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THE UNIVERSITY OF BRITISH COLUMBIA

Campus Operations and Risk Management
The University of British Columbia | Okanagan Campus
1138 Alumni Avenue | Kelowna BC | V1V 1V7 Canada

UBC Okanagan District Energy Decarbonization Strategy

Revision 1 – December 18, 2020

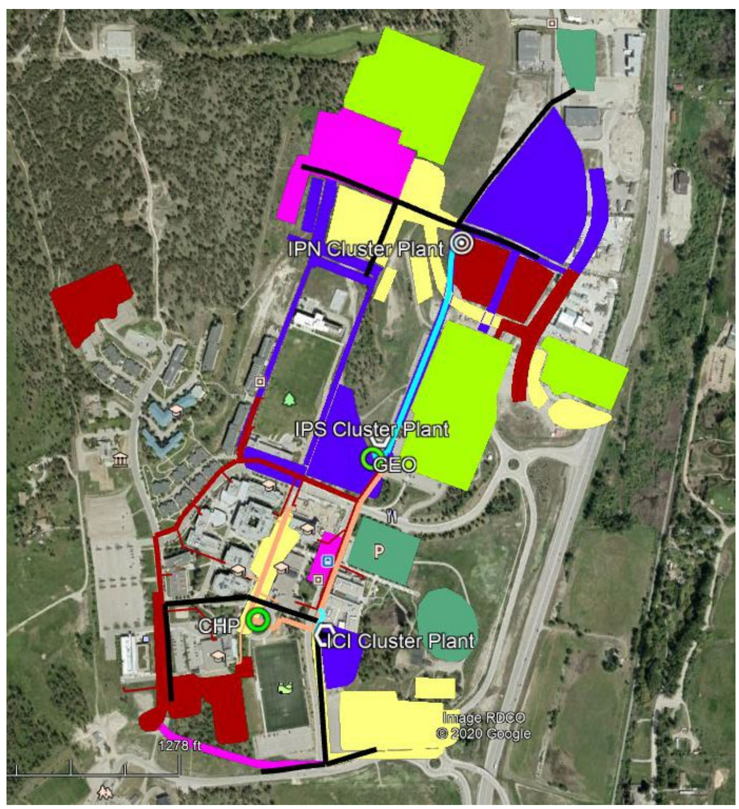
Overview

UBC Okanagan (UBCO) district energy systems are well positioned for modernization, renewal, and growth. Existing infrastructure has high value for decarbonization when combined with measures to reduce energy demand in both new and existing buildings. Low temperatures enable broad integration of waste heat and renewable energy and leverages the very green power grid in the region.

This document communicates UBCO district energy decarbonization strategy in a transition to a future state that is affordable, sustainable, and resilient in service to connected customers. Important new elements include high lift heat pumps and thermal storage adjacent to the GEO building to displace natural gas use. Plus, service to a first cluster plant in the ICI building from which surrounding buildings are served.

With this transition strategy, existing UBCO district energy infrastructure is made flexible to support different renewal and expansion scenarios. A foundation is laid for strategically aligned and resource efficient investments in the future. Clusters are connected. Future building connections are simple. Sustainable, affordable, and resilient service is provided to campus customers.

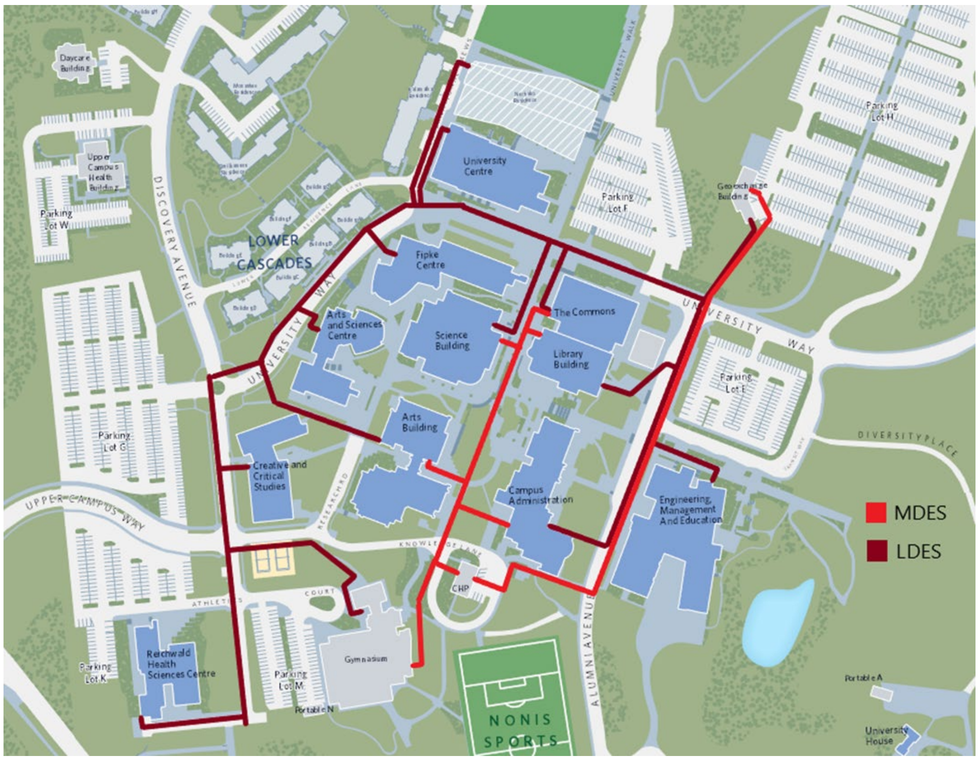
The stage is set for deep decarbonization at campus scale.



djoule DISTRICT ENERGY

Current State of District Energy Systems

UBC Okanagan has two district energy distribution systems serving the main campus as illustrated in the map below. Legacy academic buildings are served by a medium temperature district energy system (MDES) that distributes 80ºC (176°F) supply water via insulated carbon steel piping. Newer buildings are served by an ambient low temperature district energy system (LDES) designed for energy sharing with supply temperatures maintained in an 8 to 25°C (46 to 77°F) range.

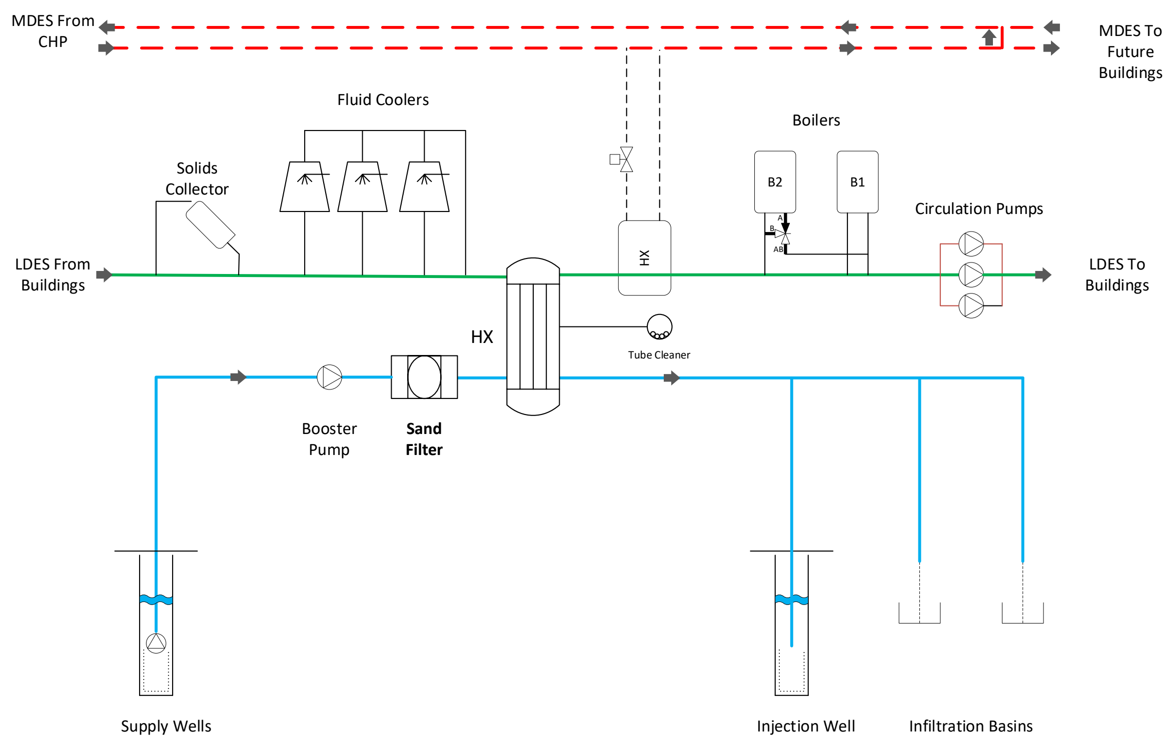


The LDES system provides ambient temperature water to each connected building through a PVC pipeline. This system is integrated with heat pumps in each connected building to provide heating and/or cooling as needed. Domestic hot water (DHW) pre-heat exists on a case by case basis. Some legacy buildings have LDES service for heating only. Except for Nechako, none of the existing residential buildings are connected to district energy service.

District heating generated with natural gas boilers in the central heating plant (CHP) and delivered through the MDES system at medium grade temperature of 80C (176F). Higher temperature differences reduce flow rates and pipe sizes, and distribution systems are insulated to minimize heat losses. At present, there are no thermal storage provisions and no low carbon or renewable thermal energy generation strategies employed. Options for integration of waste heat and renewable energy are limited by the distribution temperature.

Waste heat from building cooling is a primary source of heat in the LDES system. Heat is also generated from cooling groundwater with heat pumps, with maximum flow constrained by infiltration capacity. These resources are augmented by a gas boiler in the geo-exchange (GEO) building and an MDES connection between the CHP and GEO. Low temperature heat distribution is not insulated as temperature differences relative to groundwater are low. Heat pumps in connected buildings cool or heat the LDES loop to transfer thermal energy to and from buildings. Many more options exist to generate and store waste heat and renewable energy.

In the LDES system heat is injected or rejected from the loop with a combination of gas boilers, fluid coolers, and geothermal. The open loop geothermal system continues to be a challenge in operation. There are expensive fixed regulatory costs. Groundwater temperatures drop to 2.8°C (37°F) in the winter which pushes heat pumps in LDES connected buildings to their ragged edge. Infiltration capacity is limited. Well and infiltration sites are attractive to campus planning for other use.



Every building connected to the current LDES system has its own building scale heat pump system to transfer heat into hydronic heating and/or cooling systems. Employing this strategy to date has provided many benefits to UBCO including the following:

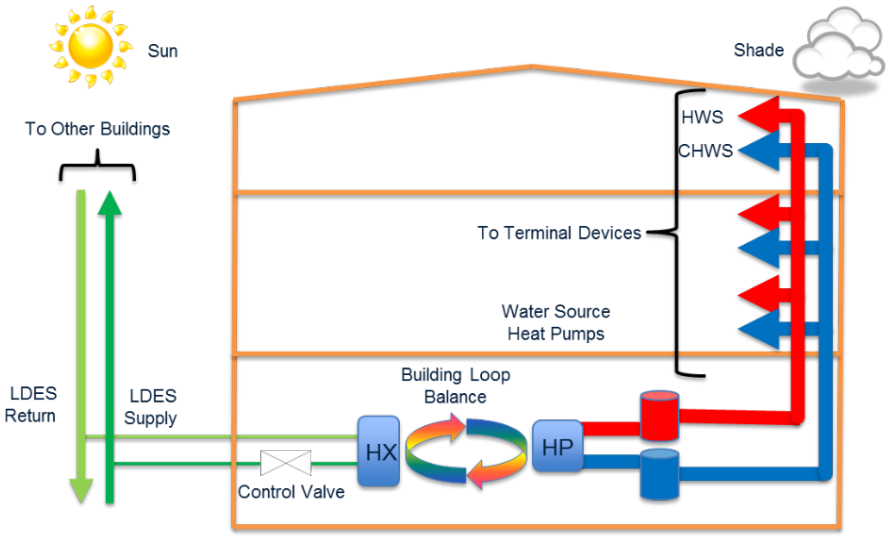
Energy Efficiency and Carbon

- Compatible with many low carbon and waste heat resources
- Enables energy sharing within and between buildings
- Minimal distribution heat losses
- Optimizes boiler efficiency

Campus and Building Operations

- Centralized maintenance
- Simple and low-cost pipe infrastructure
- Reduced space requirements for building mechanical equipment
- Takes advantage of campus system diversity
- Provides for both heating and cooling

Current LDES benefits aside, the investment is smaller scale heat pump equipment in every connected building has higher capital and operating cost relative to district energy alternatives with more scale. As such, transition is focused on aggregating load, preserving benefits, and improving performance. Decarbonization strategies are designed to maximize waste heat recovery and to displace gas boiler heat injection in the MDES and LDES systems.



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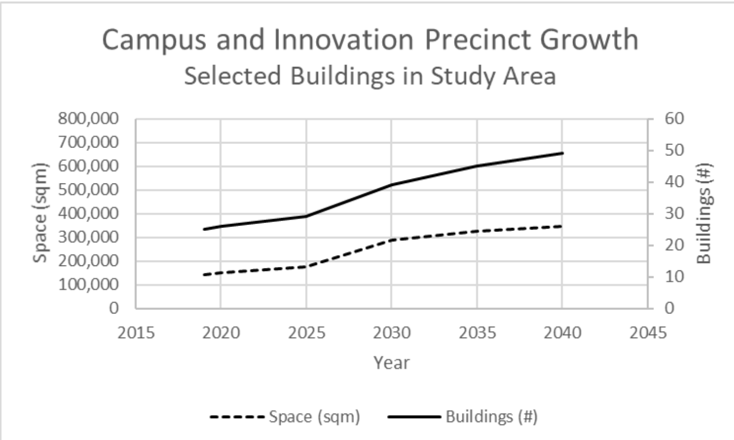
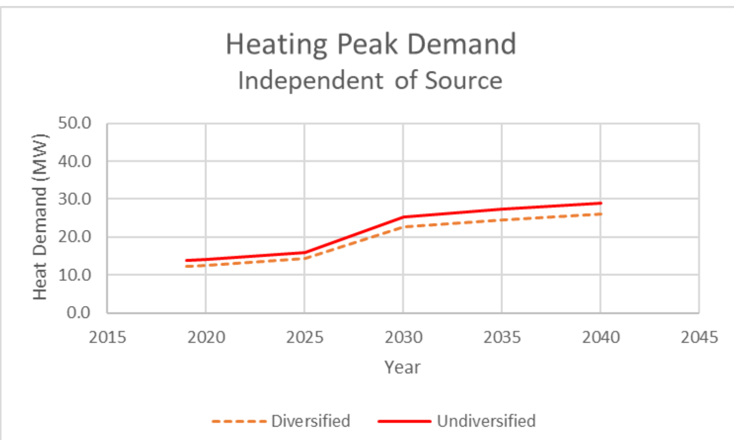
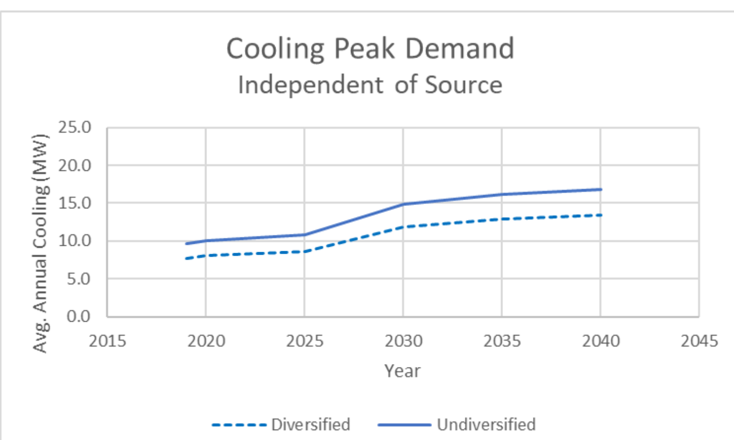
Space and Load Growth

Assessment of building space and thermal load provide foundation for the analysis. Loads and annual energy use is assessed considering vintage, space, and type of use. Growth (or not) is a modeled sensitivity variable, among many other variables.







Alternatives Assessment

Over the last two years UBCO has explored a range of alternatives to serve projected thermal load on campus and in the Innovation Precinct while aligning with campus sustainability, resilience, and economic goals. These alternatives included growing with (1) packaged systems, (2) central heating and cooling plants, (3) with LDES connections, and (4) a hybrid cluster plant approach.

Pro-forma analysis through 2050 was developed to compare technical, environmental, and economic performance of heating, domestic hot water, and cooling systems including buildings with and without district energy service. The favored UBCO strategy was subjected to broad sensitivity analysis to ensure alignment and economic merit.

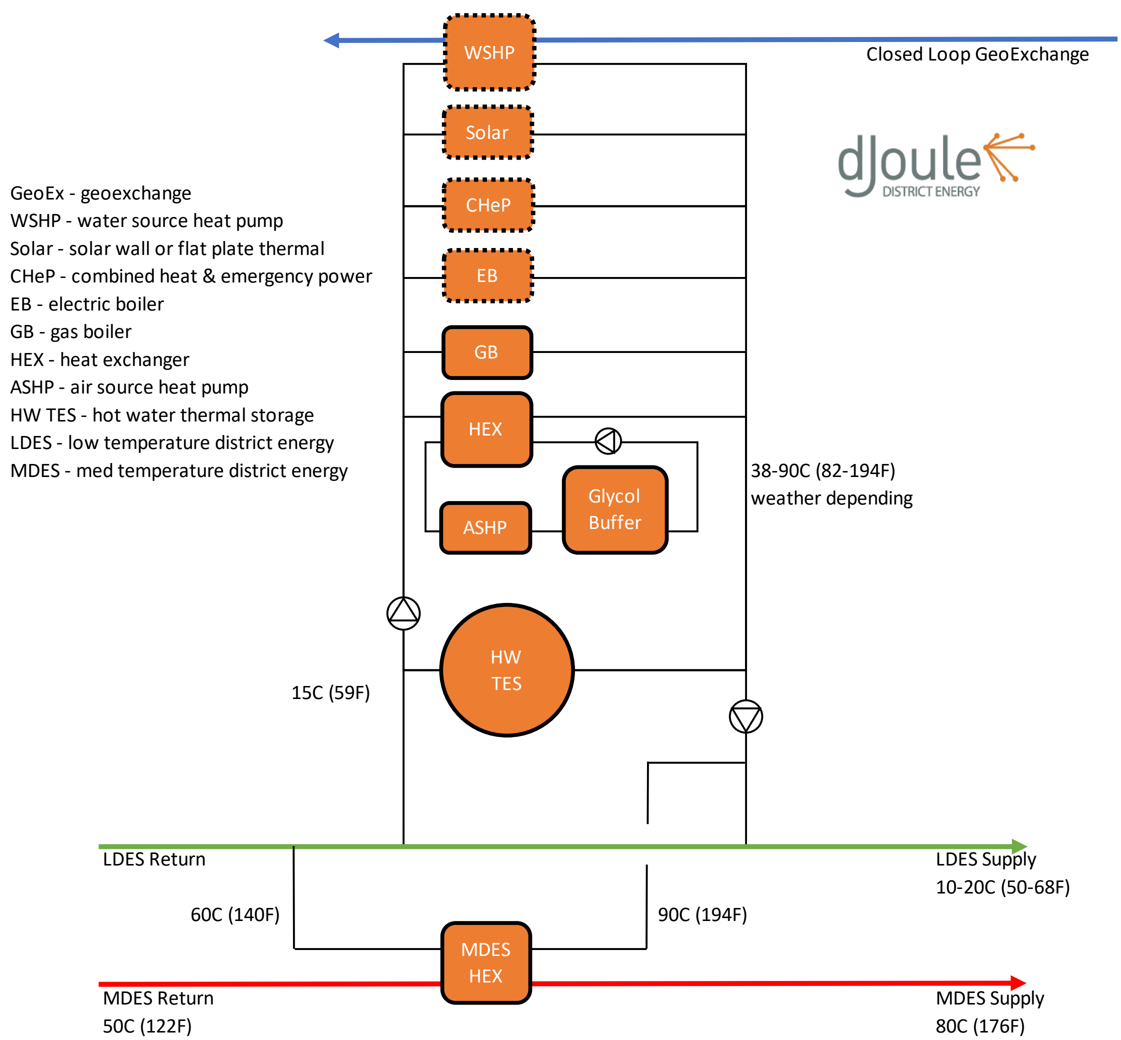
An overview of thermal costs in the selected alternative is illustrated in present value below. This assessment includes all thermal generation whether connected or not to district energy service. The total is the sum of district and building systems, as well as growth and existing buildings. Decarbonization is not yet considered.

PV Costs @ WACC	Alt 4 District	Alt 4 Building	Alt 4 Total	Alt 4 Growth	Alt 4 Existing
Revenue Required	**$ 60,368,758**	**$ 29,063,662**	**$ 89,432,420**	**$ 32,735,602**	**$ 56,696,818**
Natural Gas	$ 8,503,018	$ 4,873,549	$ 13,376,567	$ 3,633,178	$ 9,743,389
Electricity	$ 9,183,992	$ 3,587,115	$ 12,771,106	$ 7,516,814	$ 5,254,292
Carbon	$ 3,475,579	$ 1,983,622	$ 5,459,201	$ 1,975,584	$ 3,483,617
Water/Wastewater	$ 1,768,701	$ 846,066	$ 2,614,767	$ 1,114,999	$ 1,499,768
Chemicals	$ 884,350	$ 423,033	$ 1,307,384	$ 557,500	$ 749,884
Total Variable Costs	**$ 23,815,640**	**$ 11,713,385**	**$ 35,529,025**	**$ 14,798,075**	**$ 20,730,950**
Operating Labor	$ 12,772,353	$ 9,895,080	$ 22,667,433	$ 4,359,625	$ 18,307,808
Maintenance	$ 3,831,706	$ 2,968,524	$ 6,800,230	$ 1,307,888	$ 5,492,342
General & Admin	$ 1,915,853	$ 1,484,262	$ 3,400,115	$ 653,944	$ 2,746,171
Total Fixed Costs	**$ 18,519,912**	**$ 14,347,866**	**$ 32,867,778**	**$ 6,321,457**	**$ 26,546,321**
Capital Recovery	**$ 18,033,206**	**$ 3,002,411**	**$ 21,035,617**	**$ 11,616,070**	**$ 9,419,547**
Capital Costs	**Alt 4 District**	**Alt 4 Building**	**Alt 4 Total**	**Alt 4 Growth**	**Alt 4 Existing**
Modernization	$ -	$ -	$ -	$ -	$ -
Renewal	$ 7,126,609	$ 1,560,203	$ 8,686,813	$ -	$ 8,686,813
Growth	$ 13,737,606	$ 1,601,406	$ 15,339,012	$ 13,737,606	$ 1,601,406
Total Capital Costs	**$ 20,864,216**	**$ 3,161,609**	**$ 24,025,825**	**$ 13,737,606**	**$ 10,288,218**
Capital Recovery	**$ 18,033,206**	**$ 3,002,411**	**$ 21,035,617**	**$ 11,616,070**	**$ 9,419,547**
2050 Full Buildout	**Alt 4 District**	**Alt 4 Building**	**Alt 4 Total**	**Alt 4 Growth**	**Alt 4 Existing**
Natural Gas (GJ)	60,792	23,393	84,184	38,145	46,039
Electricity (MWh)	8,405	2,066	10,472	7,466	3,005
Carbon (MTCO2e)	3,061	1,175	4,236	1,921	2,315
Total Capacity (MW)	43.4	19.5	62.8	27.1	35.7
FTE (thermal gen)	14.5	6.5	20.9	9.0	11.9

Future State of District Energy Systems

Key strategy for decarbonization features the integration of air source heat pumps (ASHP) and hot water thermal energy storage (TES). This approach is designed for baseload down to outside air temperatures as low as -5C (23 deg F) before gas boiler heat is required. These hours represent less than 10% of the annual operating hours in a year.

The objective is to economically displace gas boiler use in both the LDES and MDES systems and to minimize the availability risk of high global warming potential (GWP) refrigerants. Gas boilers have over 60 times the carbon intensity as electric heat pumps in the British Columbia electricity grid, assuming 92% efficient boilers and 3.0 COP heat pumps. UBCO decarbonization strategy features high lift R744 (CO_2) heat pumps at a GEO building location capable of producing 90C (194F) or 60C (149F) in a single lift. Compared to other refrigerants, the GWP of R744 is 1, compared to 2088 for R410a and 631 for R513a.



High lift ASHPs operating with glycol become the main baseload tool for decarbonization down to approximately -5C (23F). TES and gas boilers serve the peak heating demand.

Future options considered include closed loop geo, solar thermal, dispatchable combined heat and emergency power, and electric boilers. All strategies that would be opportunistically deployed based on the weather and grid conditions.

GEO Plant Site ASHP Comparison

The low temperature operation of the LDES system makes it a very useful asset for waste heat recovery from space cooling and for the extraction of heat from ambient air. When cooling waste heat is limited, an ASHP uses a refrigerant to cool the air to make and inject heat. This heat can be stored and dispatched to displace heat otherwise generated with gas boilers at the grade it is produced. The higher the temperature difference the smaller the volume and cost of a stratified TES tank for the same capacity and duration.

For this analysis, multiple brands of ASHP were explored, each with a different refrigerant at a total capacity in the 700-730 kW (2.39-2.49 MMBtu/h) range. This is a heating capacity designed to serve the anticipated LDES system baseload (~20-30% of the peak) and to provide the majority of the annual heat injection required by the system. Smardt and Mayekawa ASHPs outperformed the other options in this application. Systems would be located outside the GEO building in insulated containers.

Smardt is selected with R-513a (GWP=631) and can deliver 37.8°C (100°F) to the LDES system only. It has two magnetic drive compressors and an estimated turnkey cost of **$862,000**. Mayekawa is a high lift machine that uses R-744 refrigerant (GWP=1) with an estimated turnkey cost of **$1.274 million**. Heat can be supplied at higher grade to decarbonize both the LDES and MDES systems at equivalent overall COP. The incremental investment provides greater flexibility and less refrigerant risk. Capital costs are offset by much smaller buffer and TES tanks for equivalent thermal capacity.

	Smardt TTH375 ASHP (2 Total)	Mayekawa Unimo ASHP (12 Total)
	Locate Outside GEO Building	Locate Outside GEO Building
	Outside Air Temperature = 0°C	Outside Air Temperature = 0°C
Performance:	Lift To 37°C (100°F) To Heat LDES	Lift To 90°C (194°F) To Heat M/LDES
Refrigerant Charge, total:	R-513a, 660 lbs, GWP = 631	R-744 (CO2), 528 lbs, GWP = 1
Outside Air Temperature °C:	0	0
Water Entering (From LDES) Temp °C:	33.9	15.0
Hot Water Leaving Temp °C:	**37.8**	**90.0**
Hot Water Flow (gpm)	726	35
Hot Water Circ Pump Power (kW):	8	2
Buffer Tank Capacity (gal)	7,000	240
Heat Pump Input Power (kW) @ 0°C:	178	312
Heating Capacity (kW) @ 0°C:	716	690
COP Heat Pump Only (#):	**4.02**	**2.21**
Power For Controls/Instruments (kW):	0.5	0.5
Total Heat Pump System Demand (kW):	213	315
Total Heat Pump System COP (#):	**3.36**	**2.19**
Building Heat Demand Served (kW)	953	690
Building DHRC System Input (kW) at 4 COP	238	not required
Overall System COP (#) Air to Heating Water	**2.11**	**2.19**

GEO Plant Site Hot Water TES

Thermal energy storage (TES) is a key element of district energy decarbonization strategy at UBCO. At the GEO location TES is as a dispatchable resource to opportunistically store waste heat and renewable energy from campus cooling, the electric grid, and onsite generation resources. It can deliver electric demand response with scale and serve as a valuable capacity asset at peak in lieu of additional gas boilers. It can used as a backup resource and to allow for maintenance. In the table below the capacity is sized for about 25% of the anticipated MDES peak heating in 2030.

Hot Water Thermal Energy Storage

HW TES at GEO Building

	SI Units	English Units	
hours	8	8	discharge time at peak (hrs)
liters	563,828	128,000	volume (gallons)
cubicmeters	564	19,911	volume (cuft)
sqm	30.8	332	tank area (sqft)
meters	6.3	20.6	tank internal diameter (ft)
meters	18.3	60.0	tank height (ft)
MW	3.5	12.0	capacity (MMBtu/h)
MWh	28.1	96.0	energy (MMBtu)
deg C	50.0	90	delta T (deg F)
cfs	0.59	267	flow rate (gpm)
#	2.92	2.92	height to diameter ratio

2400 cubic meter HW TES example

Estimated Costs (CAD)

3%	construction escalation from 2008
$291,816	boiler plant unit cost ($/MW) for comparison
$1,238	HW TES cost estimate ($/cubic meter) with 10% foundation

Low	High	
$ 211,548	$ 423,097	excluding foundation, non pressurized
$375.20	$750.40	per cubic meter
$ 423,097	$ 846,194	excluding foundation, pressurized
$750.40	$1,500.80	per cubic meter

$ 698,110	HW thermal storage capital cost ($)
$ 1,026,269	avoided boiler plant capital cost ($)
$ (328,160)	incremental cost ($)
$ 942,448	total HW TES capital cost with 35% soft costs ($)

GEO Plant Site Future Alternatives

The following alternatives have not been considered in detail in the district energy decarbonization strategy. These alternatives may be considered in a next phase after the primary baseload ASHP and TES strategy is put into operation.

High Lift Water Source Heat Pump (WSHP)

The open loop geothermal system at UBCO serves the LDES system. It has technical, regulatory, and operational challenges with high fixed annual costs in the range of $100,000 per year (~$2 million present value @ 5%) and there is value in the some of the land used to support other development. Conversion to a smaller closed loop glycol geoexchange system is an option worth exploring to avoid future capital and operating costs.

A high lift CO2 heat pump system with characteristics shown in the table below is estimated at **$1.24 million**. This system would charge the TES and serve both the LDES and MDES systems.

	Mayekawa Unimo WSHP (6 Total)
	Locate Inside GeoExchange Building
	Closed Glycol Loop In 37F Water Table
	Lift To 90°C (194°F) To Heat MDES
Refrigerant Charge, total:	R-744 (CO2), 264 lbs, GWP = 1
Water Entering (From LDES) Temp °C:	15
Hot Water Leaving Temp °C:	**90**
Hot Water Flow (gpm)	18
Hot Water Circ Pump Power (kW):	2
Buffer Tank Capacity (gal)	120
Heat Pump Input Power (kW) @ 0°C:	129
Heating Capacity (kW) @ 0°C:	357
COP Heat Pump Only (#):	**2.77**
Source Glycol (% By Volume & Type):	20% Propylene Glycol
Source Glycol Entering Temp °C:	-0.6
Source Glycol Leaving Temp °C:	-2.7
Source Glycol Flow (gpm):	**428**
Glycol Circ Pump Power (kW):	9.4
Power For Controls/Instruments (kW):	0.5
Total Heat Pump System Demand (kW):	140.9
Total Heat Pump System COP (#):	**2.53**

At a scale that suits UBCO, there are numerous additional water source heat pump options with approximately **2/3 the total installed cost**, fewer compressors, and higher efficiency. Smardt can provide a competitive magnetic drive, R-513 heat pump with a maximum source to supply temperature difference of 65°C (117°F). However, the upper supply temperature limit is 69°C (156°F) which limits availability to the LDES system.

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Solar Thermal (Solar)

Solar thermal energy is an intermittent resource that would have high utility at UBCO, even in the winter, when the sun is shining. Flat plate systems would be used to reduce cost and oriented to maximize the energy generation in colder months. Efficiencies exceeding 75% are expected compared to 15% for solar photovoltaics. The low temperature LDES system and thermal storage would enable remarkable system efficiency and availability. 400-500 kWh per sqm collector would be expected at this latitude with approximately 3 sqm land needed per 1 sqm collector.

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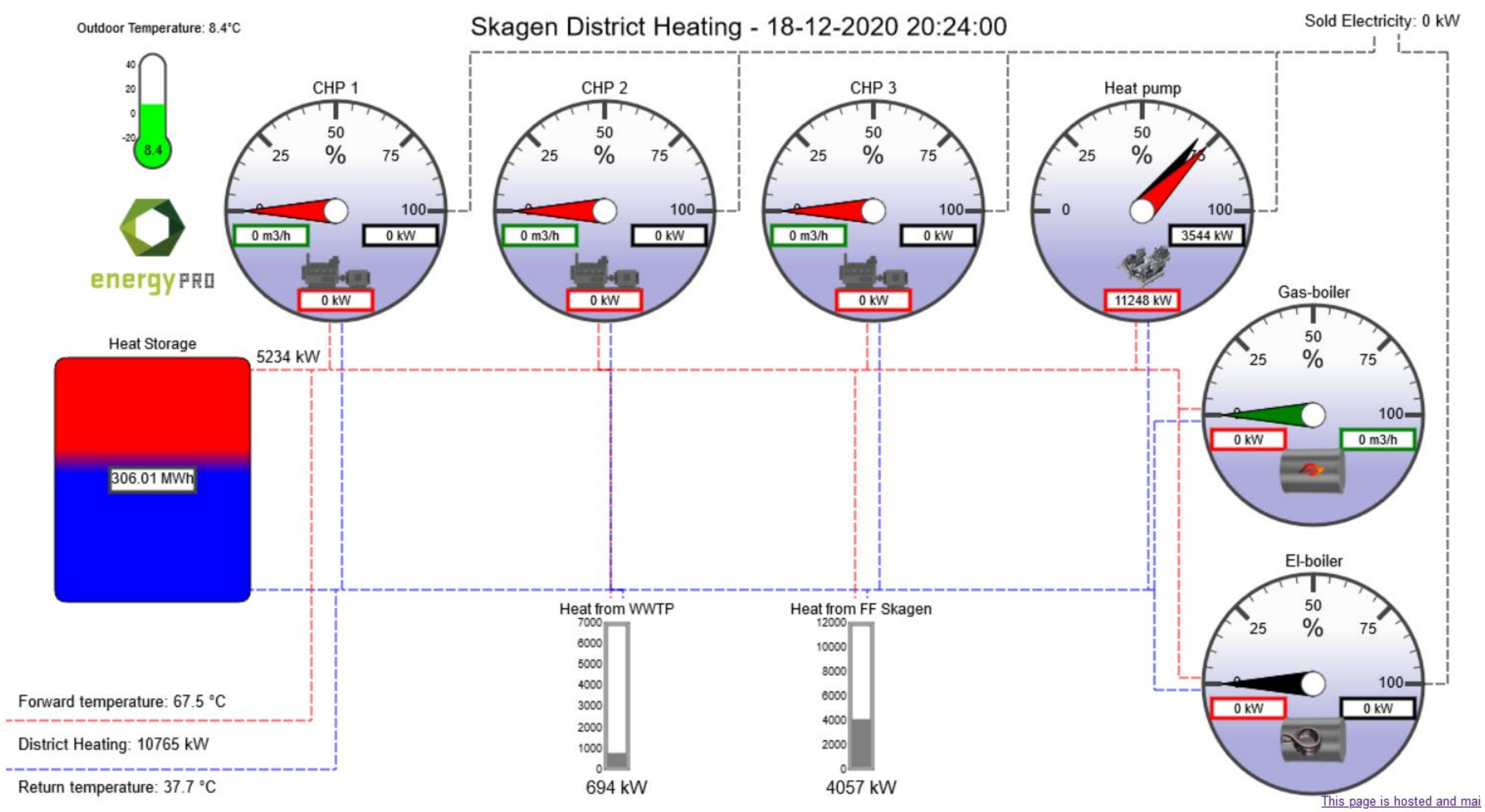
Combined Heat and Emergency Power (CHeP)

Two 1.9 MW (6.5 MMBtu/h) non-condensing boilers located in the central heating plant will reach the end of useful life and will need to be renewed or replaced to supply heat at 80°C (176°F) in the MDES system. In addition, there are a variety of aging and planned backup diesel generators on the campus for the supply of emergency power. Aggregate capacity is significantly higher than the campus peak, carry operating cost, and take up valuable space.

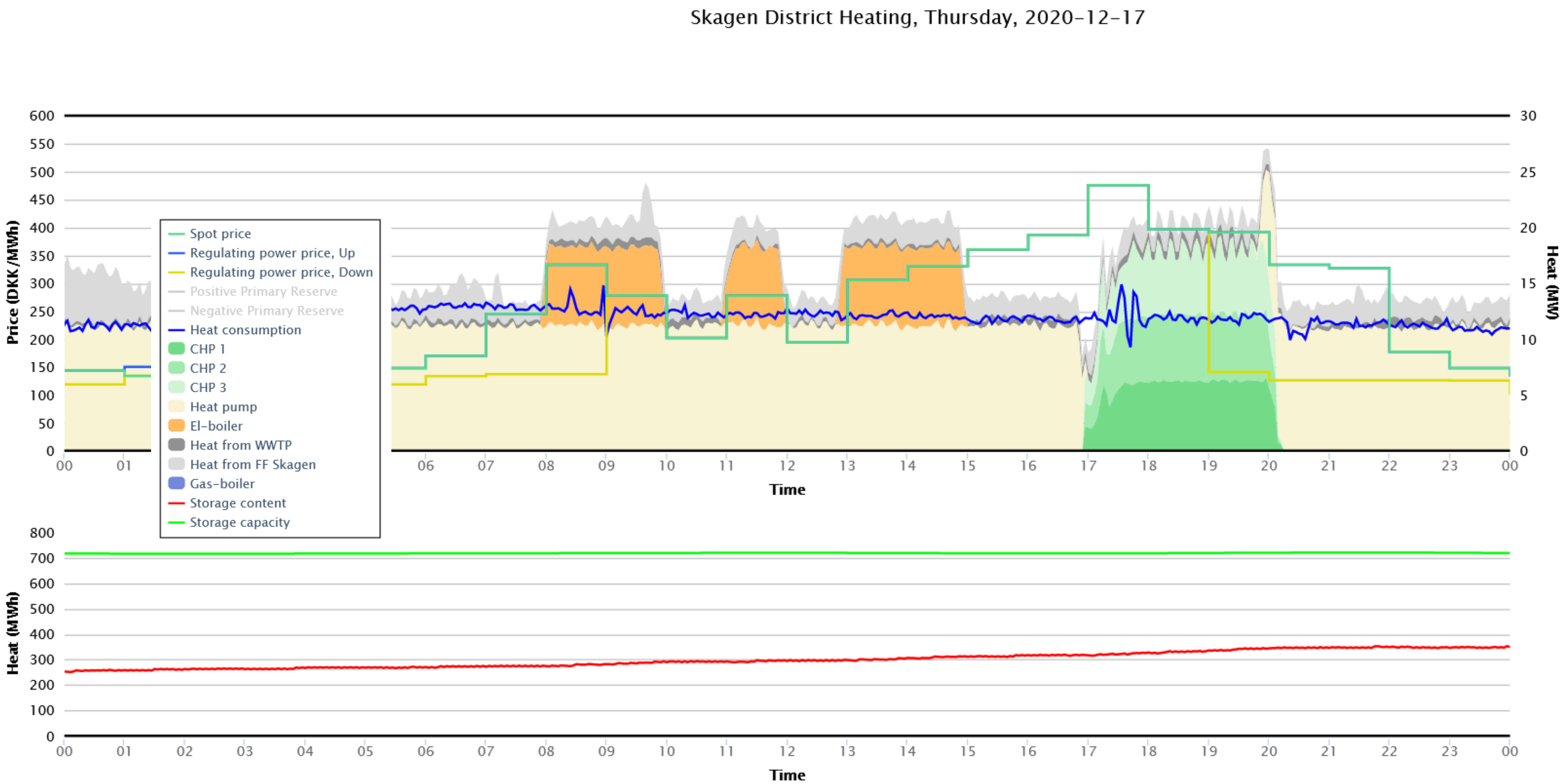
Heat pumps in district and cluster plants will increase campus power demand and consumption. New buildings such as the ICI will require emergency power for critical loads and may employ strategies for demand response to reduce electric demand at peak when called upon to do so by the electric utility. UBCO is charged for electricity demand by the kW at the higher of a 15-minute monthly peak or 75% of the annual peak.

A separate heat and emergency power (SHeP) strategy would be defined as separate investment in gas boilers, backup diesel generation, and diesel storage with no provisions for demand response. In contrast, a modern CHeP strategy would combine these investments into a system that is opportunistically dispatched to provide peak heating, to serve the emergency power need, and/or sell demand response as an electricity prosumer to the utility. Such a system would be dispatched only when needed based on a carbon or price signal from the electricity grid to ensure that it reduces both costs and carbon.

An excellent example of an operating system with this capability is Skagen District Heating in Denmark. (http://www.energyweb.dk/skagen/?english&history). This is one of many similar district energy systems that are coupled with the electric power sector in the region. It is a highly resilient system that operates to provide district heating service to its customers with a combination of heat pumps, thermal storage, waste heat, combined heat and power, electric boilers, and backup gas boilers. Gas is consumed for only a fraction of operating hours in the year.



As a district heating utility, Skagen operates to satisfy thermal energy demand in the network. As illustrated on a cold day, the system is generating most of its heat with heat pumps. TES is used to collect waste heat recovered from wastewater and industry. Surplus heat is recovered from power generation or electric boilers dispatched in response to spot, regulating, or reserve price signal to improve economics.



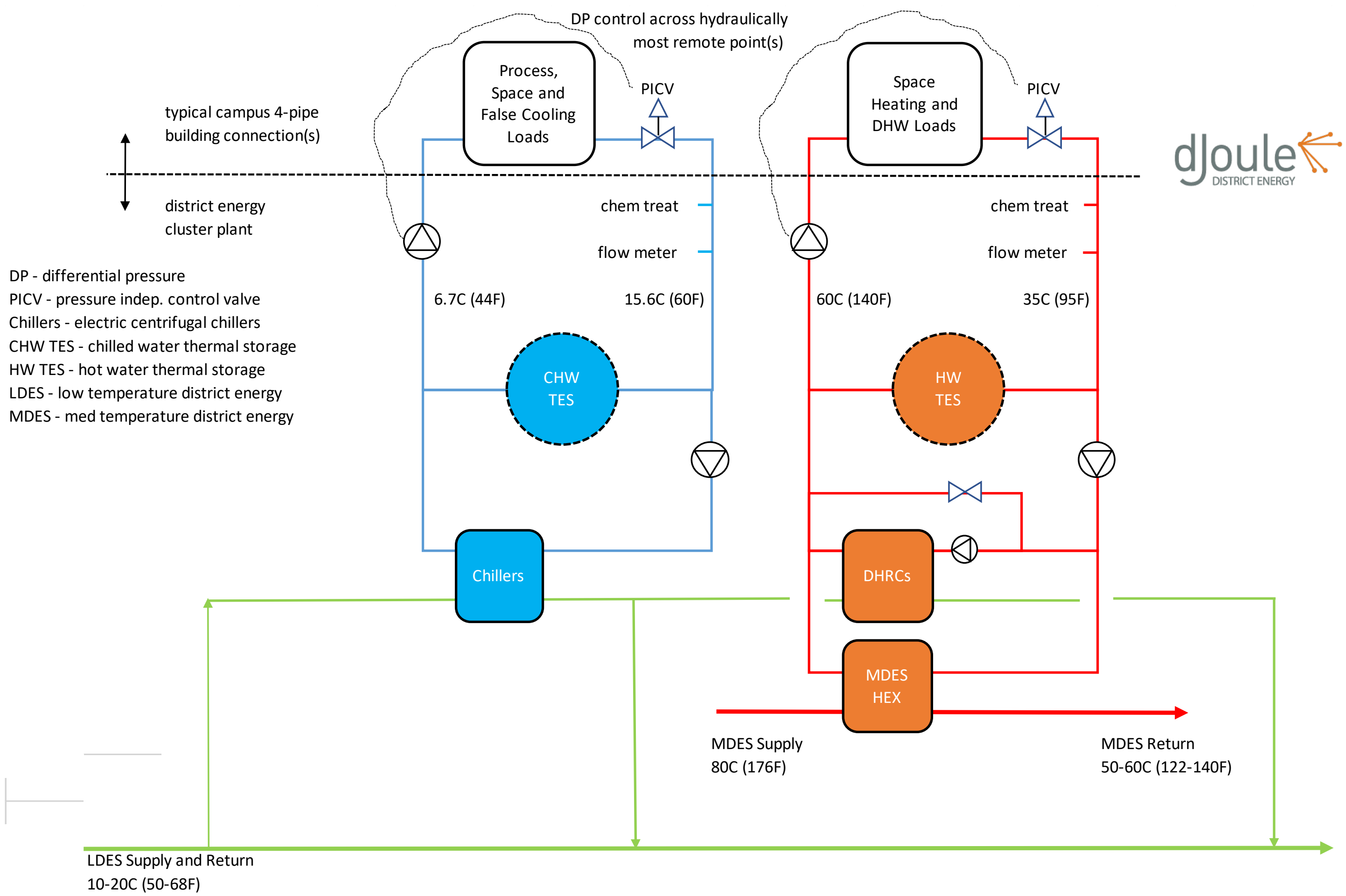
Cluster Plant Integration

The ICI building is identified as the first location for a cluster plant in the UBCO district energy strategy. It is located at a site near both LDES and MDES systems and is the next major building in development on campus. Existing ADM and EME buildings are close to ICI and may be targets for connection in the near term. Additional buildings identified for simple 4-pipe connection from this plant are shown in the table below.

ICI Cluster Connected Buildings		Heating			Cooling		
Building	Space	Heat	Peak	Annual	Cool	Peak	Annual
Identifier	sqm	%	MW	MWh	%	MW	MWh
ADM	5,792	100%	0.37	602	100%	0.41	553
EME	16,520	88%	1.83	3,518	100%	1.38	1,503
GYM	4,957	100%	0.30	463	0%	0.00	0
GYMH	909	100%	0.05	74	100%	0.07	75
Campus Plan 16 - ICI - Inf Proj 1.4	12,296	100%	1.13	1,585	100%	0.43	458
Campus Plan18/19 - Inf Proj 3.6	19,488	100%	1.79	2,513	100%	0.68	726
Campus Plan 9 - Inf Project 3.7	8,070	100%	0.38	462	100%	0.15	175
Campus Plan 10	7,908	100%	0.37	452	100%	0.25	171
Campus Plan 11 - Inf Proj 4.11	5,272	100%	0.25	302	100%	0.00	114
Campus Plan 12 - Inf Proj 4.12	5,272	100%	0.25	302	100%	0.17	114
Totals (Metric)	**86,484**	**99%**	**6.72**	**10,273**	**90%**	**3.54**	**3,889**
Totals (English)	**930,906**	**1,528**	**22.9**	**35,055**	**1,100**	**1,005**	**1,105,916**
English Units	sqft	EFLH	MMBtu/h	MMBtu	EFLH	tons	ton-hrs

Cluster plants emerged in the district energy strategy with the realization that high costs were incurred with development, ownership, and operation of heat pump systems in every building connected to the LDES. Economies of scale are achieved with LDES and MDES integration into cluster plants that provide simple 4-pipe service to the site and other building customers downstream.

In the ICI cluster plant, electric chillers reject condenser heat to the LDES. Dedicated heat recovery chillers intercept waste heat and cool the LDES to provide space heat and domestic hot water (DHW). Hot and chilled water TES provide for peak capacity, electric demand response, and the integration of more waste heat and renewable energy. MDES is designed for backup, peaking, and polishing as needed and is positioned for decarbonization and described earlier.



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Major Equipment in the ICI Cluster Plant

District Heating & DHW	SI Units		English	
Peak Heating & DHW Demand	6.72	MWth	22.9	MMBtu/h
HW Cluster Plant				
DHRC #1	0.88	MWth	3.0	MMBtu/h
DHRC #2	0.88	MWth	3.0	MMBtu/h
MDES HEX #1	1.76	MWth	6.0	MMBtu/h
MDES HEX #2	1.76	MWth	6.0	MMBtu/h
MDES HEX #3	1.76	MWth	6.0	MMBtu/h
HW TES 8 hrs	2.34	MWth	8.0	MMBtu/h
Installed Capacity	9.38	MWth	32.0	MMBtu/h
Firm N+1 Capacity excluding TES	7.03	MWth	24.0	MMBtu/h
HW Cluster Plant Distribution				
Rated Pressure	10	bar	150	psi
Supply Temperature	60.0	deg C	140	deg F
Return Temperature	35.0	deg C	95	deg F
Delta T	25.0	deg C	45	deg F
District Cooling	**SI Units**		**English**	
Peak Cooling Demand	3.54	MWth	1,005	tons
CHW Cluster Plant				
Chiller #1 (electric centrifugal)	1.76	MWth	500	tons
Chiller #2 (electric centrifugal)	1.76	MWth	500	tons
CHW TES 8 hrs	1.76	MWth	500	tons
Installed Capacity	5.28	MWth	1,500	tons
Firm N+1 Capacity excluding TES	3.52	MWth	1,000	tons
CHW Cluster Plant Distribution				
Rated Pressure	10	bar	150	psi
Supply Temperature	6.7	deg C	44	deg F
Return Temperature	15.6	deg C	60	deg F
Delta T	8.9	deg C	16	deg F

The ICI cluster plant shall be designed to accommodate growth in service to the ICI and other new and existing buildings in the surrounding area.

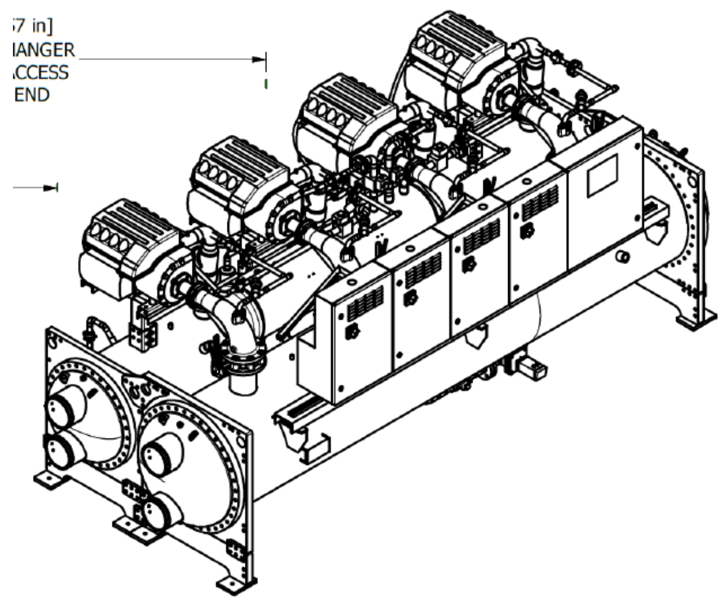
It shall be designed to accommodate heating and cooling capacities and requirements aas expressed in the adjacent table in a basement level plant room no smaller than 448 sqm (4,820 sqft).

Recommended chillers and dedicated heat recovery chillers (DHRC) shall be magnetic drive with a low GWP refrigerant that is not identified for future replacement.

ICI Cluster Plant Chiller and DHRC Recommendations

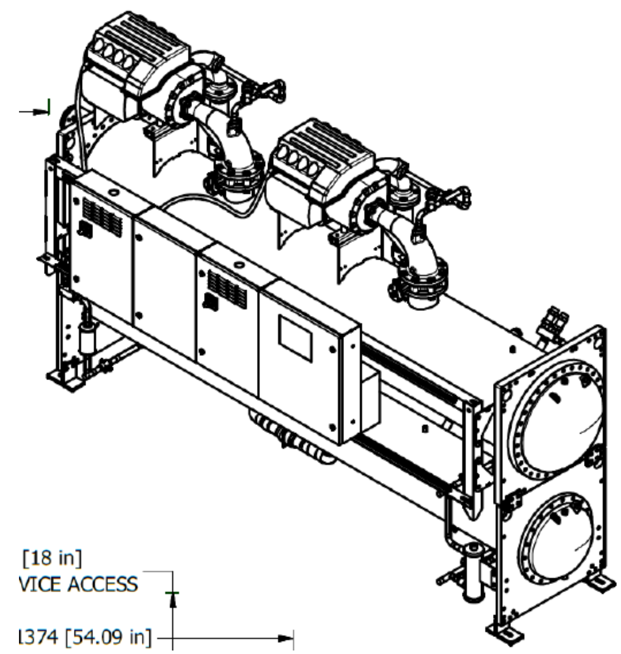
Among the available chiller options the following selection was made. Budgetary price, performance, and footprint details were provided to UBCO and considered competitive. Each unit has four compressors to enable high turndown, reliability, and redundancy. One of two chillers is envisioned in the initial installation.

	(2) Smardt Chillers	
	Locate Inside ICI Cluster Plant	
	Provide 2-Pipe Chilled Water	
	Reject Heat to LDES or DHRC	
Chiller Characteristics (each)	WWHP, R513A	
Compressor configuration	1-4*TTS400, single circuit	
Measurement units	Metric	English
Cooling capacity (kW, tons)	1,760	500
Heating capacity (kW, MMBtu/h)	2,006	6.8
Power input (kW)	245.6	245.6
COP_cooling_comp (#)	7.17	7.17
COP_heating_comp (#)	8.17	8.17
Evap. LWT (deg C, deg F)	6.7	44
Evap. EWT (deg C, deg F)	15.6	60
Evap. Flow (lps, gpm)	47.3	750
Cond. EWT (deg C, deg F)	21.0	70
Cond. LWT (deg C, deg F)	29.0	84
Cond. Flow (lps, gpm)	60.0	950
Min. capability ratio (%)	8.8%	8.8%
Source water side pump power (kW)	3.79	3.79
Hot water side pump power (kW)	4.68	4.68
Total system COP_cooling (#)	6.93	6.93
Total system COP_heating (#)	7.89	7.89
Refrigerant charge (kg, lbs)	500	1,100
Base dimension (mm, in)	4210 x 1754	166.75 x 69.06
Base area (sqm, sqft)	7.4	80.0



Among the available DHRC options the following selection was made. Budgetary price, performance, and footprint details were provided to UBCO and considered competitive. Each unit has two compressors to enable high turndown, reliability, and redundancy. One of two DHRCs is envisioned in the initial installation.

	(2) Smardt DHRC	
	Locate Inside ICI Cluster Plant	
	Provide 2-Pipe Heating Water	
	Cool Chiller Leaving Water or LDES	
DHRC Characteristics (each)	WWHP, R513A	
Compressor configuration	1-4*TTS400, single circuit	
Measurement units	Metric	English
Cooling capacity (kW, tons)	735	209
Heating capacity (kW, MMBtu/h)	887	3.0
Power input (kW)	152.4	152.4
COP_cooling_comp (#)	4.82	4.82
COP_heating_comp (#)	5.82	5.82
Evap. LWT (deg C, deg F)	21.0	70
Evap. EWT (deg C, deg F)	29.0	84
Evap. Flow (lps, gpm)	22.0	348
Cond. EWT (deg C, deg F)	40.0	104
Cond. LWT (deg C, deg F)	60.0	140
Cond. Flow (lps, gpm)	10.6	168
Min. capability ratio (%)	15.7%	15.7%
Source water side pump power (kW)	5.48	5.48
Hot water side pump power (kW)	3.47	3.47
Total system COP_cooling (#)	4.55	4.55
Total system COP_heating (#)	5.50	5.50
Refrigerant charge (kg, lbs)	320	704
Base dimension (mm, in)	3766 x 840	148.27 x 33.07
Base area (sqm, sqft)	3.2	34.1



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Thermal Storage in the ICI Cluster Plant

Hot Water Thermal Energy Storage

HW TES at ICI Cluster

	SI Units	English Units	
hours	8	8	discharge time at peak (hrs)
liters	751,771	170,667	volume (gallons)
cubicmeters	752	26,548	volume (cuft)
sqm	41.1	442	tank area (sqft)
meters	7.2	23.7	tank internal diameter (ft)
meters	18.3	60.0	tank height (ft)
MW	2.3	8.0	capacity (MMBtu/h)
MWh	18.8	64.0	energy (MMBtu)
deg C	25.0	45	delta T (deg F)
cfs	0.79	356	flow rate (gpm)
#	2.53	2.53	height to diameter ratio

Estimated Costs (CAD)

3%	construction escalation from 2008
$291,816	boiler plant unit cost ($/MW) for comparison
$1,238	HW TES cost estimate ($/cubic meter) with 10% foundation

Low	High	
$ 282,065	$ 564,129	excluding foundation, non pressurized
$375.20	$750.40	per cubic meter
$ 564,129	$ 1,128,258	excluding foundation, pressurized
$750.40	$1,500.80	per cubic meter

$ 930,813	HW thermal storage capital cost ($)
$ 684,180	avoided boiler plant capital cost ($)
$ 246,634	incremental cost ($)
$ 1,256,598	total HW TES capital cost with 35% soft costs ($)

Chilled Water Thermal Energy Storage

CHW TES at ICI Cluster

	SI Units	English Units	
hours	8	8	discharge time at peak (hrs)
liters	1,585,767	360,000	volume (gallons)
cubicmeters	1,586	56,001	volume (cuft)
sqm	104.1	1,120	tank area (sqft)
meters	11.5	37.8	tank internal diameter (ft)
meters	15.2	50	tank height (ft)
MW	1.8	500.0	capacity (tons)
MWh	14.1	4000.0	energy (ton-hrs)
deg C	8.89	16	delta T (deg F)
cfs	1.67	750	flow rate (gpm)
#	1.32	1.32	height to diameter ratio (#)

Estimated Costs (CAD)

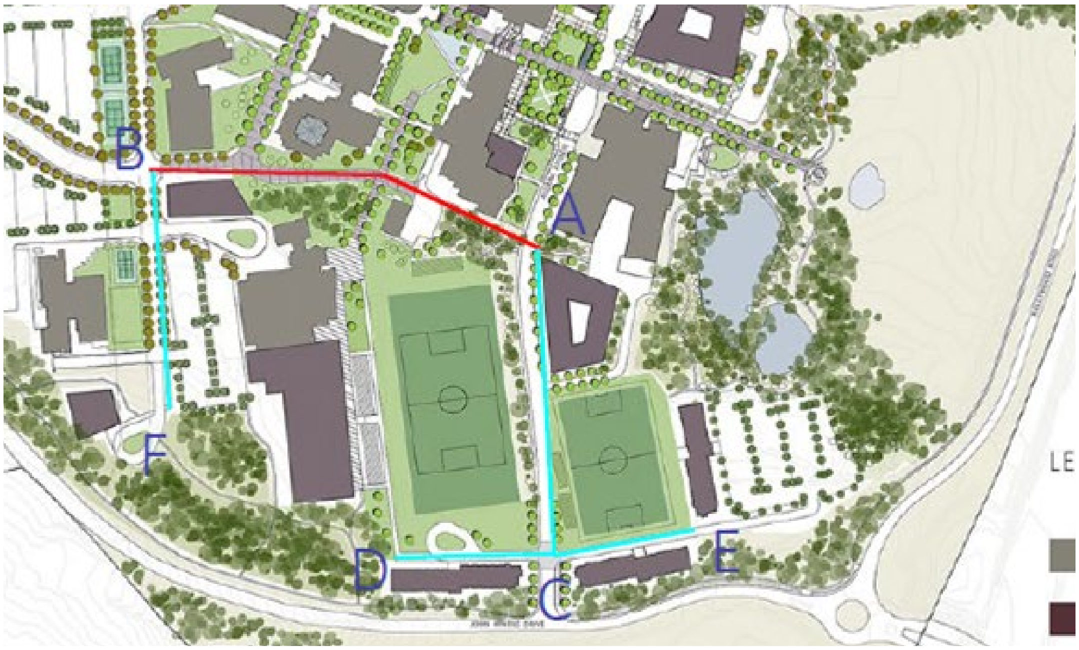
3%	construction escalation from 2008
$1,438,934	chiller plant unit cost ($/MW) for comparison
$1,238	HW TES cost estimate ($/cubic meter) with 10% foundation

Low	High	
$ 594,980	$ 1,189,960	excluding foundation, non pressurized
$375.20	$750.40	per cubic meter
$ 1,189,960	$ 2,379,920	excluding foundation, pressurized
$750.40	$1,500.80	per cubic meter

$ 1,963,434	CHW thermal storage capital cost ($)
$ 2,530,250	avoided chiller plant capital cost ($)
$ (566,816)	incremental cost ($)
$ 2,650,636	total CHW TES capital cost with 35% soft costs ($)

4-Pipe Distribution from the ICI Cluster Plant

District heating and cooling distribution from the ICI cluster plant to serve identified buildings is simple four pipe. Rough order of magnitude estimate for the distribution, branches, and energy transfer (whether ICI or other connected buildings) is as follows.



4-Pipe Distribution Leaving Plant

Chilled Water @ 3.54 MW (1005 tons) - 95 lps (1508 gpm) - 200 mm (8")
Hot Water @ 6.72 MW (22.9 MMBtu/h) - 64 lps (1018 gpm) - 200 mm (8")

Distribution path	Trench meters	Unit cost	Total cost
A-B	290		
B-F	135		
A-C	250		
D-E	250		
Main Dist. (tm)	925	$2,117	$ 1,957,810
Branches (#)	10	$30,000	$ 300,000
HW ETS (kW)	6,723	$159	$ 1,069,300
CHW ETS (kW)	3,536	$80	$ 281,195
Total			**$ 3,608,306**

assumes design and construction in common trench
distribution routing through buildings as appropriate
ETS connections from ICI cluster plant are direct 4-pipe with metering
flow may be split if two branches and pipe size reduced