TRIGENERATION AT UNIVERSITY OF MINNESOTA INSTALLATION OF A MODERN ABSORPTION CHILLER & DISPATCHING STRATEGIES





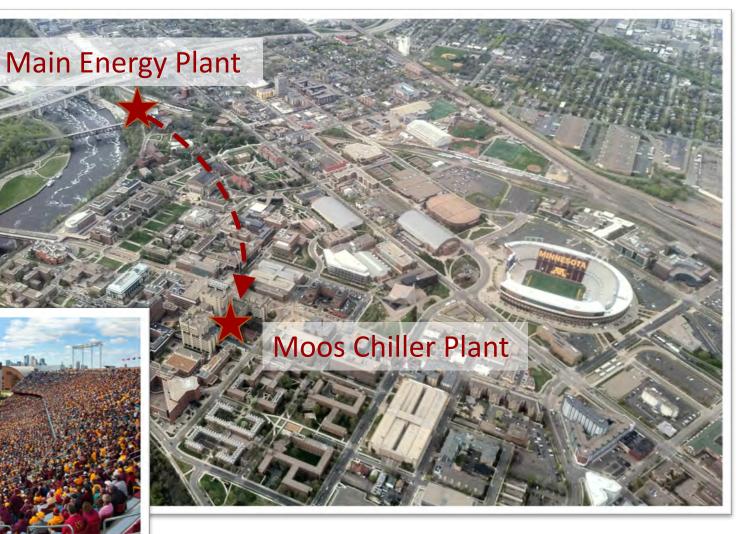


OVERVIEW



PRESENTATION TOPICS

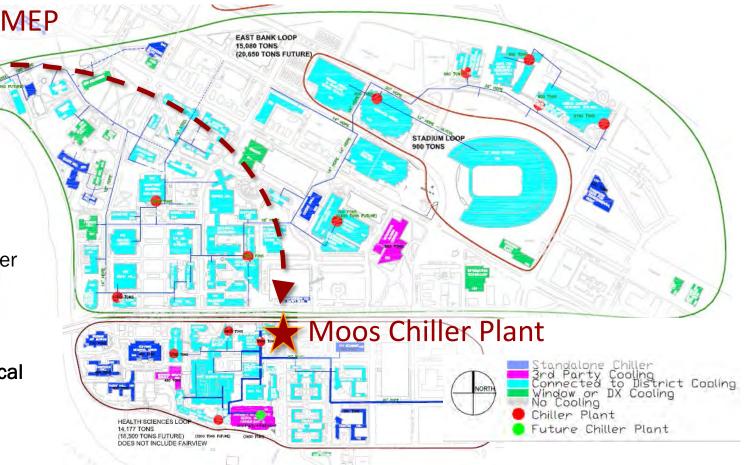
- Background
- Why Absorption?
- Laying Out the Project
- Carbon Footprint Reduction
- End Results





UNIVERSITY STEAM AND CHILLED WATER UTILITIES

- U of MN tri-generation system
 - Multiple co-gen heating plants
 - Multiple chilled water districts
- 2017 Project: 24MW Gas Turbine with Heat Recovery
 - Centerpiece of Trigeneration System
- Academic Health Sciences
 - Largest and most consistent chilled water user
 - Campus is fully developed in this district
 - Projects are usually retrofits within existing building envelopes
 - Outages of infrastructure in this mission critical area of campus are high impact and very infrequent





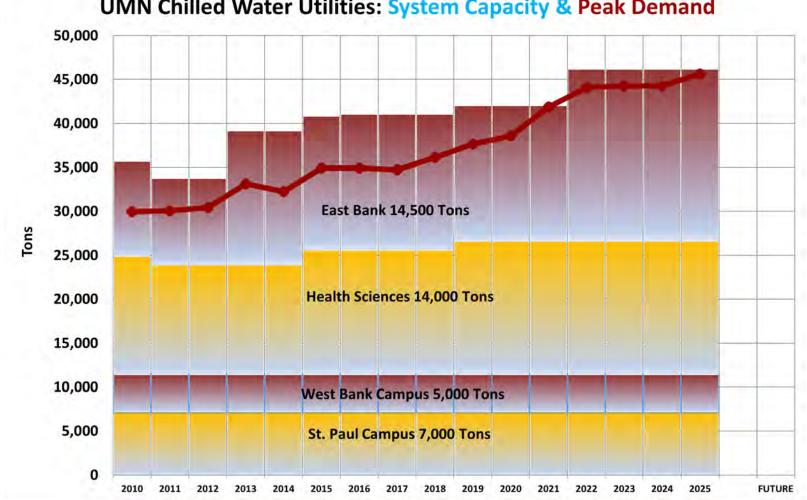
TRI-GENERATION WITH MAIN ENERGY PLANT

- MEP began commercial operation in 2017
- CHP 101: Match thermal and electric loads
- Campus Electric Peak Demand Reduction
 - Peak demand charges ~50% of annual campus electric costs



GE LM2500 DLE Dual Fuel 220 MMBtu/hr Input (HHV) 24 MWe Generator Output





UMN Chilled Water Utilities: System Capacity & Peak Demand

Demand-Limiting Strategies

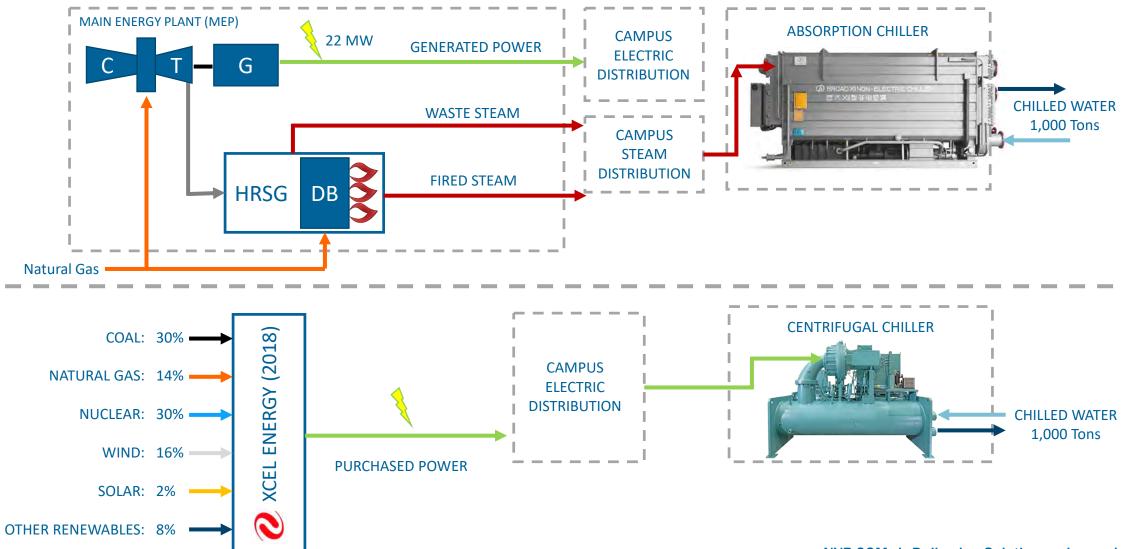
- Steam absorbers (~9,000 tons) ٠
- Future steam turbine chillers ۲ (6,000 tons)
- Future inlet air cooling on MEP ٠ turbine (900 ton load, +2 MW output)
- Building mass thermal energy ۲ storage
- (Future) Traditional TES options, ice ٠ and/or chilled water storage



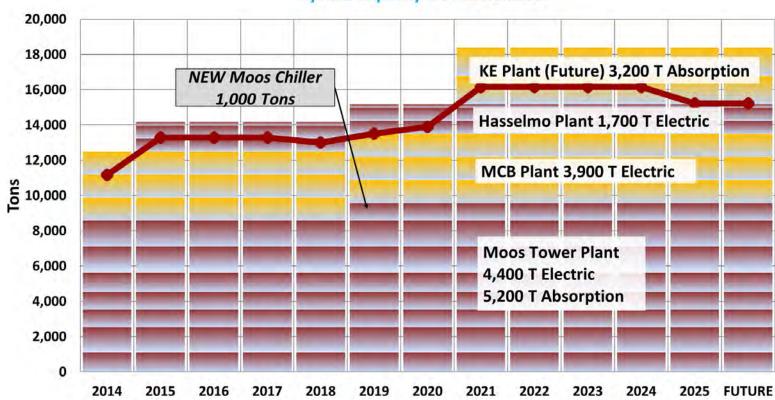


CONVENTIONAL

CHILLER



ACADEMIC HEALTH CHILLED WATER DISTRICT



UMN Health Sciences District System Capacity & Peak Demand

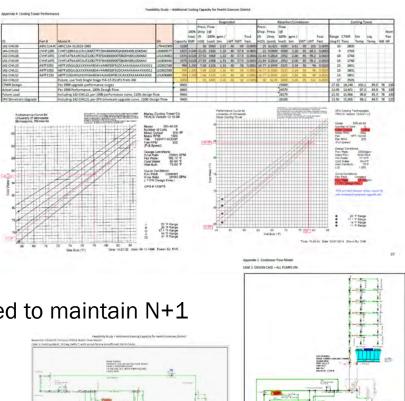






ADDITIONAL COOLING CAPACITY - PROJECT SCOPE

- Projected 1,000 tons of additional cooling capacity by 2020
- Internal feasibility study: chiller technologies and infrastructure
 - Rigging Challenges Moos Tower mechanical room is 50' below grade
 - Limited space available
 - Minimal outage available
 - Maintain adequate access for all existing equipment
- Projects required to support new chiller:
 - Cross-over piping upgrades (chilled water and condenser water) required to maintain N+1
 - Replacement of existing chilled water pumps
- Adequate cooling tower capacity available for new chiller





Chiller Technologies

- The following chiller technologies were considered:
 - Electric centrifugal:
 - Insufficient electric feeder capacity,
 - <u>Negative</u> impact on campus peak electric demand charges
 - Steam turbine:
 - For this part of the system, would require staffing change, MN statute requires a licensed boiler operator on-site for start-ups
 - Absorption:
 - Peak electric demand reduction
 - Locational flexibility
 - University operators already have experience with this technology.
 - Deemed the best available technology for this application.







WHY ABSORPTION?



Lifecycle Cost Analysis

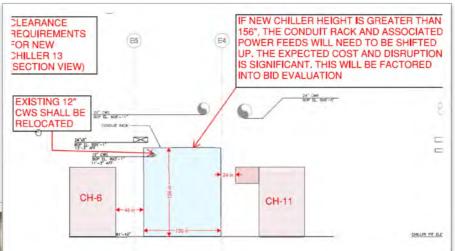
			Capital Cost			Annual	Cost	3 			9	30	Yr Lifecycle Cost	(5)		
Alt. #	* All costs in 2017 dollars		Capital Cost Subtotal		Hrc		Annual Energy Cost (M)	Annual Maint Cost	Annual Variable Fuel Cost	30 Yr Cum. Op.	/0	and the second second	Total Variable	Overhaul + Maint Cost ubtotal		30 Yr Lifecycle Grand Total (M rates)
	Existing Fleet	Capacity	(\$)	(hours)	(ton-l LC	A of <u>e</u>	xistin	<u>g</u> elec	ctric chi	ller (p	еак) 🗖	\$ 5,17	75,844	5)		(\$ - 2017)
	Trane Horizon (peak)	1000	N/A, Existing	400	400,000	1.2	7.54	26,219	\$ 25,281	12000	Ş 758,42 -	+	÷ 5,555,464	802,570	4,756,054	\$4,756,054
	Trane Horizon (cogen)	1000	Asset	1200	1,200,000	1.35	7.54	26,219	\$ 67,415	36000	\$2,022,464	\$1,917,036	\$ 3,939,500	834,570		\$4,774,070
	Trane Horizon (base)	1000		2400	2,400,000	1.35	7.54	26,219	\$ 134,831	72000	+ ./	\$ -	\$ 4,044,925	882,570		\$4,927,439
	Existing Centrifugal (peak)	1400	N/A Existing	400	400,000	0.628	0.1034	11,542	\$ 25,974	12000	\$ 779,222	\$3,195,060	\$ 4,822,082	353,761		\$5,175,844
	Existing Centrifugal (cogen)	1400	Asset	1200	1,200,000	0 545	0.102.4	44 540	6 62 004	2000	6101703			362,261		\$4,911,583
	Existing Centrifugal (base)	1400		2400	2,40	_CA of	new	abso	rber (ba	aseloa	d) 📴	\$4.9	75,538	118,261	4.947,583	\$4,947,583
-	New Chiller Install													-		
1	Vendor #1 2 stage (peak)		Redacted	400	400,000	1.5	7.54	- / -	\$ 20,225	12000		\$3,195,000	\$ 3,801,799	814,570		\$ 5,271,369
2	Vendor #1 2 stage (cogen)		Redacted	1200	1,200,000	1.731	7.54	26,219	\$ 52,577	36000		\$1,917,036	\$ 3,100,020	870,570		\$ 5,625,530
	Vendor #1 2 stage (base)		Redacted	2400	2,400,000	1.731	7.54	26,219	\$ 105,154	72000	\$2,365,968	<u>Ş</u> -	\$ 2,365,968	954,570		\$4,975,538
4	Vendor #2 1 stage (peak)		Redacted	400	400,000	0.678	7.54	,	\$ 44,745	12000	\$1,342,344	\$3,195,060	\$ 4,537,404	576,676		\$6,779,080
5	Vendor #2 2 stage (peak)		Redacted	400	400,000	1.31	7.54	26,219	\$ 23,158	12000	\$ 694,740	\$3,195,060	\$ 3,889,800	802,570		\$6,522,370
6	Vendor #2 2 stage (cogen)		Redacted	1200	1,200,000	1.43	7.54	26,219	\$ 63,644	36000	\$1,431,990	\$1,917,036	\$ 3,349,026	834,570		\$6,013,595
7	Vendor #2 2 stage (base)		Redacted	2400	2,400,000	1.43	7.54	26,219	\$ 127,288	72000	\$ 2,863,979	Ş -	\$ 2,863,979	882,570		\$ 5,576,549
8	Vendor #3 1 stage (peak)		Redacted	400	400,000	0.71	7.54	,	\$ 42,728	12000	\$1,281,844	\$3,195,060	\$ 4,476,904	588,676		\$ 6,665,580
9	Used Vendor #3 1 stage (peak)	1000	Redacted	400	400,000	0.71	7.54	18,689	\$ 42,728	12000	\$1,281,844	\$3,195,060	\$ 4,476,904	643,676	5,120,580	\$6,420,580

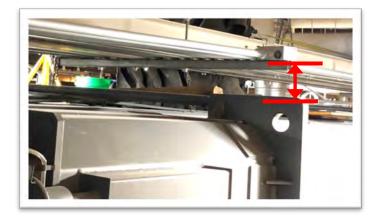
Chiller Procurement

- Clearances: Rigging and Final Location
- Disassembly and Reassembly requirements called out to accommodate available clearances.

hillor Droguromant











Chiller Selection

- Chiller RFP:
 - Pre-bid site walkthrough required for all vendors
 - Submit chiller performance (zero tolerance at full design load conditions)
 - Submit condenser and chilled water DPs
- Factory Performance Test
- On-Site Performance Test

Attachment C: Chiller Performance Guarantees

Mandatory On-Site Field Performance Demonstration Test

Actual performance data to meet or exceed submitted data in Attachment B per specified COP tolerance.

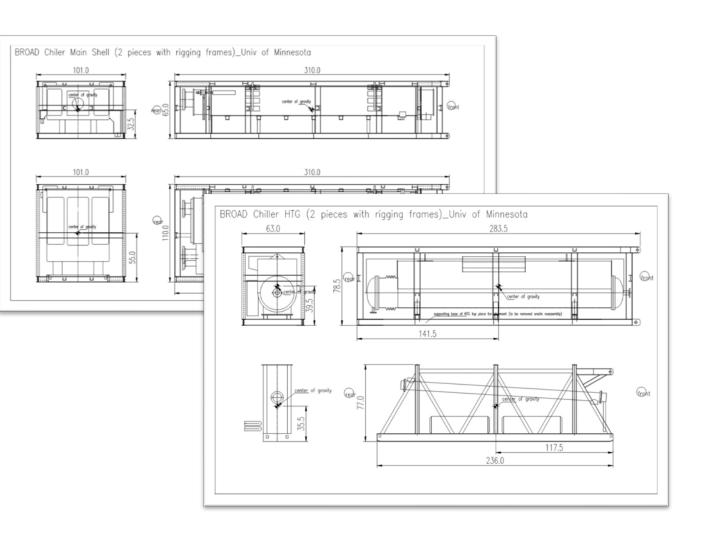
Performanc	e Map	Evap. Delta T	Lvg Evap	CND	Steam Ent Ter	np. (deg	F)	COP T	olerance	
Load	Tons	deg F	deg F	85	80	75	70	Upper Limit	Lower Limit	
100.0%	1000	18			$>\!$	$>\!$	\times	none	ZERO @ 85F	
100.0%	1000	12	40		\geq	\geq	\geq	none	AHRI 560	
80.0%	800	12	40	$>\!$		$>\!\!<$	\times	none	AHRI 560	
60.0%	600	12	40	$>\!\!<$	$>\!$		×	none	AHRI 560	
40.0%	400	12	40	>>	>>	>		none	AHRI 560	
	Average			#DIV/0!	#DIV/0!	#DIV/0!	****			

Non-Mandatory Factory Condenser Flow Performance Test

CND Pump I	Energy	Evap. Delta	p Ch	D/ABS F	low (gpr	n)	CND/ABS dp (ft H20)					
Load	Tons	deg F	deg F	8	5 80	75	70	85	80	75		
100.0%	1000		18 4	10	>	\geq	\times		>	>	>	
100.0%	1000		12 4	10	\geq	\geq	\succ			\sim		
80.0%	800		12 4	10 >>		\sim	\ge	>		\searrow	>	
60.0%	600		12 4	10	\mathbb{X}		X	>	>		>	
40.0%	400		12 4	10	\sim	>		>	>	> <		
	Average			#DIV/0	! #DIV/0!	#DIV/0!	####	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/	

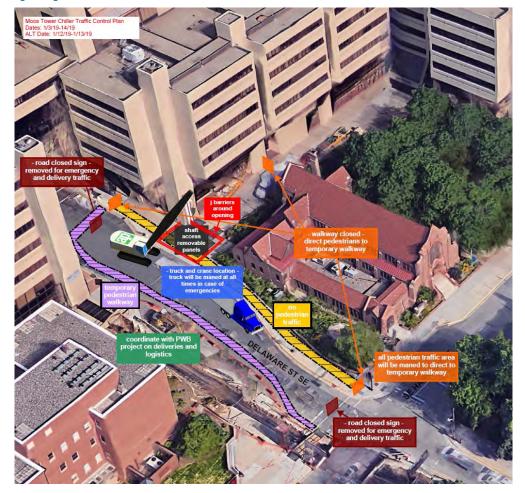
Chiller Selection

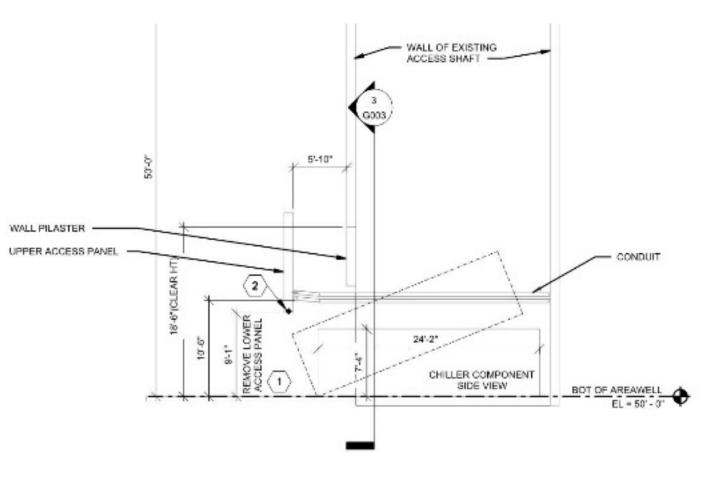
- Broad Model BS400
- Design Conditions:
 - 1,000 tons capacity
 - Evaporator: 40°/58°F
 - Condenser: 85°/97°F
 - Inlet Steam Pressure: 125 psig, saturated
 - Steam Consumption: 8,385 lb/hr
 - COP: 1.4
 - Steam powered condensate pump
- Tube Materials:
 - Evaporator: Copper
 - Condenser: Cupronickel
 - Absorber: Curponickel
 - HTG: Titanium
 - LTG: Cupronickel





Equipment Install – Shaft Access





Moos Tower Chiller Layout and Installation

- Laser scan was essential for adequate clearance for piping, tube pull and chiller service
- Existing single stage absorption chiller was shifted 3' to provide additional clearance
- Careful scheduling of outages, then proceeded with assembly











Chiller Performance Tests

- Witness performance test done at the Broad factory in China
 - NV5 was present
- Field performance test done upon completion of installation
 - Design capacity and peak performance were tested to zero tolerance
 - Part-load performance tested based on AHRI conditions
 - Field performance and tight metering specification included in RFP for chiller for OEM reference





		40% Performance Data Bacware Jascware Jascware Jascware															
				100.000	-	147	OVEL 1	AD-OWEL-	142-CWRT-	142-CWRT-	142-CW51	- 141-CWS	π-			142-STTF-80	
	1			CHW (To			6 OIW FL		(Temperatur	(Temperatu	r (Tempera		nur 142-5	T-R106 142-51	FL-R06 142-STPR-R06		
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							60%	Perform	ance Da	ta							
								42-CWRT-	142-CWRT-	142-CW5		/ST-					
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	5/8/20		575.0	1072	.3125	1210	1995	55.3	87.		43.7	74.2	4602	-	126.3		
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	1	100% 18DT Ratin	g Per Spec/Bid	_	1000.0		200				40.0				Tolerance (%)	1	1.4

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Chiller Operation

- Features of modern absorption chillers:
 - Modern PLC's are configured ensure the absorption machine stays out of the crystallization zone
 - Automatically limits capacity on low entering water temperature
 - Modern machines have automatic purge systems to maintain vacuum
 - Improvements in steam control valves have allowed absorbers to react better to load changes
 - Tube metallurgy (CuNi, SS, titanium) have reduced tube issues and improved reliability
- The absorbers are typically run at 80-90% load
 - Maximizes equipment life (reduced HTG temp)
 - Lower entering tower water temperature reduces absorber capacity
 - Lower tower temp improves overall plant efficiency

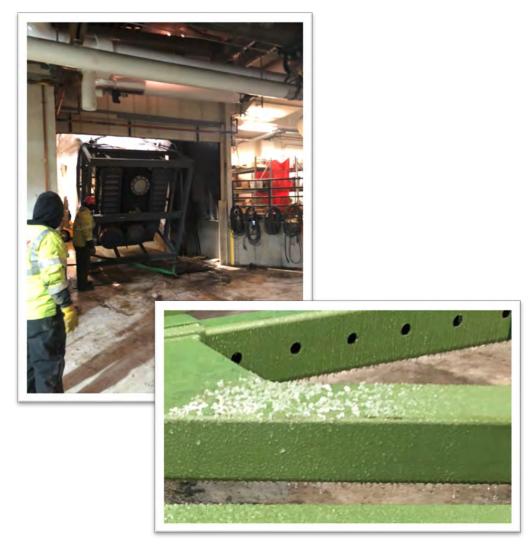




Lessons Learned

- Reassembly was more labor intensive than we had planned.
- Having a skilled contractor in place as a partner was key, especially given the tight physical constraints in all directions.
- We utilized a steam-powered condensate pump for this project. Finding adequate vertical clearance was a significant challenge.
- Laser scanning of the entire plant was a major timesaver in such a crowded plant
- Highly recommend detailing out each pipe support location when possible to avoid extra costs from fieldrouting
- Chiller delivery in -20F windchill is not fun. . .

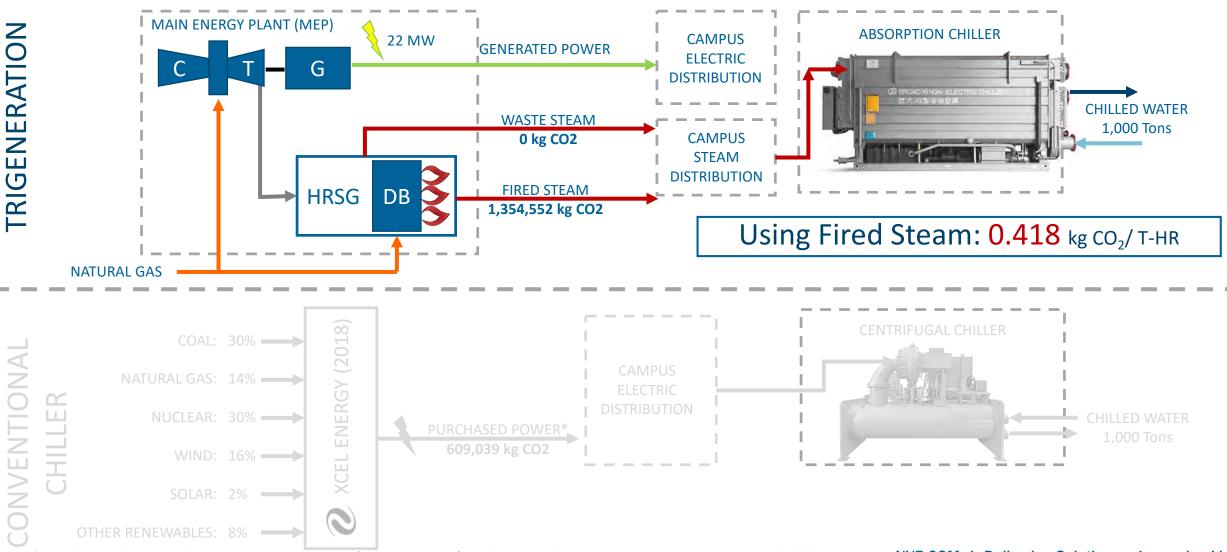




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ANNUAL CHILLER CO₂ EMISSIONS DEPENDS ON DISPATCH METHOD



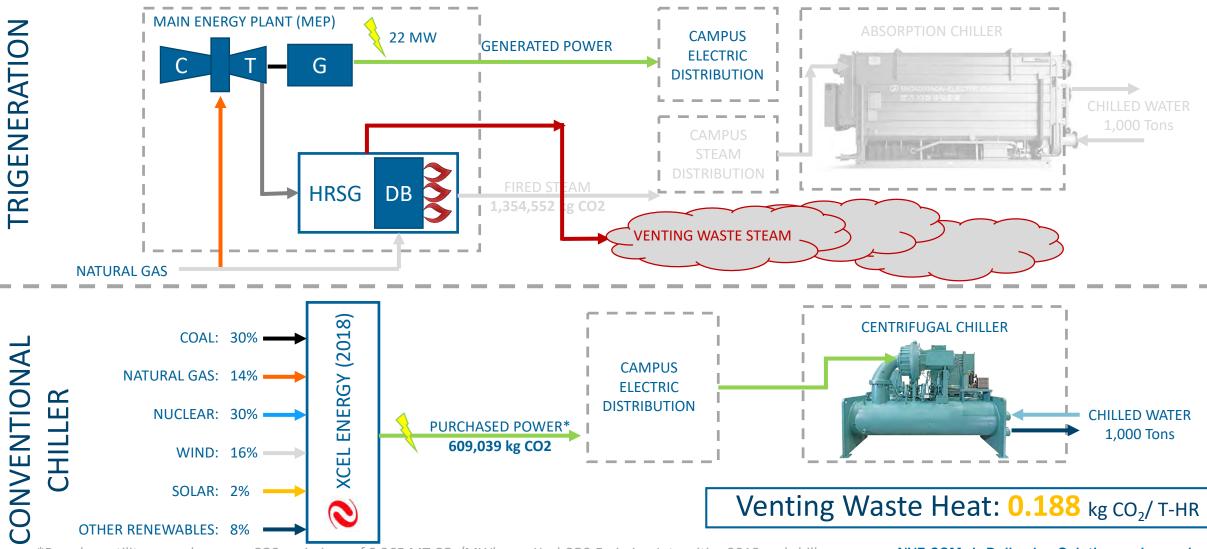


*Based on utility annual average CO2 emissions of 0.365 MT CO_2/MWh , per Xcel CO2 Emission Intensities 2018 and chiller efficiency of average fleet efficiency 0.515 kW/ton

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ANNUAL CHILLER CO₂ EMISSIONS DEPENDS ON DISPATCH METHOD



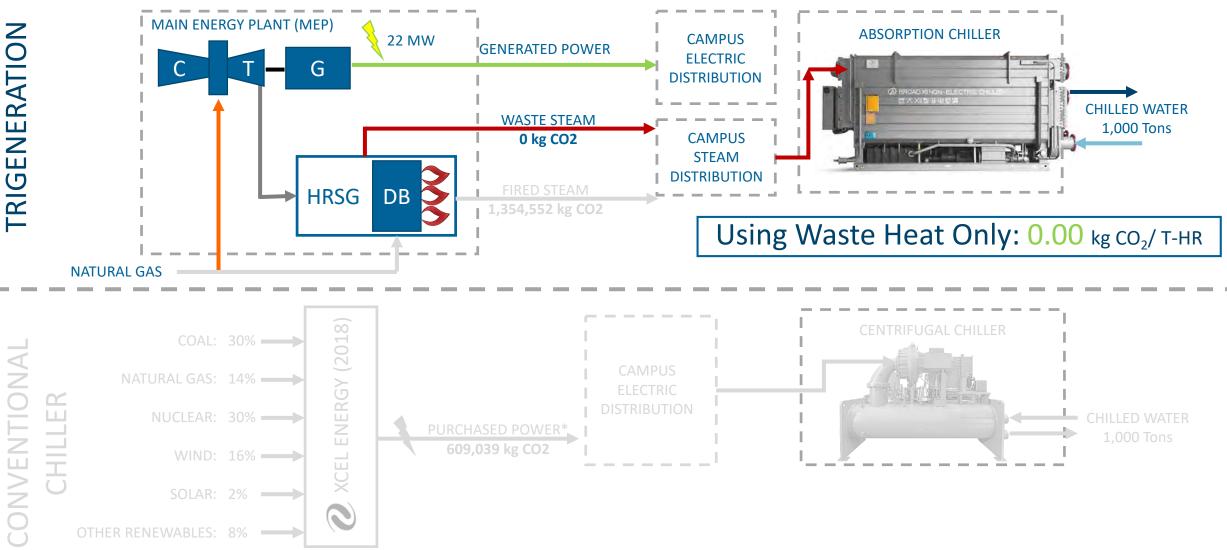


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ANNUAL CHILLER CO₂ EMISSIONS DEPENDS ON DISPATCH METHOD



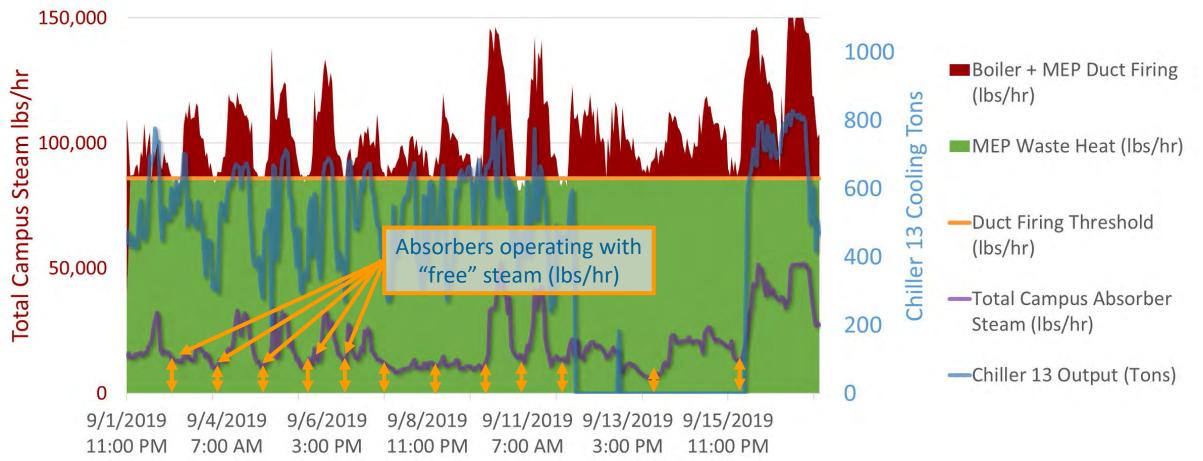


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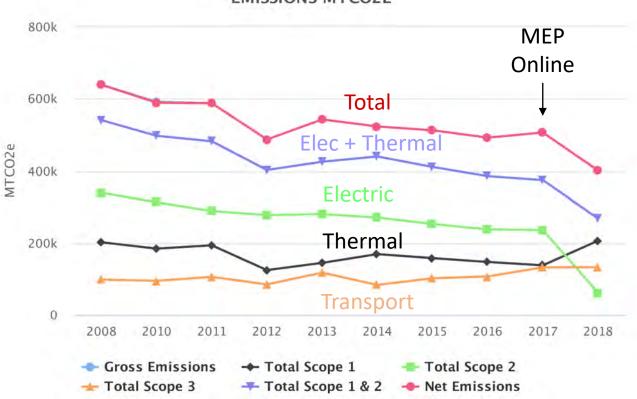


Moos Chiller 13 Operation vs. MEP Operation



Campus Cooling CO2 Footprint Reduction

- MEP reduces UMN CO2 footprint by 25%
- Conservation measures and fuel source improvements have provided another ~15% reduction
- Venting waste steam while generating at MEP is economically favorable
- Absorption cooling with this waste heat has a 40% lower CO2 footprint and ~80% lower fuel cost vs electric centrifugal plant
- → Abs. cooling is a key thermal load to balance our CHP system and maximizing value
- → Every pound of steam saved on campus during summer improves cooling CO2 footprint



EMISSIONS MTCO2E



QUESTIONS?



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