildings and 55F for semi-heated buildings like warehouses.

- ***Overall Boiler Efficiency:*** Is the total efficiency of a boiler including radiation and convection losses of the boiler and energy expelled in the flue gas. This was calculated by determining the total energy inputted to the steam per lb accounting for the energy returned by the condensate (1063 btu/lb for 110 psi steam generated from 180F condensate) and dividing by the natural gas energy consumed by the boilers.

- ***Distribution Efficiency:*** Is the total efficiency of the distribution and buildings systems as defined by useful steam energy delivered to the building divided by the steam energy generated at the Steam Plant.

- ***Useful Steam Energy:*** Is the energy used by the buildings for heating purposes. The amount of non-useful (parasitic) energy lost to the system was determined by completing a regression analysis of steam generated at the plant versus heating degree days. Useful steam was then calculated by subtracting this parasitic energy from the steam energy generated at the plant.

System Losses

Losses in a district steam system are largely static and due to the nature of the system. This can be seen from the above table that as HDD decreases per year, the system efficiency also decreases. This is due to the losses becoming a larger percentage of the total load.

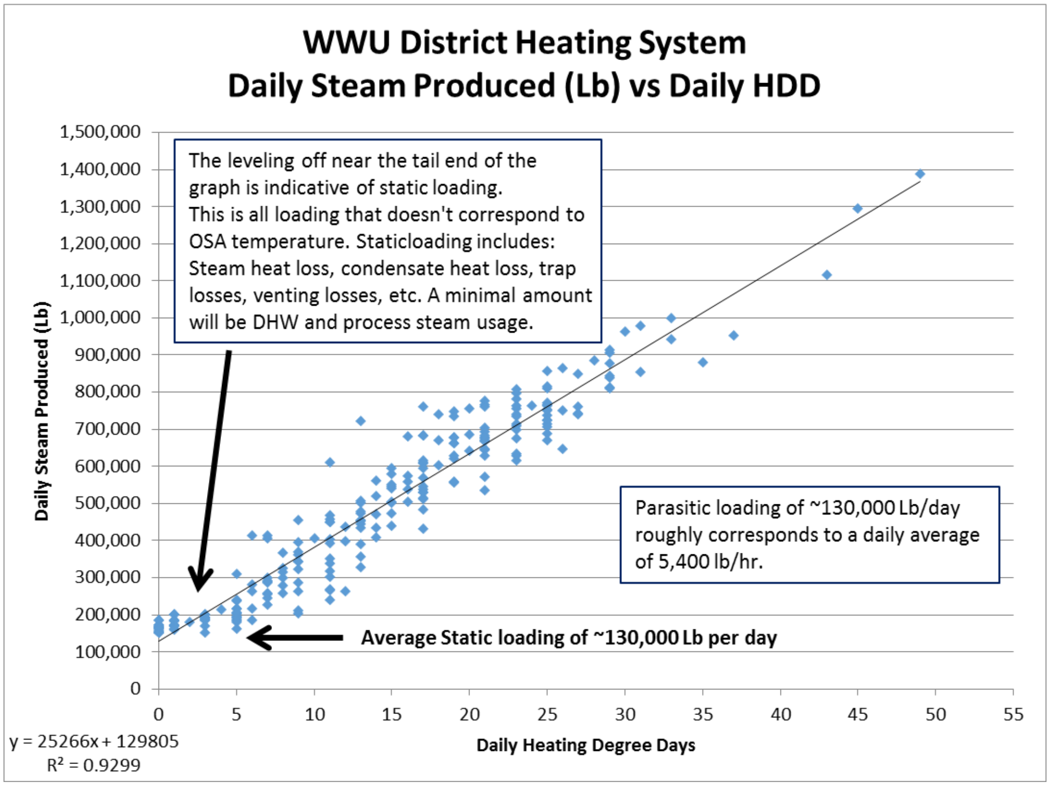
There are multiple categories of loss for a steam system. Steam distribution lines are essentially at constant temperature and pressure throughout the year. Since the lines are located in a tunnel system that is below grade, they are subjected to a nearly constant temperature year round as well. This corresponds to a near continuous level of heat loss from the distribution piping. Also, since steam lines are kept at a consistent pressure, any steam leaks on the steam distribution would also be fairly constant.

Condensate line losses are somewhat similar in nature to steam losses as they are co-located in the same tunnel system and subjected to the same external temperatures. Condensate will experience less loss due to a smaller temperature differential and due to pipes not being completely full as flow is staggered due to condensate receivers.

Steam systems are also subject to physical steam losses due to venting required. Vents are located at deaerator tanks, low pressure flash tanks, and condensate receivers. Venting at deaerators are fairly constant throughout the year while low pressure flash tanks and condensate receivers will vary with the load of the system.

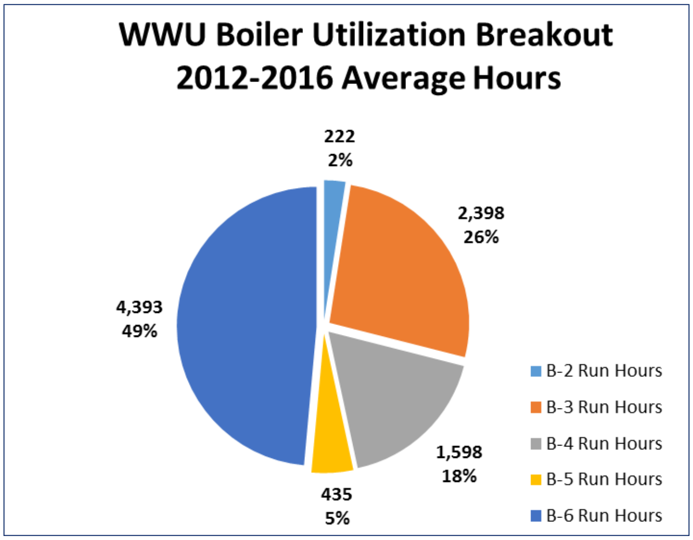
At the building level, buildings that directly use steam are typically older and are likely to have multiple steam control valves that are not operating optimally and thus contributing to the inefficiency of the system.

To determine the amount of distribution energy loss a regression analysis was completed plotting the daily steam production versus heating degree days. The Y-intercept of this regression line represents the average daily energy loss in pounds of steam. For the five year average from 2012-2016 the average daily parasitic loading on the steam system is 130,000 lbs of steam. For a 24-hour period this represents an average boiler loading of 5,400 lb/hr. This calculation reinforces the anecdotal parasitic loading noted by steam plant personnel of 6,000 lb/hr minimum.



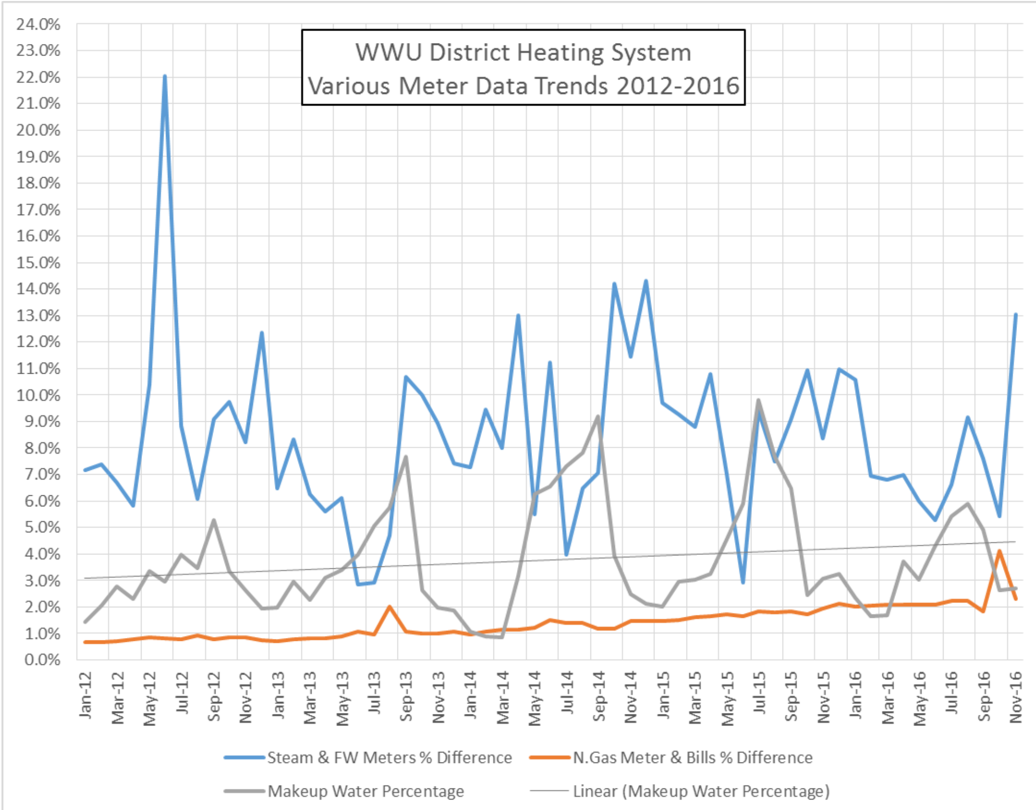
Steam Boiler Utilization

During the efficiency analysis it was noticed that there is a wide range in run hours for each boiler. The graph below breaks out the average run hours for each boiler from 2012-2016. The range of usage for each individual boiler varied from 2%-49% over this time period. The reasons for the variation in usage appear to be due to the age, efficiency, and min/max steam production capability. This wide range of usage means that significantly more work is being performed by B-6 than the rest of the boilers in the Steam Plant. The two least usage boilers, B-2 and B-5, run for approximately 27 days total per year together while B-6 runs for 183 total days on average.



Meter Errors and Drift

During the analysis of the steam system it was noticed that some of the metering was providing values that differed with other meters in the facility or meters owned by the utility. The following graph displays the percent difference in readings between two sets of meters: the two main steam meters (B-2,3,4,5 and B-6) versus the main feed water meter and the "O.S. Gas Meter" versus natural gas billing data. The graph also displays the percentage of makeup water over the same time period.



As shown in the graph above, there is a significant difference in the mass flow reported by the steam and feed water meter. It is currently believed that the feed water meter is reading more accurate numbers than the steam meters as the reported mass flow corresponded to expected boiler efficiencies from the above energy analysis. In general, water flow meters are typically more accurate than steam meters (especially so at lower/part loads) and experience less drift over time. To validate the meter readings a portable ultrasonic flow meter can be attached to the feed water pipe to calibrate the feed water metering. The steam meters could then either be calibrated to the feed water meter or if a manual differential pressure metering station is already installed in the steam distribution the meters can be calibrated to those.

The “O.S. Gas Meter” also shows a difference in reading from the reported utility bills. This difference is relatively small but is drifting wider over time. It is currently believed that the reported utility usage is reading more accurate numbers as it also corresponded to expected boiler efficiencies from the above analysis. It could be assumed that the utility usage is correctly calibrated as utility grade meters are typically very resilient but to ensure complete accuracy the utility can be contacted to test their metering. The internal WWU meter could then be calibrated to the utility.

Also included in this graph is the percentage of makeup water used over time. This usage appears to be quite variable over time with the spikes in usage corresponding to the summer shutdown period. However, looking at a linear trend line over time appears to show an increase in makeup water usage. It is not clear what could be driving the usage increase and currently the loss levels don't appear to be such that it is a major concern. It is also worthwhile to note that for this type of steam system it is impossible to have zero makeup water usage. Water loss will happen at each vent (condensate receivers, low pressure flash tanks, deaerator tanks) where there is direct contact with the atmosphere. In fact, the makeup water usage appears to be sufficiently below average for a steam system of its age and scale.

5.2. Future growth evaluation

5.2.1. Steam Plant Capacity and Requirements for Future Expansion

Steam Generation Capacity

The five boilers housed in the Steam Plant have a total installed capacity of approximately 255,000 lbs/hr of steam. A campus of this type typically requires a certain level of steam production redundancy, meaning that the heat load can still be served even if the largest boiler is off-line for repairs. For the WWU campus to have full (N+1) redundancy, sufficient generation capacity needs to be installed to handle a peak load with the largest unit not operating. Assuming that Boiler #5 (which is the largest boiler) is not operational, the plant will still have the capability of generating 155,000 lb/hr.

Steam Header Capacity

While installed generation capacity is typically the largest concern, pipe sizing in the Steam Plant also needs to be considered when determining maximum distribution capacity. Steam piping is typically sized by limiting maximum velocity in order to control erosion in the pipe and fittings due to entrained water droplets and debris. The higher the velocity the higher the rate of pipe erosion and degradation over time. Recommended limits to velocity vary; ASHRAE 2013 Fundamentals states "steam velocity should be 8,000 to 12,000 fpm, with a maximum of 15,000 fpm." While Spirax

Sarco recommends a maximum velocity of 7,200 fpm. For this report the 7,200 fpm velocity limit is used to remain consistent with the 2007 Master Plan document.

Boilers #2,3,4 directly connect into a common 8” header while Boilers #5,6 directly connect into the 14” main distribution line. An 8” branch line interconnects the 14” distribution and the main header together. There are two additional distribution lines that branch off the 8” common header: a 6” line to the north trench and a 2” line to the Arts Building. Using the pipe sizing limit of 7,200 fpm only 129,200 lb/hr should be sent out for building use (14”: 104,300 lb/hr, 6”: 22,300 lb/hr, and 2”: 2,600 lb/hr) from the Steam Plant with the current header configuration.

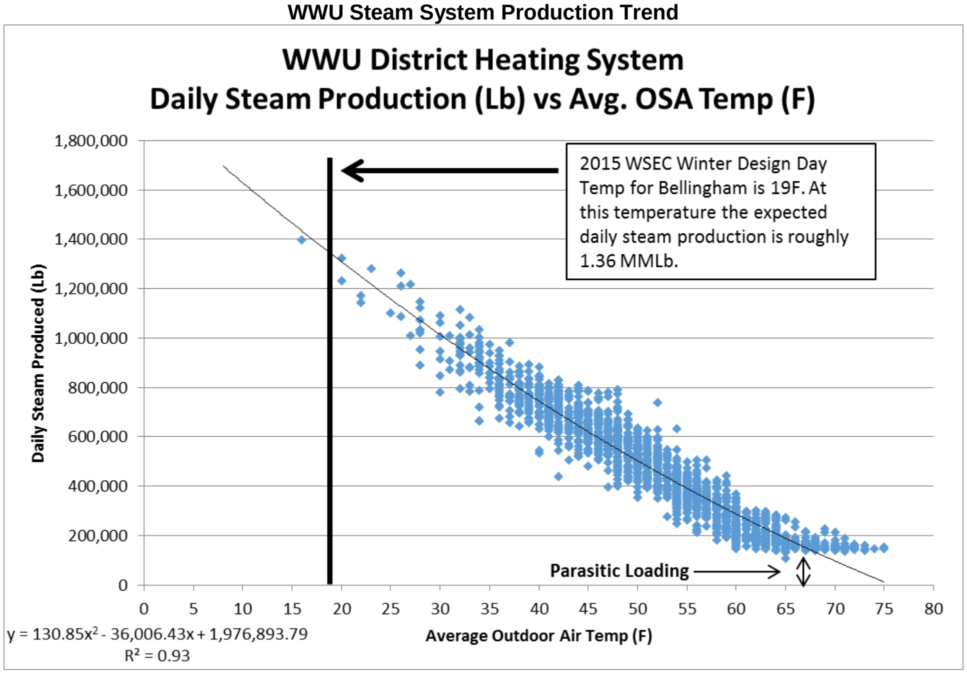
Steam System Load

It has been reported that the record peak steam production of approximately 80,000 lb/hr happened on January 10th, 2006 with an outdoor air temperature that ranged from 12-24F during the day and wind speeds of 4-10 MPH. Instantaneous measurements can be a useful benchmark to correlate steam production requirements to outdoor air temperature but one should exercise caution when using these numbers to determine the exact sizing requirements of a central heating facility. The reasoning for this is that a district heating system’s loading is dependent on multiple buildings that may not all be fully loaded due to building diversity. Building occupation affects room set points, heat load from people/lighting/computers, fresh air load requirements, etc. which all have an impact on the required heating load. A singular day of readings is not typically sufficient enough to truly estimate system peak loading even though it does provide a very good point of reference to compare more empirical data.

In order to determine expected peak system loading an analysis must be completed to understand the system. There are two methods to analyze peak heating requirements of district systems called “white-box” and “black-box” analysis. White-box analysis would be if all the buildings were simulated in energy modeling software where all details of interior requirements can be specified. This method would ensure that the buildings could be specified to have maximum load with solar/weather functions accurately represented; however it is dependent upon the capabilities of the person developing the model and the assumptions contained therein.

Black-box analysis is typically used with historical data to predict heating loads. It is termed black-box because the system is lumped together as a whole and there is no data regarding the individual actions of the buildings of the system. The following graph depicts a black-box analysis approach regarding peak steam loading for WWU.

WWU Steam System Production Trend



The above graph was generated from daily steam records as kept by boiler operation staff. The data provided details daily steam operation parameters for the boilers for the years 2012-2016. As noted on the graph, on a 19F day the approximate daily steam production would be 1.36 MMlb of steam. For a 24 hour period this corresponds to an average loading of 57,000 lb/hr. Peak loading will typically be within 1.5x to 2x this daily average for a total peak loading of approximately 85,000 - 114,000 lb/hr.

While this analysis was completed with daily steam data, the accuracy could be improved with 10 or 15 minute interval data to gain a more precise peak loading estimate.

With the above analysis the maximum expected loading on the steam system is 114,000 lb/hr. This is sufficiently below the current redundant capacity of the Steam Plant of 155,000 lb/hr and the below the maximum steam distribution capacity of 129,200 lb/hr. Assuming a nominal heating intensity of 40 btu/hr/sq.ft for new buildings, approximately 380,000 sq.ft can be added to the district steam system without the need for additional generation capacity or distribution mains.

5.2.2. Future Buildings Heating Requirement

Heating energy usage of new and remodeled buildings will be highly dependent on the type of heating system chosen for the building. A building that uses direct steam for in-building heating typically consumes more energy than a building that uses hot water heating. With the continual improvement to the requirements on new buildings, heating systems will be forced to become smaller and utilize lower grade heating mediums.

The rule of thumb for typical office type buildings is a heating intensity requirement of 40 btu/hr/sq.ft with high performance buildings pushing below 20 btu/hr/sq.ft. For the WWU campus, 40 btu/hr/sq.ft will most likely be more typical for most office type buildings unless specifically designed for high performance.

5.2.3. Tunnel Capacity and Requirements for Future Expansion

Nominal Pipe Capacities

WWU's standard material specification for steam distribution pipe in the tunnel system is schedule 40 A53 black steel pipe with welded connections for pipes 2-1/2" and larger and schedule 80 threaded for all sizes smaller. Standard material specification for condensate distribution pipe is schedule 80 A53 black steel pipe with welded connections for pipes 2-1/2" and larger and threaded for smaller.

For condensate pipe sizing there are two typical design parameters used: pressure drop per 100 ft for 6" pipe and smaller and condensate velocity for 8" pipe and larger. For these two parameters there are two common specifications for allowable pressure drop and water velocity. One school of thought is to limit pressure drop to 2.5' of pressure per 100' of pipe and maintain velocities below 7 fps. The other is to limit pressure drop to 4' of pressure per 100' and maintain velocities below 10 fps. The 2007 Master Plan followed the 2.5' of pressure drop per 100' design velocity and that will be used in this document to remain consistent. It is important to note that if existing pipe sizing was to potentially become a concern with the addition of load on the system, changing the design criteria to 4' drop per 100' of pipe can be a sufficient way to increase capacity of the existing system (at the cost of upgrading pumping head capacity/increased pump energy usage and additional wear of the piping material).

Using a steam pipe sizing criteria of limiting maximum velocities to 7,200 fpm and the condensate piping criteria discussed above, the following table was created detailing maximum flow rates for various pipe sizes.

Pipe Size	Max Flow Rate for HPS at 100 psig	Max Flow Rate for Condensate at 2.5'/100'	Max Flow Rate for Condensate at 4'/100'
Nominal	lb/hr	GPM	GPM
1"	600	5	7
1-1/2"	1,400	15	24
2"	2,300	30	45
2-1/2"	3,700	50	75
3"	5,700	90	130
4"	9,800	185	270
6"	22,300	545	800
8"	38,600	1,000	1,560
10"	60,800	1,570	2,460
12"	86,300	2,220	3,500
14"	104,300	2,680	4,220

Steam Distribution Capacity

A regression analysis was completed using monthly condensate readings from 2011-2016 to determine expected maximum loading at each building based on a 19F design day. The results of that analysis can be seen in the table below. It is important to note that this value differs from the steam system load analysis completed in the preceding section. The reason for this is that this analysis determines the required heat load at each building and excludes all energy losses in the associated distribution piping.

It is also important to note that this table represents individual peak building load capacity, not the overall system diversified peak. Due to building diversity, it would be an extremely unlikely occurrence that all buildings would see peak load at the same time. This method of analysis will provide a conservative estimate for the steam distribution capacity.

Building	Est. Design Consumption Lb	Average Loading Lb/hr	Estimated Peak Load Lb/hr
ACADEMIC INSTRUCTION CTR	920,540	1,237	2,500
ARNTZEN	1,049,726	1,458	3,000
BIOLOGY BUILDING	2,156,786	2,899	5,800
BOND HALL	749,738	1,008	2,100
BOOKSTORE	118,835	160	400
BUCHANAN TOWERS	1,933,516	2,599	5,200
CARVER GYM	1,011,209	1,359	2,800
CHEMISTRY BUILDING	3,495,890	4,699	9,400
COLLEGE HALL	220,113	296	600
COMMISSARY	418,846	563	1,200
COMMUNICATIONS	818,446	1,100	2,300
EDENS NORTH	409,015	550	1,100
EDENS SOUTH	326,613	439	900
ENGINEERING TECH	1,055,211	1,418	2,900
ENVIRONMENTAL CTR.	1,141,382	1,534	3,100
FAIRHAVEN ACADEMIC	271,471	365	800
FAIRHAVEN TOWERS	1,808,565	2,431	4,900
FINE ARTS	1,285,601	1,728	3,500
FRASER HALL	179,339	241	500
HAGGARD	472,484	635	1,300
HIGGINSON	372,118	500	1,100
HIGHLAND I & II	328,746	442	900
HUMANITIES	450,352	605	1,300
MATHES	856,278	1,151	2,400
MILLER HALL	789,833	1,062	2,200
NASH	1,030,210	1,431	2,900
OLD MAIN	1,180,680	1,587	3,200
PARKS HALL	354,735	477	1,000
PERFORMING ARTS	962,885	1,294	2,600
RIDGEWAY COMPLEX	4,035,000	6,004	12,100
RIDGEWAY DINING	1,013,088	1,362	2,800
SMATE (SCI/ED/TECH)	206,662	278	600
STUDENT RECREATION	1,355,075	1,821	3,700
VIKING COMMONS	1,087,149	1,510	3,100
VIKING UNION	1,106,175	1,487	3,000
WILSON LIBRARY	792,874	1,066	2,200
Totals:	**35,765,184**	**48,794**	**99,400**

1. Peak monthly consumption determined by linear regression of data from 2011-2016
2. Peak monthly consumption calculated to 2015 WEC design day of 19F
3. Peak loading is assumed at 2x average loading
4. Ridgeway Complex is sum of individual Ridgeway buildings.
5. Data for Carver is pre-remodel

With the preceding estimate for building full load steam requirements, the distribution system was analyzed for the maximum capacity that could be expected. Three main distribution branches were identified; T-1 with buildings from Carver to Nash, U-1 with buildings from Miller to Higginson, and T-2 with buildings from Chemistry (Morse) to Buchanan.

These distribution branches are interconnected in segments to allow buildings to be fed from multiple directions. Branches T-1 and U-1 are interconnected between Wilson Library/Old Main and Nash/Higginson. Branches T-1 and T-2 are interconnected between Ridgeway and Student Recreation.

The following table was created by adding up building loads along the presumed direction of flow. This assumption, about the presumed direction of flow along the branch lines, essentially ignores the feed potential from the interconnections. Overall, the distribution system appears to have adequate capacity to add significant new loads. The 10” branch line preceding carver gym can support an additional 19,200 lb/hr at the current design velocity. The 6” line to Miller hall can support an additional 13,800 lb/hr and the 10” line to the Chemistry Building (Morse) can support an additional 15,000 lb/hr.

There does appear to be one potential bottleneck in the distribution system that currently exceeds the design limit of 7,200 fpm for steam velocity; the line between Bond Hall and Haggard. The expected maximum flow exceeds the pipe capacity by 100 lb/hr. This is currently not a problem as flow can be provided from the interconnection point to loop U-1 to feed buildings “downstream” (Wilson, Humanities, and Fraser in the current assumed flow direction).

It is also important to note that even in a worst case scenario where a branch line is obstructed or valved off there would not likely be any adverse effects to the piping system. The above numbers are based on a full steam flow scenario which would be quite unlikely due to system diversity. In addition to this, steam velocities could likely be doubled to a maximum of 15,000 for short periods of time indicating that there is an approximate safety factor of 2 in regards to velocity.

The values for condensate are shown for reference only as they reflect what the theoretical maximum flow would be if all the condensate receivers were discharging simultaneously. In reality, all the building's condensate flows would be staggered due to the built in storage the condensate receivers provide.

A visual representation of the current distribution capacity can be found in the appendix.

Branch	Bldg. Initials	Building Name	HPS Line Inches	Required Capacity Lb/hr	Available Capcity Lb/hr	PC Line Inches	Required Capacity GPM	Available Capacity GPM
Fine Arts	FI	Fine Arts	2"	3500	-1,200	1-1/2"	12	3
T-1	CV	CARVER GYM	10"	41,600	19,200	3-1/2"	388	-150
T-1	HI	HIGHLAND I & II	10"	38,800	22,000	3-1/2"	371	-133
T-1	SL	SMATE (SCI/ED/TECH)	10"	37,900	22,900	3-1/2"	365	-127
T-1	RC-ALL	RIDGEWAY COMPLEX	10"	37,300	23,500	3-1/2"	335	-97
T-1	RC	RIDGEWAY DINING	10"	25,200	35,600	3-1/2"	262	-24
T-1	BH	BOND HALL	6"	22,400	-100	3-1/2"	246	-8
T-1	HH	HAGGARD	6"	20,300	2,000	3-1/2"	233	5
T-1	HU + FR	HUMANITIES + FRASER	6"	19,000	3,300	3"	221	-131
T-1	WL	WILSON LIBRARY	6"	17,200	5,100	3-1/2"	199	39
T-1	CH	COLLEGE HALL	6"	15,000	7,300	4"	169	101
T-1	PA	PERFORMING ARTS	6"	14,400	7,900	4"	165	105
T-1	BK	BOOKSTORE	6"	11,800	10,500	4"	135	135
T-1	VU	VIKING UNION	6"	11,400	10,900	4"	120	150
T-1	VC	VIKING COMMONS	6"	8,400	13,900	4"	90	180
T-1	MA	MATHES	4"	5,300	4,500	4"	60	210
T-1	NA	NASH	4"	2,900	6,900	2"	30	0
U-1	MH	MILLER HALL	6"	8500	13,800	2"	129	-99
U-1	OM	OLD MAIN	6"	6300	16,000	4"	99	171
U-1	EH	EDENS SOUTH	4"	3100	6,700	1-1/2"	24	-9
U-1	EN	EDENS NORTH	4"	2200	7,600	2"	19	11
U-1	HG	HIGGINSON	4"	1100	8,700	2"	12	18
T-2	CB	CHEMISTRY BUILDING	10"	45800	15,000	6"	575	-30
T-2	BI	BIOLOGY BUILDING	10"	36400	24,400	6"	418	127
T-2	ET	ENGINEERING TECH	10"	30600	30,200	6"	313	232
T-2	AH	ARNTZEN	10"	27700	33,100	6"	295	250
T-2	PH	PARKS HALL	10"	24700	36,100	6"	277	268
T-2	ES	ENVIRONMENTAL CTR.	10"	23700	37,100	6"	255	290
T-2	CF	COMMUNICATIONS	10"	20600	40,200	6"	225	320
T-2	AI	ACADEMIC INSTRUCTION CTR	10"	18300	42,500	6"	195	350
T-2	SV	STUDENT RECREATION	10"	15800	45,000	4"	164	106
T-2	FA	FAIRHAVEN	8"	12100	26,500	4"	127	143
T-2	CM	COMMISSARY	8"	6400	32,200	4"	90	180
T-2	BT	BUCHANAN TOWERS	8"	5200	33,400	4"	30	240

5.3. System Improvements for Consideration

WWU should begin to make long term renewal and energy efficient investments in the existing district heating system; making sure to do so in a planned, flexible approach that provides short term improvements while setting the stage for long term expansion and conversion to new, more efficient production and distribution systems.

The following items are recommended improvements for consideration:

General:

- **Complete a Life Cycle Cost Analysis:** To best guide the university forward a life cycle cost analysis should be completed detailing different district heating and distribution possibilities. This analysis should be used to determine the most economical and environmentally sound path for the university.
    - At a minimum this analysis should include:
        - A long term analysis horizon of 40-50 years.
        - Comparison of “business as usual” steam production and distribution against a multitude of options encompassing operating and maintenance, renewal, fixed, variable, and capital costs:
            - Steam Production from CHP with Steam Distribution
            - Steam Production from Standard Boilers with Hot Water Distribution
            - Steam Production from CHP with Hot Water Distribution
            - Hot Water from Condensing Boilers with Hot Water Distribution
            - Hot Water from CHP with Hot Water Distribution
            - Hot Water from other technologies with Hot Water Distribution
            - Carbon reduction methods such as Biogas
            - Additional items as deemed worthwhile of study for comparison

In-building systems:

- **Update Heating System Specifications:** To best enable the future buildings to support the implementation of renewables and renewable technology into the district heating system, WWU should consider revising their building heating specifications applicable to remodels and new construction.

  This could include the requirement that all future buildings and future building renovations be connected to the district heating system and that these systems utilized low temperature in-building hot water distribution systems fed from a main heat exchanger. Consideration should be given to designing to the lowest hot water distribution temperature possible with the highest delta in temperature (160F supply temperature for existing buildings and 140F or less for new construction). This will provide a more efficient building and increase the efficiency of the overall district energy plant

  Low temperature building systems provide the most flexibility to the existing district energy system by allowing the condensate return temperature at the plant to be lowered over time. This provides lower losses within the overall distribution system while also allowing for the implementation of condensing stack economizers at the plant. It also provides for an easy transition to an overall heating hot water system for the campus at some point in the future.

  Low temperature hot water systems also enable the efficient implementation of a new heating production source at the district heating plant; such as cogeneration (reciprocating engines, micro-turbines), heat pumps, geo-exchange, and solar thermal.

- **Building Energy Transfer Stations upgrades:** Building energy transfer stations (ETS) are the interface between the district steam network and the in-building heating system. All buildings have some form of ETS that vary from a pressure reducing valve station on buildings that utilize direct steam, to a steam heat exchanger that provides hot water to a building. Various modifications can be made at the ETS and building level to make existing and future buildings more flexible and beneficial to the district heating system. These items include:

  - **Convert to heating hot water:** In buildings that still utilize direct steam from the district network, begin the conversion process to hot water. In-building hot water distribution experiences less thermal energy losses and has higher controllability than existing steam systems. Buildings converted to hot water should attempt to achieve the lowest hot water supply temperature as practical to enable better integration into a future hot water district network.

- **Reconfigure existing domestic hot water production:** In most buildings, domestic hot water can be reconfigured from taking direct steam (or being an electric standalone unit) to utilizing steam condensate and water storage. This could reduce the steam condensate return temperature low enough to enable condensing boiler operation at the steam plant. A suitably designed system could take advantage of up to 97% of the thermal energy of the steam sent to the building (corresponding to ~70F condensate return temperature – depending on building loading).

- **Lower building level steam pressure:** On buildings that utilize hot water heating there may be the opportunity to lower the discharge pressure from existing steam PRV's serving the heat exchanger. Typical design for hot water heat exchangers is typically a maximum of 15psig steam input. During a site walk it was noticed that a building heat exchanger was operating at approximately 30 psig (and it should be noted that it was unclear if this pressure was needed for an internal building process). Operating above 15 psig increases losses in the building level flash tank and condensate receiver as the latent energy of steam decreases with increasing pressure. Each building should be checked to ensure it is operating at the minimum steam pressure required.

- **Install additional building-side metering:** In buildings that utilize hot water for heat, additional meters can be installed to provide a more in-depth picture of building energy usage. Hot water supply/return temperature with flow rate trended on 5 min, 10 min, 15 min, or hourly intervals can give a detailed look into how each building is operating. This level of data collection can be used to identify problems in the building heating system and can track equipment operation/efficiency.

Distribution System

- **Convert from Steam to Hot Water (HW) District Distribution:** This measure could provide WWU an opportunity to greatly improve system efficiency, reduce operating and maintenance costs, and utilize additional automation within the plant. HW production (ideally with a goal of low temperature distribution) would also enable the central plant to incorporate renewable technologies such as low grade waste heat recovery (i.e.: from chillers, process loads, or solar thermal), thermal storage (to allow for load shifting), combined heat and power and/or ground source heat pumps. Rough order of magnitude (ROM) estimated costs and savings potentials can found below.

Conversion could happen in a few ways. The distribution system could be converted after all the campus buildings were converted to hot water, individual hot water distribution legs could be installed in the tunnel with current hot water buildings connected and converted buildings connected over time, or both in-building systems and distribution could be updated in one large project.

The conversion to HW provides the single largest potential for energy efficiency improvements and carbon reduction over the current steam production. For example, a condensing boiler HW production plant could see a thermal efficiency of 88-97% and a distribution efficiency of 90-95% for an overall efficiency of 80-92%.

District Heating Production Plant:

The production plant presents challenges not seen in the in-building/distribution system due to the age of production equipment and the need for renewal. These issues could be eliminated if a large project was implemented to avoid cost expenditures on steam renewal, however, the total cost to implement such a project would most likely be difficult to fund fully using traditional funding means. In any case, improvements made to the Steam Plant should be completed with the conversion to hot water production and distribution (in the future) in mind.

- **Budget for System Renewal and/or Replacement:** The existing district steam system is increasing in age and will be due for significant upgrades in the near future. A majority of the Steam Plant equipment is older and technically past it's useful life (although it has been thus far kept in service due to proper care and due diligence). If the steam system is to be replaced, appropriate costs should be developed depending on the technology considered. If the existing steam system is to be maintained there will be a need for some initial investment to upgrade systems in addition to a need to invest ongoing system renewal dollars annually. In the future it is recommended that following ranges of numbers be budgeted for continual renewal of the system over an assumed 15 year period:
    - Steam Plant Equipment & Piping: $750,000 - $1,100,000 per year
    - District Steam Piping: $700,000 - $1,000,000 per year

- District Condensate Piping: $450,000 - $750,000 per year

- **Install Modular Steam Boilers:** In lieu of purchasing a single large boiler of like size upon replacing existing steam boilers (and contingent upon a determination of whether the campus will at some point be converted to hot water), consideration should be given to purchasing multiple smaller, more modular, steam boilers to cover the same load. Boilers of roughly 15,000-25,000 lb/hr steam output should be able to improve overall production efficiency by providing a higher level of turn down for the low-mid level steam load that the campus currently sees.

  Multiple modular boilers reduce capital costs because smaller boilers can be purchased as replacement is needed. Maintenance and operation expenses are reduced because operation is simplified and similar parts can be kept in stock. Consider the case of five 25,000 lb/hr boilers as opposed to the current mix of boiler sizes contained in the steam plant. The minimum flow rate from the plant is roughly 5,000 lb/hr and any of the boilers can be selected to operate in this condition. As load is increased any of the boilers can be selected allowing any required unit to be down for servicing/inspection. This allows equal run hours to be spread across all boilers. The current expected steam peak could still be served from these five boilers as well: covering the load from its current minimum to maximum. In addition, the boiler equipment/parts are similar between all the boilers allowing for reduced spare parts kept on hand.

  In the existing case with multiple boilers of various sizes, minimum load typically is covered by a single boiler that can operate the most efficiently at this point. Peak loading is typically handled by the larger boilers, meaning that boiler loading is varied across the various boilers throughout the year. Also, since each boiler is a different size that means that each boiler must have its own spare parts.

- **Calibrate Natural Gas and Steam/Feed Water Meters:** Discrepancies were noticed between the supplied trending of natural gas usage and the reported usage from utility billing. There were also discrepancies noticed from the steam and feed water meters. Both sets of metering should be calibrated to ensure they are reading proper values.

- **Utilize Combustion Air Preheating:** Preheating boiler combustion air that is delivered to the boilers with heat from the exiting flue gas is a way to increase system efficiency and potentially enable condensation of the flue gas. To preheat the combustion air, a heat exchanger is installed in the boiler stack exhaust stream. Additional heat exchangers are installed in the combustion air duct work with a pumped water and glycol mixture working fluid to exchange the heat.

Typical efficiency increases range from 2% to 5% of overall boiler efficiency. Combustion air temperature can see a 100F+ rise from ambient and flue gas can see roughly the same temperature reduction.

Potential concern with installing a condensing economizer is exceeding existing fan rated static pressure. Since heat exchangers are installed both on the inlet and outlet of the boiler both forced draft and induced draft fans can be affected. Another concern is that if the existing exhaust stack's temperature is low enough, condensing of the water vapor in the flue gas can occur. This is something that would need to be designed and prepared for (as in ensuring the heat exchanger in the flue gas is made of stainless steel and designed to remove all the moisture without exposing non-stainless steel components).

A final note is that with heating of the combustion air its density will decrease the hotter it becomes. This can mean that existing air/fuel ratios and controls could need to be upgraded if an oxygen trim device does not already automatically control them. Without a full modulation of the air/fuel ratio the less dense air could mean that not enough excess air is being provided to ensure proper efficient combustion.

- **Install Condensing Economizers:** A condensing economizer could provide WWU with additional efficiency gains from the steam production equipment. Condensing economizers condense the water vapor that is produced during the combustion of fuel to extract as much energy from the combustion process as possible. The condensing economizer would be installed in the exhaust stacks of the existing boilers downstream of the current traditional economizers. Makeup water, low temperature steam condensate, or heating hot water (if such a line was created on the campus) could be pumped through the economizer to bring the exiting boiler flue gas down below approximately 130F to extract the latent heat of the flue gas water vapor. Efficiency gains could be on the order of 5% to 7% of overall boiler efficiency – dependent on how low in temperature the working fluid is.

  In order to optimize condensing economizer, a lower temperature fluid is needed to bring the exhaust gas below the condensing point. Existing makeup water flow doesn't appear substantial enough and current steam condensate return temperature is not low enough to provide full optimization of a condensing economizer. However, if this measure were to be implemented in a sequenced, coordinated effort with the implementation of high efficiency energy transfer stations and/or reutilization of waste heat from the condensate lines at select locations (for domestic HW or process loads), the condensate return temperature may be able to be lowered enough to provide substantial efficiency gains from this measure.

Improvement Overview

Below is a table denoting the estimated rough-order-of-magnitude (ROM) cost and ROM lifecycle simple payback ranges for the items listed above. The following cost numbers are the total cost to implement the project (including estimated design, management, contingency, and taxes). While lifecycle simple payback is shown in the table, a more thorough assessment of true cost and benefits would be displayed by completing a long term life cycle cost analysis of the alternatives versus business as usual. The conversion to hot water would likely show improved net present value savings over business as usual when accounting for avoided renewal, operation and maintenance cost, and energy savings over 40-50 years.

Description	ROM Cost Est (+/- 30%)	ROM Yearly Energy Savings (+/- 30%)[1]	ROM Campus Utility Carbon Reduction (+/- 30%)	ROM Lifecycle Simple Payback (+/- 30%)[2]
Combustion Air Preheating	$450,000	$20,000	1%	16
Modular Steam Boilers (25 MMBtu/h) per boiler	$1,250,000	$35,000	1%	24
Condensing Economizers (assuming lowered return water temperature)	$750,000	$75,000	3%	15
New HW Distribution System (Existing Steam Production Plant)	$22,000,000	$350,000	15%	16
New Hot Water Production & Distribution System	$38,000,000	$450,000	17%	16
CHP with Existing Steam Production and Distribution System	$16,000,000	$500,000	7%	20
New Hot Water Production & Distribution System (Recip CHP & TES)	$49,000,000	$1,200,000	25%	17

Notes:
1. ROM Energy Savings accounts for utility savings only.
2. Anticipated Simple payback when accounting for the expected required expenditure to renew, operate, and maintain the existing steam production and distribution system (business as usual; BAU). This reflects the incremental payback by implementing the proposed measure.

It should be noted that there are a few funding options when it comes to completing projects for a University. In addition to state allocations and loans there has been an increase in public-private-partnerships (PPP or P3) as an alternate funding mechanism. If there was a desire to attempt to fund the conversion to hot water in a single large project this could be attractive alternative. In a PPP a joint initiative is taken from WWU and an outside party. The outside party brings funds to construct, own, and operate a new district energy plant that then becomes a thermal utility serving WWU on a long term contract. The PPP benefits both parties by providing the University with an opportunity to fund a complete turnkey project, reduce labor requirements, reduce liability, reduce operating complexity, and the private party benefits from a long term reliable customer.

5.4. Heating System Conclusions

Western Washington University owns and maintains a significant district heating system that provides heat to the majority of the buildings on the WWU campus. This district heating system comprises of a steam generation and distribution system with the campus buildings either taking direct steam or converting the heat to hot water for in-building distribution. The following items are highlights from the main document, meant to give a brief overview of important aspects of the district heating system:

- Most of the existing steam boilers are past their useful life which will make operating and maintain them more of a challenge in the years to come. The current age span of the boilers is 22-71 years with an average age of 50 years across all five boilers.

- The overall efficiency of the district heating system is 56.5% over the last five years. This low efficiency is due to the inherit nature of steam distribution being a high temperature and near constant pressure system.

- Given the current boiler capacity, piping configuration, and distribution pipe capacity, it is expected the existing district heating system can accommodate up to 380,000 additional sq.ft. of new building space assuming a nominal heating intensity of 40 btu/hr/sq.ft.

- There are a significant number of heating technologies that can be used to supplement, augment, and/or replace the existing steam production and distribution system. These options mainly depend on if the system stays with a steam distribution system or converts to a hot water distribution system. Sticking with a steam distribution system has the advantages of utilizing existing distribution piping and equipment but typically comes at reduced benefit as compared to a hot water distribution system. Hot water distribution would see significant efficiency gains, have the ability to accommodate renewables and renewable technology, and most likely provide the highest economic benefit. All these benefits come at the cost of a much more involved and complicated project that would affect every connected building on campus.

The following is a list of recommended measures for Western to consider:

General:

- **Complete a Life Cycle Cost Analysis:** A life cycle cost analysis should be completed detailing different district heating and distribution options as compared to “business as usual” steam production and distribution. This analysis should include a long term horizon of 40-50 years and encompass all costs such as operating and maintenance, renewal, fixed, variable, and capital costs.

In-Building Systems:

- **Update Specifications:** Building mechanical specifications for remodels and new construction can be updated to promote usage of renewables and increased flexibility for the district heating system. Building specifications could be updated to require buildings to use low temperature hot water systems with high differential temperatures. This requirement would like correspond to the least building level heating usage and enable the district heating system to incorporate renewable technologies.

- **Energy Transfer Station Upgrades:** Building level energy transfer stations can be modified in a wide range of ways to enable increased efficiency gains (in the case that buildings are converted from steam to hot water), the ability to enable condensing at the steam plant (by dropping condensate return temperature with suitable design configurations), provide better data/information about building performance (by monitoring instantaneous heating usage or sub-metering specific equipment), and to provide a flexible way to decouple the building from the distribution system in the event that the distribution system is converted to hot water.

Distribution System:

- **Steam to hot water production:** Converting from steam to hot water distribution could provide significant efficiency gains both in the Steam Plant and the distribution system. Thermal efficiency would be increased in the steam plant by enabling the use of a condensing economizer with sufficient hot water return temperature. For the distribution system, overall efficiency would improve significantly due to the much lower temperatures and pressures that a hot water system operates on. Hot water production also enables for additional low temperature heat recovery opportunities as well as the integration of renewables such as solar thermal.

Heating Production Plant:

The production plant presents challenges not seen in the in-building/distribution system due to the age of production equipment and the need for renewal. Improvements made to the Steam Plant should be completed with the conversion to hot water production and distribution (in the future) in mind.

- **Budget for System Renewal or Replacement:** The existing district steam system is increasing in age and many pieces of equipment are technically past their useful life. Although system life has been extended due to proper maintenance and care, the system will need major upgrades in the near future. If the steam system is to be replaced, appropriate costs should be developed depending on the technology considered. In the future it is recommended that following ranges of numbers be budgeted for continual renewal of the system over an assumed 15 year period:
    - Steam Plant Equipment & Piping: $750,000 - $1,100,000 per year
    - District Steam Piping: $700,000 - $1,000,000 per year
    - District Condensate Piping: $450,000 - $750,000 per year

- **Modular Steam Boilers:** If the district heating system is to stay in steam production and distribution, modular steam boilers could be a sufficient way to improve operation and efficiency of the boiler system. In lieu of purchasing like for like sizes for replacement of existing boilers, smaller boilers of consistent size can be purchased instead.

- **Calibrate Natural Gas and Steam/Feed Water Meters:** Discrepancies were noticed between the supplied trending of natural gas usage and the reported usage from utility billing. There were also discrepancies noticed from the steam and feed water meters. Both sets of metering should be calibrated to ensure they are reading proper values.

- **Combustion air preheating:** This measure could be a way to increase the overall thermal efficiency from the Steam Plant and potentially enable the condensing of the water vapor in the flue gas stream.
- **Install condensing economizers:** to increase overall thermal efficiency from the Steam Plant. This measure would be dependent on a low temperature heat sink to enable condensing of the water vapor in the flue gas stream.

Improvement Overview

Below is a table denoting the estimated rough-order-of-magnitude (ROM) cost and ROM lifecycle simple payback ranges for the items listed above. The following cost numbers are the total cost to implement the project (including estimated design, management, contingency, and taxes). While lifecycle simple payback is shown in the table, a more thorough assessment of true cost and benefits would be displayed by completing a long term life cycle cost analysis of the alternatives versus business as usual. The conversion to hot water would likely show improved net present value savings over business as usual when accounting for avoided renewal, operational and maintenance cost, and energy savings over 40-50 years.

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Notes:
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It should be noted that there are a few funding options when it comes to completing projects for a University. In addition to state allocations and loans there has been an increase in public-private-partnerships (PPP or P3) as an alternate funding mechanism.

5.5. Appendices

5.5.1 Reference Material

5.5.2 Review of Heating Technologies

5.5.3 Existing Heating System Piping and Instrumentation Diagram

5.5.4 Steam Plant Layout

5.5.5 Steam/Condensate Distribution Map

5.5.1. Reference Material

Notable District Steam to Hot Water Conversion Projects:

- University of British Columbia: http://energy.ubc.ca/ubcs-story/stats-metrics/
- Stanford University: http://sustainable.stanford.edu/campus-action/stanford-energy-system-innovations-sesi
- District Energy St. Paul: http://www.ever-greenenergy.com/project/district-energy-st-paul/
- Ball State University: http://cms.bsu.edu/about/geothermal
- Eastern Illinois University: http://www.eiu.edu/sustainability/eiu_renewable.php

Notable University Steam District Energy Systems:

- Princeton University: https://facilities.princeton.edu/news/the-princeton-energy-plant
- Texas A&M University: https://utilities.tamu.edu/combined-heat-power/
- Cornell University: https://energyandsustainability.fs.cornell.edu/util/districtenergy.cfm

Notable District Energy Case / Analysis Studies:

- US ACE CRREL Report 95-18, *Efficiency of Steam and Hot Water Heat Distribution Systems*
- United Nations Environment Programme, *District Energy in Cities*
- ASHRAE Journal, May 2010, *Water & Energy Use in Steam-Heated Buildings*

5.5.2. Review of Heating Technologies for Consideration

The goal of this section is to discuss potential technologies that can supplement, augment, and/or replace the existing steam boilers that currently serve the WWU campus. Each item provides a potential pathway to a more economic and sustainable heating system for the campus.

The following information provides only a cursory overview of each technology. A thorough discussion and analysis to what technology/technologies provides the most benefit to the campus is outside the scope of this document. At a minimum, such an analysis should conduct a total cost of ownership analysis, comparing all alternatives against current operation, for an extended time horizon of 40/50 years by a qualified engineering company.

Condensing Boilers

Modular condensing boilers utilize low temperature hot water to enable condensing of the water vapor contained in flue gas due to combustion. These boilers offer substantial efficiency gains over existing non-condensing boilers. Condensing boilers can see thermal efficiencies from 92% to 98% as compared to the theoretical maximum of 86% of a non-condensing boiler.

Condensing boilers are typically made of stainless steel to handle the corrosive nature of the condensed flue gas water. The condensed water is typically collected and neutralized before being sent to drain.

The drawbacks to condensing boilers are that they are limited to producing hot water and are typically smaller in size. An equivalent means of provide stack condensing in a steam system requires the implementation of an additional condensing stack economizer and a strategy to provide the available stack heat to a reliable heating need on campus.

- **Preliminary Analysis Steam to Hot Water Conversion with Condensing Boilers**

  A preliminary analysis of the potential of applying condensing boilers in a new hot water distribution system was completed. This analysis compared the proposed hot water system to the existing steam system. In the existing steam system, the average heat load is approximately 170,000 MMBTU/year, electrical usage is 33,000 MWh/year, and carbon emissions of 24,000 Mtons/year for a total energy cost of $3,500,000/year.

In a new hot water distribution system, the expected yearly heat load on the campus is on the order of 120,000 MMBTU due to reduction in distribution losses. Electrical usage would remain relatively unchanged as the power requirements for a hot water boiler system are not noticeably different than that of a steam boiler system. The condensing boiler system could generate annual energy costs savings in the range of $300,000 - $500,000/year with carbon reductions ranging from 10%-18%.

High Temperature Heat Pumps

High temperature heat pumps (HTHP) are similar to conventional heat pumps in that they move heat from a lower grade source to a higher source. Most HTHP utilize carbon dioxide as the refrigerant and operate in a trans-critical cycle at very high pressures. Output conditions are typically 180-190F hot water and 42-45F chilled water. Typical COP's will be 3-4 for heating and max out near 7.0 for simultaneous heating/cooling operation.

In order to make use of a HTHP the WWU campus would need to convert to a heating hot water (HHW) distribution system as the production temperatures are much too low for steam generation. If WWU did convert to a HHW distribution system, a HTHP could be a compelling option for WWU once enough chilled water load was aggregated on the campus.

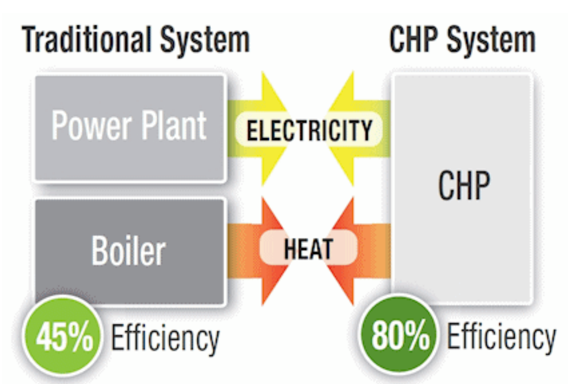
Heat recovery chillers are similar to high temperature heat pumps but typically operate with a more traditional refrigerant (R134A) and output lower grade heat (~150F or less). Typical COP's are similar to HTHP's.

Heat recovery chillers would also need a HHW distribution system in order to be integrated into the WWU campus. The tradeoff between a heat recovery chiller and HTHP is that the heat recovery chillers operate on a more traditional refrigerant and have more industry presence.

Another item of note for both high temperature heat pumps and heat recovery chillers is that the current utility structure would put a design requirement on the system in order for it to be more economical than condensing boilers/CHP in a hot water application. Current gas and electricity rates are $5.00/MMBtu and $21.79/MMBtu respectively. Assuming efficiency near the lower end for condensing boilers/CHP (90% and 80%) the required design COP would be 3.9/3.47 to equal the cost of the same sized gas burning unit. At these COPs it would most likely be a requirement to harvest the cooling provided from the unit for productive use. Another item to note is that as heating COP requirement is pushed higher it typically comes at the exchange for a lower output temperature the unit can provide.

Combined Heat and Power

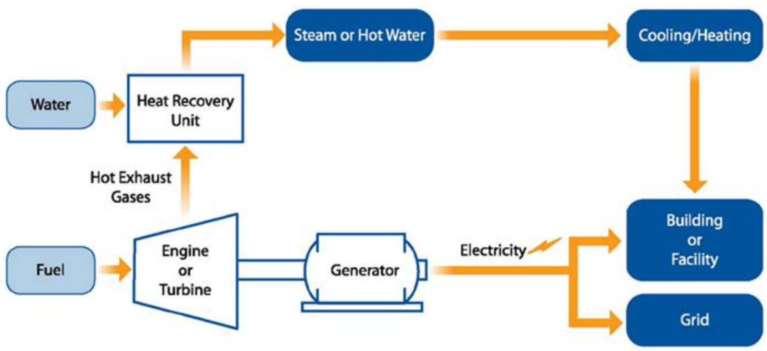
Also known as cogeneration, combined heat and power (CHP) is a way to increase the efficiency of power plants. Interestingly enough, most conventional power plants produce waste heat as a by-product of generating electricity and then discharge this valuable heat resource to the atmosphere. Standard power plants effectively use just 40 percent of the fuel they burn to produce electricity. Sixty percent of the fuel used in the electric production process ends up being rejected or "wasted" up the smokestack as heat. One of the biggest uses of fossil fuel globally is for generating this same heat resource. CHP offers the opportunity to generate electricity locally and capture the waste heat for use in heating buildings and neighborhoods**.**



CHP along with thermal storage creates a “smart grid” compatible facility capable of working cooperatively with the local utility in modes of operation that benefit both the Campus and the utility. Examples include afternoon CHP operation in the late summer and fall when hydroelectric resources can be limited. This type of operation would help the local utility especially as Washington eliminates coal generated power. The heat generated by the CHP can be stored in the thermal storage tanks for utilization during morning warm up and for reheat in buildings with Variable Air Volume (VAV) systems, a very common building HVAC system.

CHP with thermal storage also makes a campus and utility more resilient against utility source power interruptions from transmission lines and central power production facilities outages (wild fires, flooding, earthquake, terrorist, etc.). Also, thermal storage allows for the unit to be maintained without additional production equipment operating (in lieu of backup boilers or additional CHP units to provide heat).

CHP Technologies



Today's market conditions increasingly favor distributed generation fueled by natural gas and renewable fuels. The addition of heat recovery from the power generating source and thermal storage makes the economics all the more attractive. When developing a distributed generation system, there are two primary power sources: reciprocating engines and turbines. Both systems have been proven throughout the US and the world in many thousands of cogeneration installations.

Over the years, both of these technologies have continued to improve in overall operating efficiency, reliability, operating costs and emissions performance. Neither technology is necessarily superior to the other. Instead, each has attributes that make it the most suitable for a specific application due to conditions of fuel type availability and quality, thermal and electric load profile, physical space, local conditions, or other factors. There are also applications where reciprocating engines and turbines work together and provide the ideal levels of electrical reliability, efficiency and economic benefits.

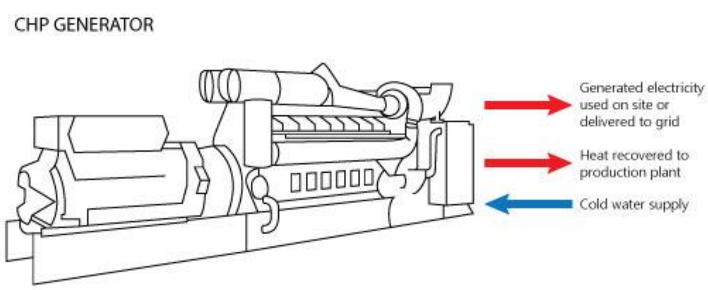
In addition to the economic benefits, CHP can help organizations live up to their sustainability, carbon-reduction, and energy-conservations goals.

As distributed generation resources, both reciprocating engines and turbine are fairly easy to install. In addition, up-front costs per kW are relatively low. The reliability is high, often up to 98 percent annually when properly maintained and operated. Both can also operate efficiently on a variety of fuels and systems are able to accommodate available space through various, flexible configurations.

Reciprocating Engine

Reciprocating engines generally are more fuel-efficient than turbines in pure electric power applications. They have lower initial cost per kW in smaller projects (less than 5 MW) and are more tolerant of high altitude and higher ambient temperatures. They operate on low to medium pressure fuel which can eliminate or reduce the costs to install and operate a gas compressor system.

While the utilization of utility provided natural gas is the most common application, engines readily accept many alternative fuels, such as biogas, digester gas, and landfill gas, as well as specialized fuels like coke gas and coal mine methane.



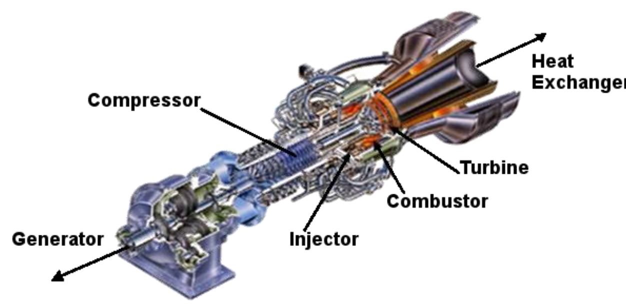
Utilized in a CHP application, engines have multiple recoverable heat sources. These include heat streams linked to exhaust, jacket water, aftercooler, and oil cooler. These recovered heat resources can be used to produce warm water, hot water, and even low quantities of medium-pressure steam (from exhaust).

One of the most obvious points of differentiation is an engine's ability to follow variable loads and to come online quickly (in most cases within 30 seconds). These attributes makes them good candidates for distributed generation in support of electric utility grids. Often, utilities need more capacity to fulfill high-cost peak demands that may occur only during a few weeks each year. This ongoing need can sometimes be filled with, fast-online resources located near the point of end use. Fuel oil powered generators have typically been used for this purpose. With stricter air-quality regulations coming into effect in recent years, coupled with an increase in fuel oil prices, gas-engines are becoming better suited to provide this resource.

With small amounts of steam that can be generated by a reciprocating engine, this technology would truly only viable if Western were to switch to a HHW system.

Gas Turbine

When utilized in a CHP application, the best asset of a gas turbine is their high heat-to-power ratio. Turbines can produce large volumes of exhaust gas at very high temperatures (often up to 1100°F). This low pressure, high volume exhaust is capable of generating high-quality, high-pressure steam, as well as high temperature hot water.



Turbine emissions are also lower than that of a reciprocating engine. They are ideally suited for loads of 5 MW and up; although continued improvements and modifications to technologies are opening the door to turbine utilization in much smaller applications. They can operate on low-energy fuels (biogas/syngas, etc.) and perform extremely well with high-Btu fuels, such as propane.

With a high uptime, turbines offer full-load operation for extended annual hours with very little downtime required for maintenance. Turbines are also relatively lightweight with a compact footprint when compared to a reciprocating engine. Today's turbines have a simple design (i.e.: no liquid cooling system and no spark plugs). Major overhauls require only combustor replacement after about 60,000 hours of duty.

For the WWU campus gas turbines could be an attractive alternative to meet the existing steam loads while producing electricity for consumption on campus. If Western decided to switch to a HHW distribution system, the turbine could also be used to produce hot water instead of steam.

Steam Turbine

Steam turbines are a tried and tested CHP technology that use steam energy to turn a generator that produces electricity. Steam turbines are typically one of the cheapest CHP technologies to install (excluding the steam generating equipment). In order to operate a steam turbine effectively, the inlet steam conditions have to be of high pressure and temperature (~600psi/700F or greater).

Steam turbines can also be used to augment gas turbines to increase the amount of electrical generation from a steam producing system. When a steam turbine is used with a gas turbine it is referred to as a “combined cycle” system.

An appealing use for steam turbines occurs when there is already an existing steam load that needs to be fulfilled by a central generating plant. Steam can be produced at high temperature and pressure, ran through the turbine, and sent out to the distribution at the desired lower pressure. Steam turbines can also be used in an “energy storage” scheme where steam flow can be diverted to/from a turbine depending on current steam demand from the distribution system, effectively acting like a buffer to baseload production.

In order for Western to integrate steam turbines into their existing steam plant effectively, new higher pressure class boilers and piping would be needed to allow for operation of the turbines.

Preliminary CHP Analysis

A preliminary analysis of the potential of applying combined heat and power was completed. This analysis compared the proposed CHP system to the existing steam system. In the existing steam system, the average heat load is approximately 170,000 MMBTU/year, electrical usage is 33,000 MWh/year, and carbon emissions of 24,000 Mtons/year for a total energy cost of $3,500,000/year.

An initial high level analysis of the potential financial benefits of CHP on campus indicates a range of energy cost savings of $700,000 - $1,400,000 per year; as well as an overall campus utility carbon reduction of 15-25%. This preliminary analysis was based on the application of a thermal base loaded system serving a heating hot water distribution system; and would include the implementation of thermal storage.

Thermal Energy Storage

Hot Water Thermal Energy Storage

Hot water thermal energy storage (TES) is a means to collect and productively use waste heat supplied from a cogeneration system or other intermittent waste heat source. It also extends the availability of cogeneration alternatives to serve the campus load and displace natural gas boilers when the daily heat load profile varies above and below the output capacity of the system installed. By doing this, it serves to shave the peak load and distribution system requirements, which help to reduce the installed capital cost of the production equipment. Lastly, it enables the cogeneration to run intermittently (daily cycle) during the lowest load periods during the summer. This will address minimum equipment turndown capability and facilitate scheduled maintenance.

High Temperature Thermal Energy Storage

High temperature thermal energy storage has made significant advances in recent years. Most notable is the current development of heat storing concrete that can store temperatures of up to 800F, enabling the creation of steam from a hot oil loop. These concrete storage systems are of comparable costs to current hot water TES, designed to be modular, and can be cast to conform to existing site shape conditions/requirements.

The development of this technology is still ongoing and therefore not currently recommended for implementation. It is, however, recommended to be aware of this technology as it could provide Western with an alternative to purchasing new generation equipment, provide flexibility in operation, and expanding the capability for other technologies such as CHP to be integrated into the existing steam system.

Augmenting System with Solar PV

Photovoltaic (PV) panels convert energy from the Sun to electricity. A PV system consists of the PV panels, an inverter to convert DC power produced by the panels to AC, electrical conditioning equipment, and electrical metering equipment. Additional equipment is needed to enable Sun tracking which allows the panels to be optimally positioned throughout the day.

A 1000 kW system consisting of fixed 300-watt nominal solar panels would require an area of roughly 75,000 sq. ft. of roof space. Using a tool developed by the National Renewable Energy Laboratory called PVWatts a system sized at 1000 kW with fixed PV panels would produce an average of 1,110,000 kWh per year which would be valued at roughly \$83,000/year at the campus' current yearly blended electrical rate of \$0.075/kWh. This electrical production is roughly 3.5% of what the campus consumes per year (in 2016 31,391,495 kWh was consumed by the campus).

A ROM cost to implement a 1000 kW PV system would be in the order of \$4.5-6.2 million for fixed angle, average efficiency PV panels.

There are significant concerns and design considerations that would need to be resolved in implementing PV panels on the campus. The first hurdle would be working on/in older buildings. PV panels would require a support structure to be installed on each roof and structural evaluation of the roof supports. The panels would also add additional maintenance personnel time to inspect the system and keep the panels clean, requiring time spent working on the roof.

Augmenting System with Solar Thermal

Following the study of PV panels, implementation of Solar Thermal was evaluated. Two common types of solar thermal collectors are flat plates and evacuated tubes. Flat plates consist of a dark sun absorbing flat plate and transfers heat to water. Flat plates typically have a lower maximum operating temperature at roughly 160F or less. Evacuated tubes typically use a heat pipe surrounded by a dark sun absorbing evacuated glass tube. Evacuated tubes can produce high temperatures at roughly 350F or less. Solar thermal would also need to be implemented into a HHW distribution system as the operating temperatures are generally too low for steam production.

Using the same are allotment of 75,000 sq. ft. as the PV analysis above, approximately 1000 solar thermal collectors can be installed. This amount of panels could provide 3,000 – 6,500 MMBtu/year of heating depending on system hot water temperatures.

A ROM cost to implement a 1000 panel solar thermal system would be in the order of $2.5-$3.5 million for standard evacuated tube collectors.

Concerns and design considerations with solar thermal are similar to PV panels due to the roof mounted installations. Additional concerns include the additional piping required to interconnect each solar thermal system to the district heating network. Additional pipe runs would need to be made at each building spanning from the roof to the mechanical room. Solar thermal would also require significant storage capacity to enable its operation due to the intermittent availability of the Sun and the non-concurrent nature of heating load and solar radiation.

Additional Technologies for Future Consideration

Geo-exchange

Geo-exchange dissipates or gains energy with the earth through a series of drilled "wells". Each well contains a loop of pipe which connects back to a main header to serve a heat pump or a series of heat pumps. This type of heat pump configuration is typically called a ground source heat pump (GSHP). GSHPs benefit from a near constant ambient temperature to extract or dissipate heat from/to which greatly improves COPs during harsher weather periods. A GSHP system would need to be coupled with a HHW distribution system as the output temperatures are too low to generate steam.

There are significant concerns and design considerations that would need to be resolved in implementing a main GSHP on the campus. The first would be the very large well field and associated piping. Each well would need to be interconnected and piped back to the main Central Plant building. This piping would take up considerable underground real estate meaning any future projects requiring pipe routing through the identified areas would need to be well planned and coordinated. Another area of concern would be the pumping energy required to circulate fluid through the piping network. Even if the piping network was designed with pumping efficiency in mind, the sheer amount of piping would still correspond to significant pumping requirements. A final concern is with the degradation over time with the well fields. If heating and cooling loads are not balanced the ground surrounding the well fields will rise/fall in temperature over time reducing the capacity of the well field. For a single building heating system this may be fine since the well field can be oversized to accommodate for any potential degradation. This may be a problem for a district energy system on the campus due to the longevity of the campus and the planned growth of the system.

GSHP systems also have to overcome the design requirement imposed by the utility rate structure. For WWU with their existing low natural gas cost it would likely be difficult to compete against technologies such as condensing boilers or CHP.

Overall, GSHP system are typically better suited for single building applications as the well fields can be done in the building profile or parking area. For the WWU Campus, remote buildings could be a viable candidate for GSHP systems. Any buildings that are near of the district heating system would likely see a better life cycle cost by directly connecting to the district heating system and serving hot water or using the district heating/cooling lines to provide tempering required for a building level water to water heat pump system.

Fuel Cells

Market tested industrial Fuel cells (carbonic type) produce power by reacting a hydrogen rich fuel (such as natural gas) with oxygen from ambient air to produce electricity, heat, and water. Fuel cells offer some of the highest electrical generation efficiencies of CHP units with a typical range of 40% - 60%.

Due to the use of natural gas as the hydrogen fuel source, the fuel cell emits essentially the same amount of CO2 as a combustion device. However, since there is no actual combustion in a fuel cell the unit does produce lower amounts of nitrogen oxide(s) and other pollutants.

A typical fuel cell installation appears to require roughly twice the same area as an equivalent sized reciprocating engine.

Given the limited amount of U.S. installations, size of plant required, and equivalent CO2 emissions as compared to more traditional technology such as reciprocating engines and combustion turbines, fuel cells are not currently a viable alternative for WWU.

Biomass/Biogas/Syngas

A biomass system consumes suitable wood fuel to produce heat. The wood fuel used in a biomass system is considered carbon neutral as burning the wood fuel releases as much carbon as the tree absorbs over its lifetime. Biomass systems require additional emission control devices to reduce the particulate matter created as a result of combustion. Biomass systems also require significant fuel transportation and storage equipment consisting of staging area for shipments of raw fuel, storage bin, and fuel augers to move fuel from storage areas to the boiler.

Biomass systems can be used to produce either steam or hot water depending on the type of boiler used.

In addition to being a net zero alternative, biomass systems also benefit from typically lower fuel costs.

A biogas system uses gas produced from the breakdown of organic matter as a fuel source. Biogas can be produced from multiple sources such as landfills and waste water treatment plants. Syngas is similar to biogas but differs in how the term is defined. Syngas is typically reserved for synthetic gases created from a specific process with a fuel. Either biogas/syngas could be integrated into the existing central plant as it can typically use the existing natural gas pipeline infrastructure. The modifications that would be required at the plant would be boiler upgrades and potential fuel conditioning.

Biogas could be generated on the WWU campus by means of anaerobic digestion (AD) depending on the waste streams available on campus. If there is sufficient food waste from the kitchens on campus and/or landscape waste, AD could be a viable option to reduce waste and produce carbon-neutral gas.

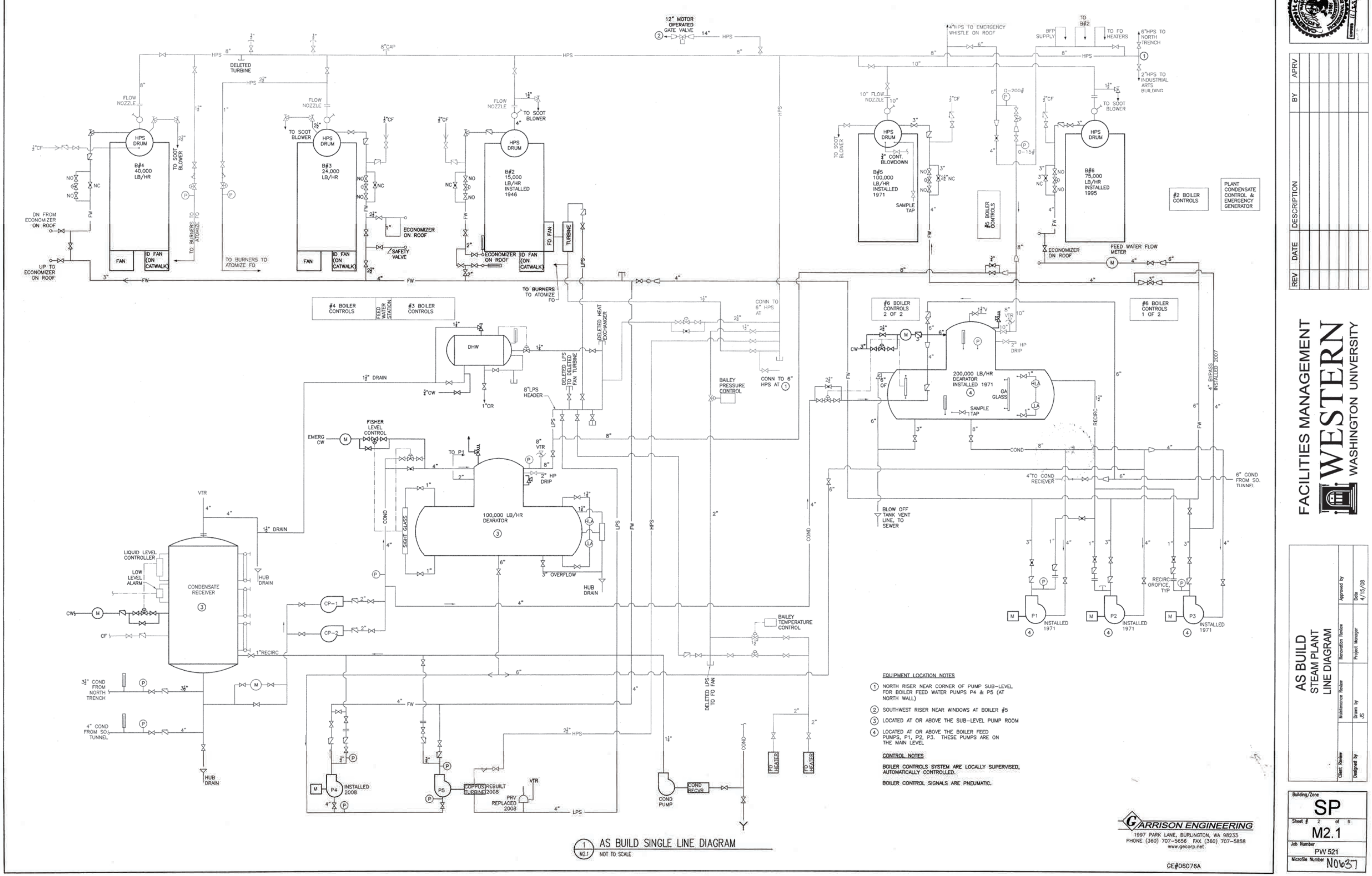
A previous study about the potential application of Biomass/Biogas has already been completed for Western Washington University. For a more detailed discussion on the topic, please review the previously completed study.

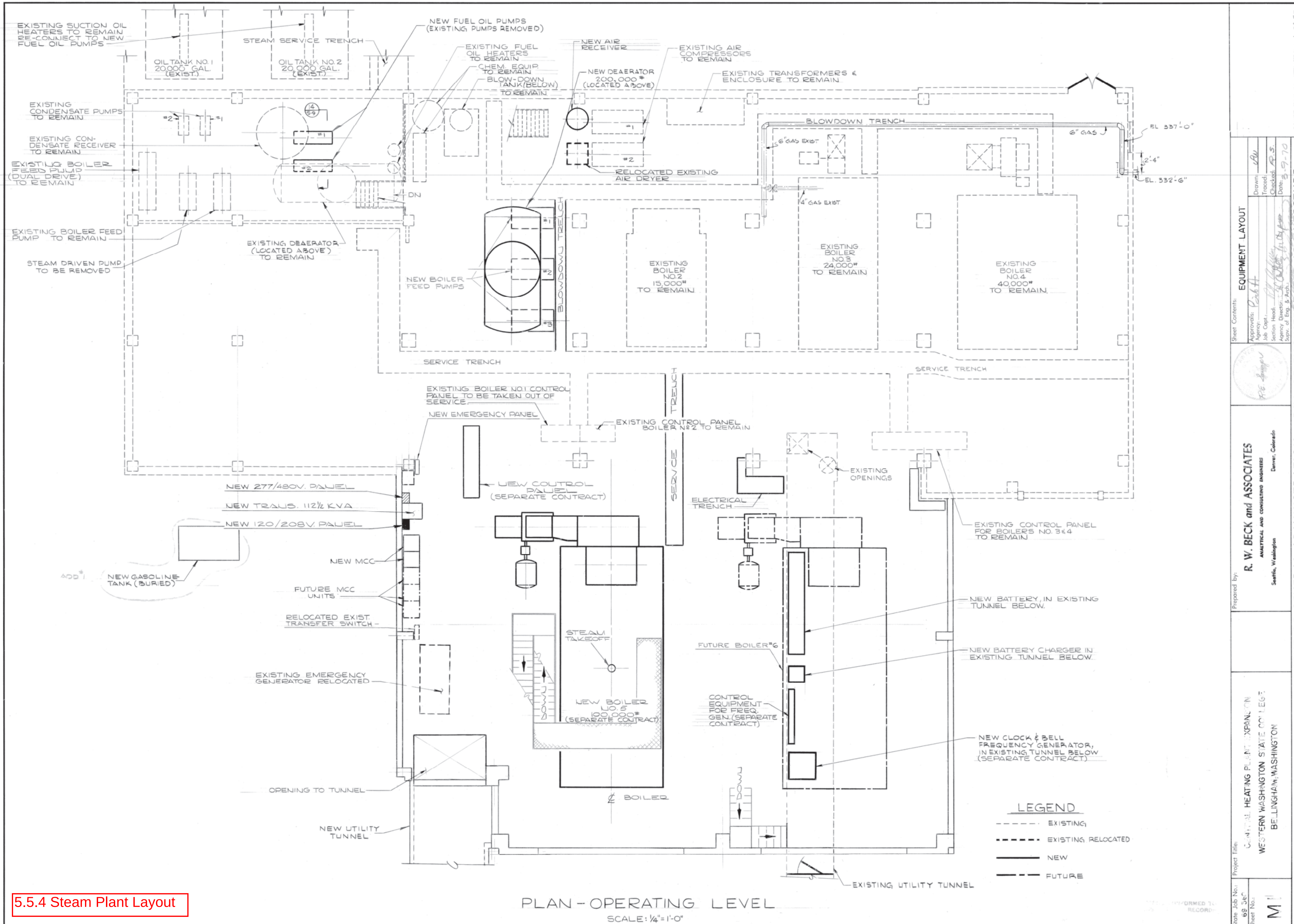
Waste Heat Recovery

A waste heat recovery system captures heat that would otherwise be wasted to the atmosphere for useful heating purposes. On the WWU campus there may only be limited waste heat available for recovery. Waste heat from the boiler exhaust streams can only be captured if there are additional technologies implemented to lower condensate temperature or if a new hot water distribution system is implemented. Heat could be recovered from the few chilled water systems located on campus if there was sufficient year round loading.

There is the potential for waste heat recovery from sources not located on the WWU campus. A previous study indicated a potential waste heat source at the nearby PSE Encogen Power Plant located on the waterfront. For a more detailed discussion on the topic, please review the previously completed study.

5.5.3 Heating System Piping and Instrumentation Diagram





5.5.4 Steam Plant Layout

5.5.5 Steam/Condensate Distribution Map

ASSUMES CLOCKWISE LOOP FLOW — C

ASSUMES COUNTER CLOCKWISE LOOP FLOW — CN

TUNNEL

TRENCH

MANHOLE

MECHANICAL ROOM ACCESS

HORIZONTAL ACCESS DOOR

ABANDONED STEAM TRENCH

NOTES:

1. LOADS ARE ESTIMATES BASED ON INFORMATION OF UNVERIFIED ACCURACY
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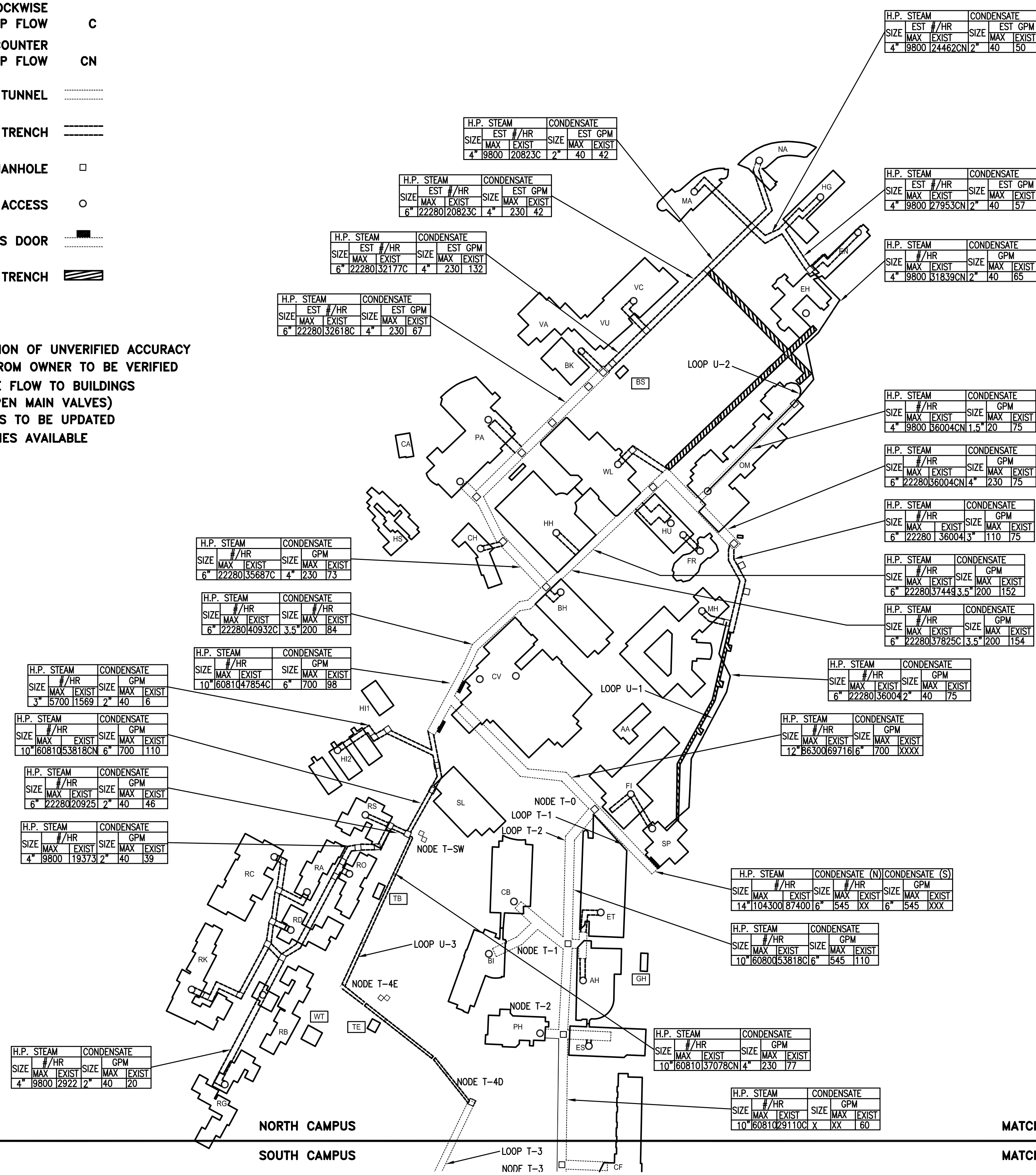


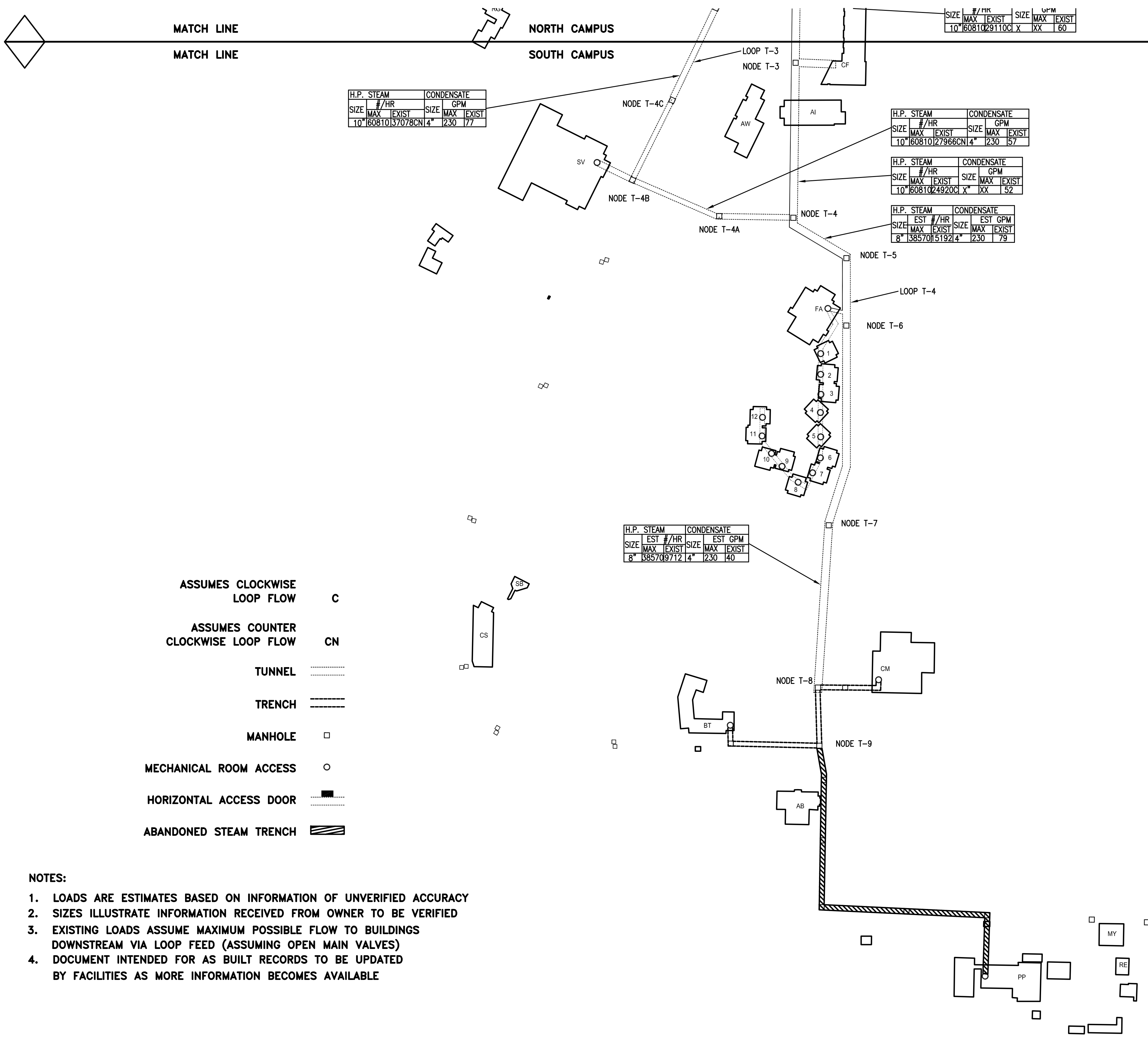
MATCH LINE — NORTH CAMPUS

MATCH LINE — SOUTH CAMPUS

BRANCH STEAM AND CONDENSATE TO BUILDINGS

Mark	Description	H.P. Steam			Condensate		
		Exist	Exist	Max	Exist	Exist	Max
			Peak	Recmnd		Peak	Recmnd
		Branch	Branch	Branch	Branch	Branch	Branch
		Size	lb/Hr	lb/Hr	Size	GPM	GPM
AI	ACADEMIC INSTRUCTION CENTER	6"	2,500	22,300	2-1/2"	31	50
AH	ARNTZEN	4"	3,000	9,800	4"	18	270
BI	BIOLOGY BUILDING	6"	5,800	22,300	3"	105	90
BH	BOND HALL	4"	2,100	9,800	2"	13	30
BK	BOOKSTORE	2"	400	2,300	1-1/4"	15	11
BT	BUCHANAN TOWERS	4"	5,200	9,800	2"	30	30
CV	CARVER GYM		2,800			17	
CB	CHEMISTRY BUILDING	6"	9,400	22,300	3"	158	90
CH	COLLEGE HALL	3"	600	5,700	1-1/2"	4	15
CM	COMMISSARY	4"	1,200	9,800	2"	60	30
CF	COMMUNICATIONS		2,300			30	
EN	EDENS NORTH	4"	1,100	9,800	2"	7	30
EH	EDENS SOUTH	3"	900	5,700	1-1/4"	5	11
ET	ENGINEERING TECH	3"	2,900	5,700	2"	17	30
ES	ENVIRONMENTAL CTR.	3"	3,100	5,700	1"	30	5
F?	FAIRHAVEN ADMIN		800			5	
	FAIRHAVEN TOWERS		4,900			30	
FI	FINE ARTS	2"	3,500	2,300	1-1/2"	12	15
FR	FRASER LECTURE HALL		500		1"	9	5
HH	HAGGARD	4"	1,300	9,800	2"	12	30
HG	HIGGINSON	3"	1,100	5,700	1"	12	5
HI	HIGHLAND II	4"	900	9,800	2"	5	30
HU	HUMANITIES	1-1/2"	1,300	1,400	1"	8	5
MA	MATHES	4"	2,400	9,800	3"	30	90
MH	MILLER HALL	4"	2,200	9,800	2"	30	30
NA	NASH	4"	2,900	9,800	3"	30	90
OM	OLD MAIN	6"	3,200	22,300	2-1/2"	75	50
PH	PARKS HALL		1,000		1-1/4"	23	11
PA	PERFORMING ARTS	3"	2,600	5,700	2"	30	30
	RIDGEWAY COMPLEX	6"	12,100	22,300	2"	73	30
RA	RDG ALPHA	2"	1,300	2,300	1-1/2"	10	15
RB	RDG BETA		2,100			17	
RD	RDG DELTA	2"	1,300	2,300	1-1/4"	10	11
RG	RDG GAMMA		2,300			18	
RK	RDG KAPPA		2,800			23	
RO	RDG OMEGA		1,200			10	
RS	RDG SIGMA		1,200			10	
RC	RIDGEWAY DINING	2-1/2"	2,800	3,700	1-1/2"	17	15
SL	SMATE (SCI/ED/TECH)	4"	600	9,800	2"	30	30
SV	STUDENT RECREATION	4"	3,700	9,800	3"	37	90
VC	VIKING COMMONS	3"	3,100	5,700	2"	30	30
VU	VIKING UNION	4"	3,000	9,800	2"	30	30
WL	WILSON LIBRARY	3"	2,000	5,700	2-1/2"	30	50

5.5.5 Steam/Condensate Distribution Map



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