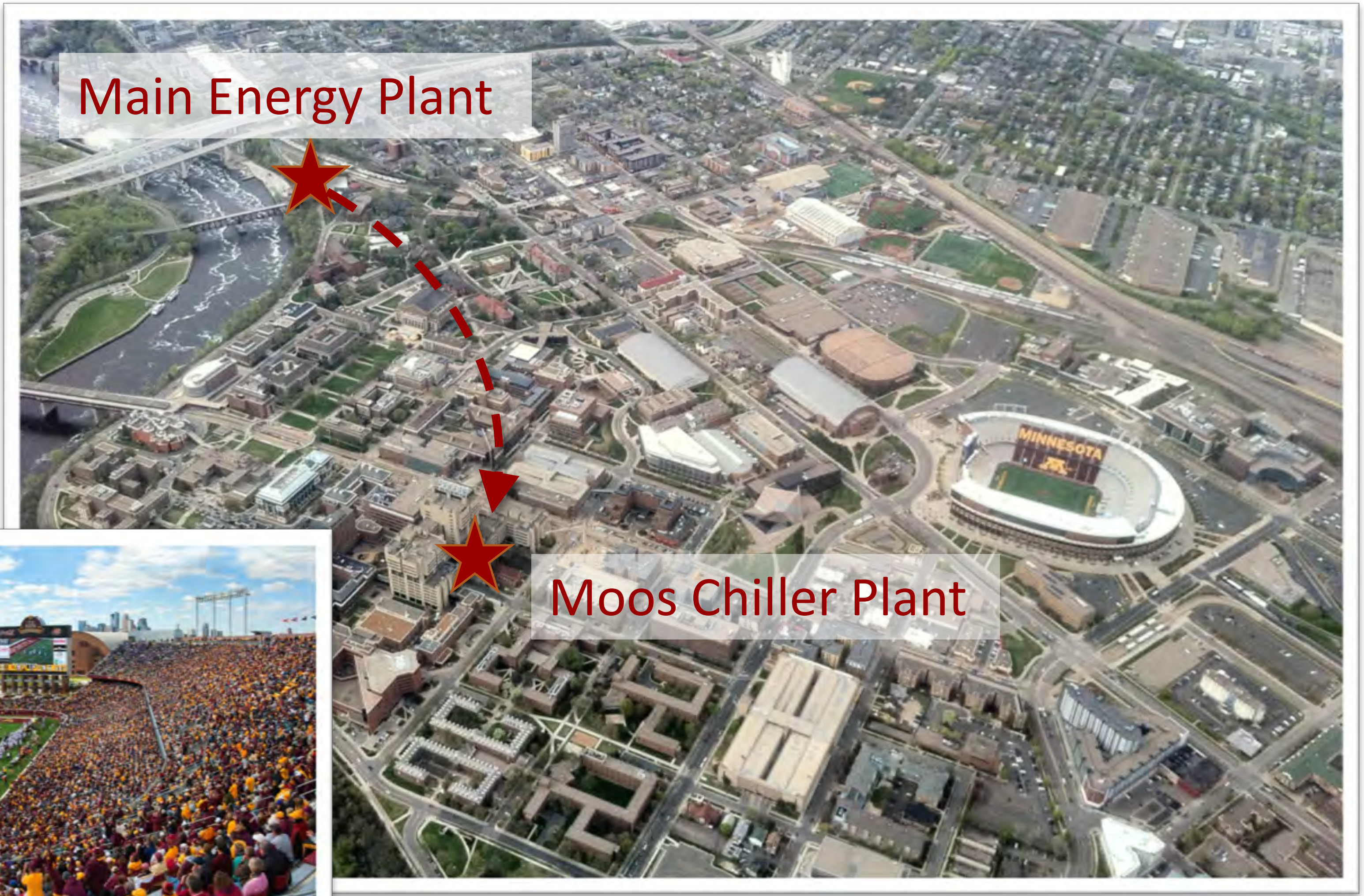
TRIGENERATION AT UNIVERSITY OF MINNESOTA

INSTALLATION OF A MODERN ABSORPTION CHILLER & DISPATCHING STRATEGIES

OVERVIEW

PRESENTATION TOPICS

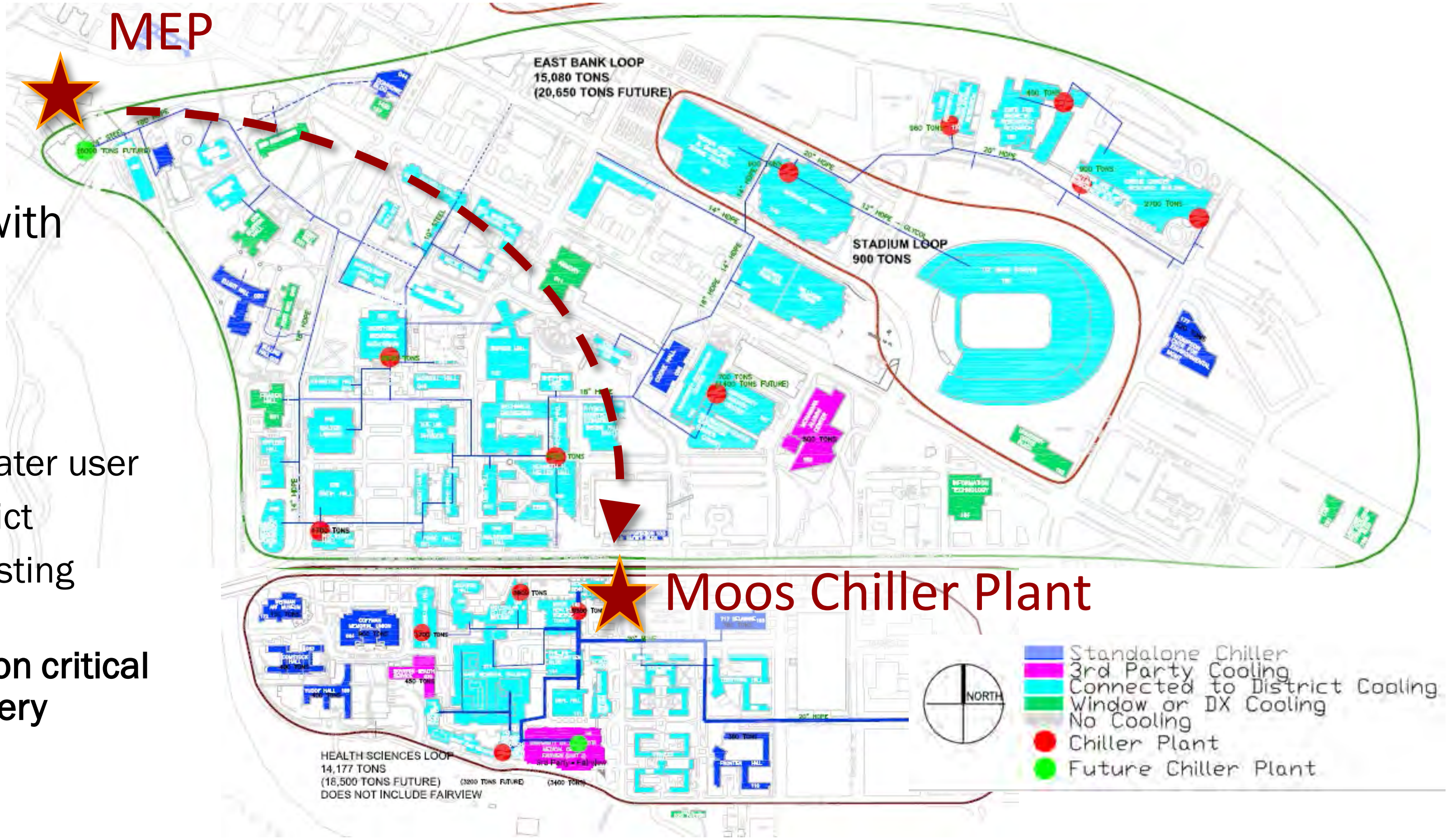
- Background
- Why Absorption?
- Laying Out the Project
- Carbon Footprint Reduction
- End Results



BACKGROUND

UNIVERSITY STEAM AND CHILLED WATER UTILITIES

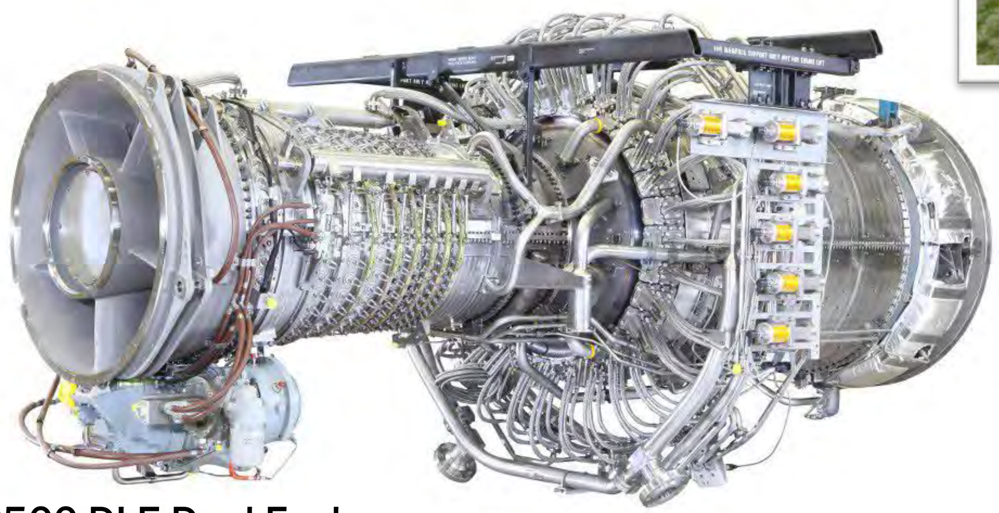
- U of MN tri-generation system
  - Multiple co-gen heating plants
  - Multiple chilled water districts
- 2017 Project: 24MW Gas Turbine with Heat Recovery
  - Centerpiece of Trigeneration System
- Academic Health Sciences
  - Largest and most consistent chilled water user
  - Campus is fully developed 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**



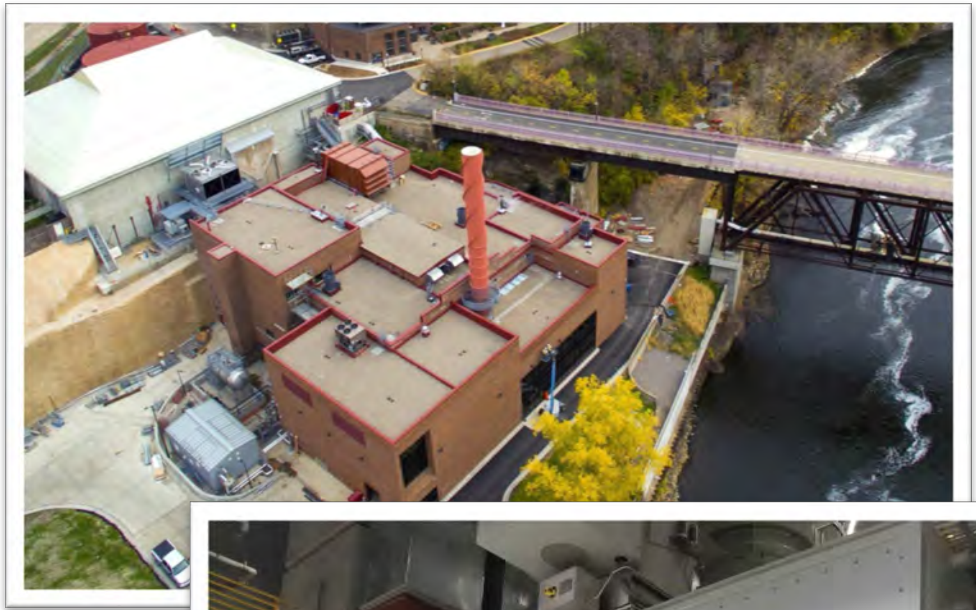
BACKGROUND

TRI-GENERATION WITH MAIN ENERGY PLANT

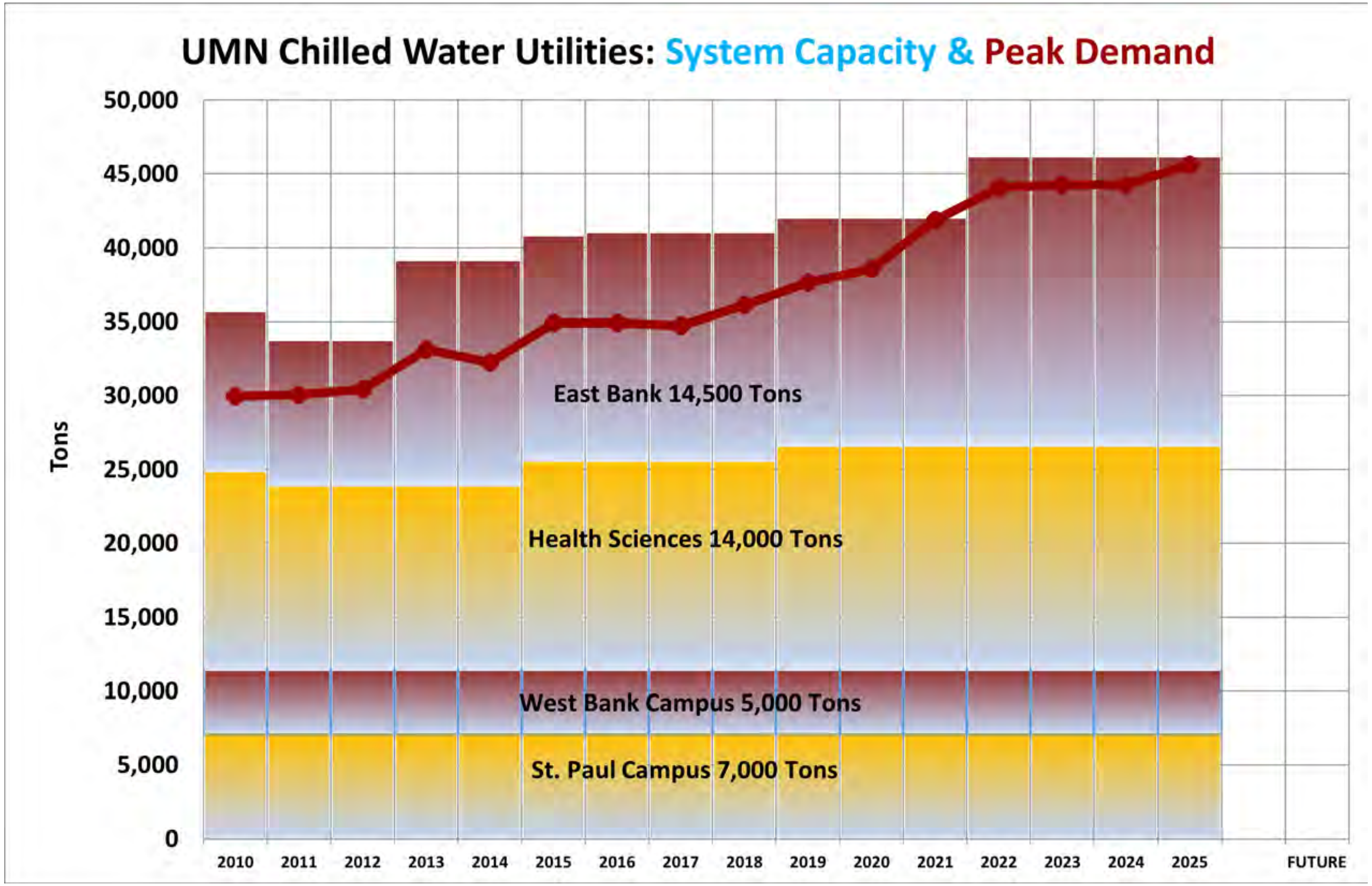
- MEP began commercial operation in 2017
- CHP 101: Match thermal and electric loads
- Campus Electric Peak Demand Reduction
  - Peak demand charges ~50% of annual campus electric costs



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



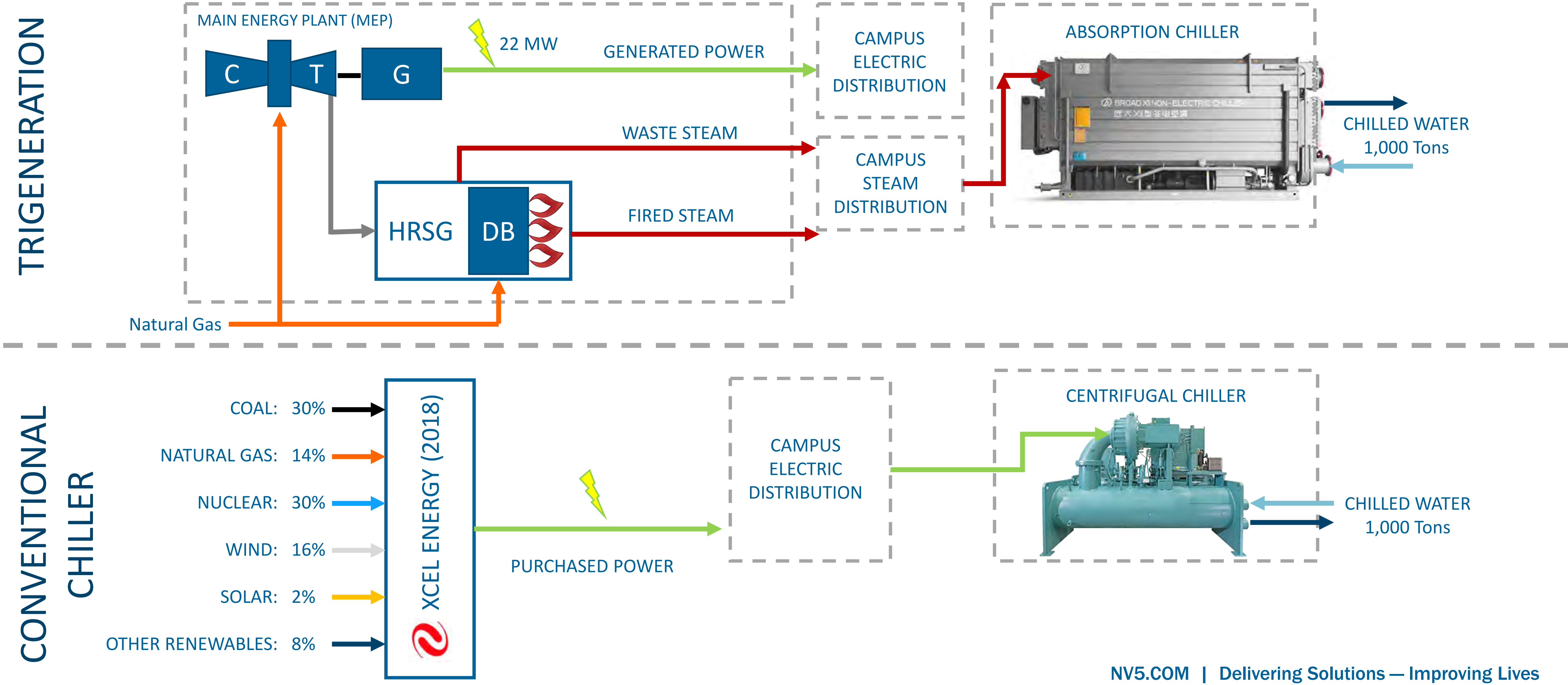
BACKGROUND



Demand-Limiting Strategies

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

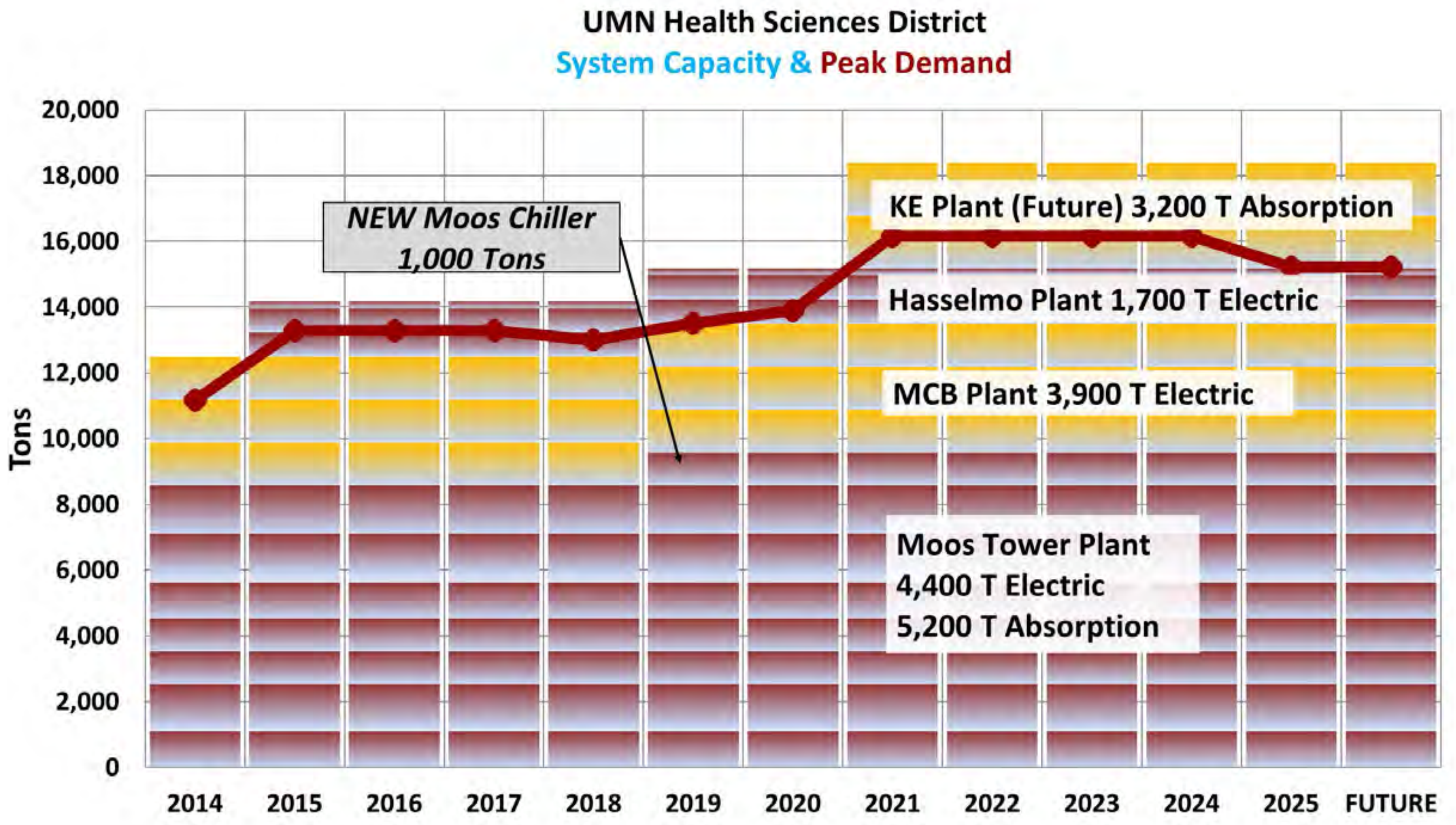
BACKGROUND



TRIGENERATION
MAIN ENERGY PLANT (MEP)
C
T
G
22 MW
GENERATED POWER
CAMPUS ELECTRIC DISTRIBUTION
ABSORPTION CHILLER
WASTE STEAM
CAMPUS STEAM DISTRIBUTION
CHILLED WATER 1,000 Tons
HRSG
DB
FIRED STEAM
Natural Gas
CONVENTIONAL CHILLER
COAL: 30%
NATURAL GAS: 14%
NUCLEAR: 30%
WIND: 16%
SOLAR: 2%
OTHER RENEWABLES: 8%
XCEL ENERGY (2018)
PURCHASED POWER
CAMPUS ELECTRIC DISTRIBUTION
CENTRIFUGAL CHILLER
CHILLED WATER 1,000 Tons

BACKGROUND

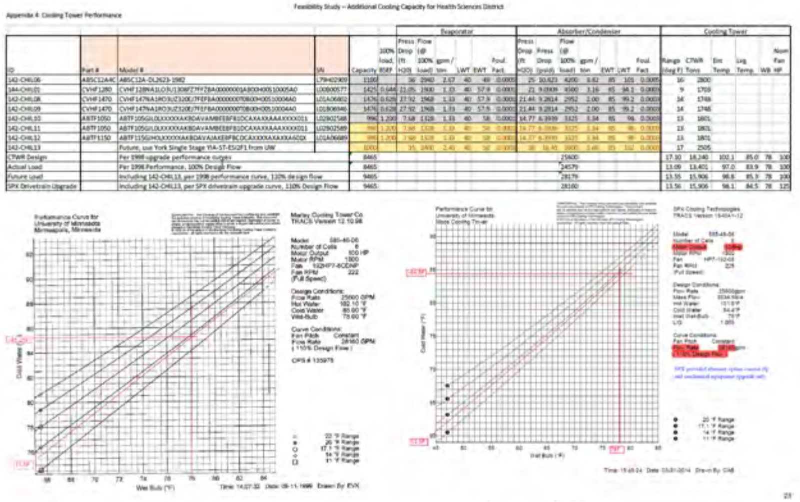
ACADEMIC HEALTH CHILLED WATER DISTRICT

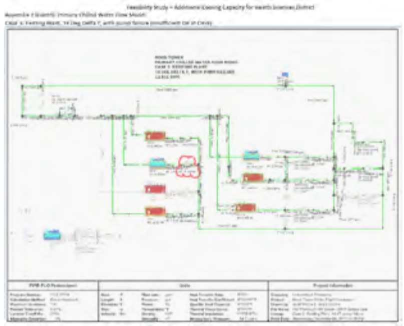


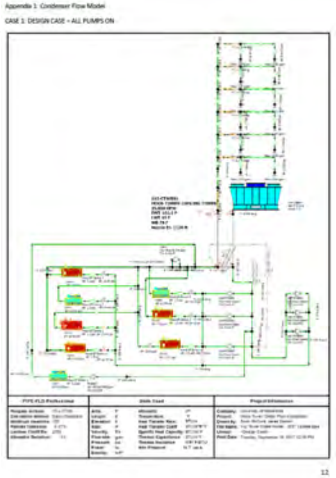
BACKGROUND

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



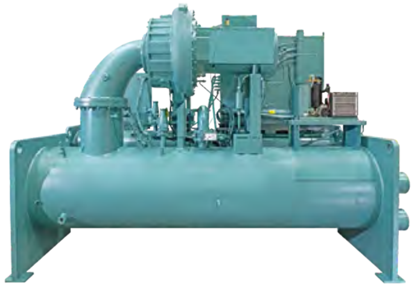




BACKGROUND

Chiller Technologies

- The following chiller technologies were considered:
  - Electric centrifugal:
    - Insufficient electric feeder capacity,
    - Negative 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.



Lifecycle Cost Analysis

Alt. #	* All costs in 2017 dollars		Capital Cost	Annual Cost						30 Yr Lifecycle Cost (5)						
			Capital Cost Subtotal	Est. Annual Operating Hours	Annual Ton Hrs	APLV Eff.	Annual Energy Cost (M)	Annual Maint Cost	Annual Variable Fuel Cost	30 Yr Cum. Op.	30 Yr Var. [illegible]	Req. Supp. Capacity Var. Fuel [illegible]	Total Variable [illegible]	Overhaul + Maint Cost subtotal	30 Yr O&M Subtotal	30 Yr Lifecycle Grand Total (M rates)
	Existing Fleet	Capacity	($)	(hours)	(ton-[illegible]									($)		($ - 2017)
	Trane Horizon (peak)	1000	N/A, Existing Asset	400	400,000	1.2	7.54	26,219	$ 25,281	12000	$ 758,424	[illegible]	[illegible]	802,570	4,756,054	$ 4,756,054
	Trane Horizon (cogen)	1000		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	$ 4,774,070
	Trane Horizon (base)	1000		2400	2,400,000	1.35	7.54	26,219	$ 134,831	72000	$ 4,044,929	$ -	$ 4,044,929	882,570	4,927,499	$ 4,927,499
	Existing Centrifugal (peak)	1400	N/A, Existing Asset	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	$ 5,175,844
	Existing Centrifugal (cogen)	1400		1200	1,20[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	382,261	4,911,583	$ 4,911,583
	Existing Centrifugal (base)	1400		2400	2,40[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	418,261	4,947,583	$ 4,947,583
	New Chiller Install															
1	Vendor #1 2 stage (peak)	1000	Redacted	400	400,000	1.5	7.54	26,219	$ 20,225	12000	$ 606,739	[illegible]	$ 3,801,799	814,570	4,616,369	$ 6,271,369
2	Vendor #1 2 stage (cogen)	1000	Redacted	1200	1,200,000	1.731	7.54	26,219	$ 52,577	36000	$ 1,182,984	$ 1,917,036	$ 3,100,020	870,570	3,970,590	$ 5,625,590
3	Vendor #1 2 stage (base)	1000	Redacted	2400	2,400,000	1.731	7.54	26,219	$ 105,154	72000	$ 2,365,968	$ -	$ 2,365,968	954,570	3,320,538	$ 4,975,538
4	Vendor #2 1 stage (peak)	1000	Redacted	400	400,000	0.678	7.54	18,689	$ 44,745	12000	$ 1,342,344	$ 3,195,060	$ 4,537,404	576,676	5,114,080	$ 6,779,080
5	Vendor #2 2 stage (peak)	1000	Redacted	400	400,000	1.31	7.54	26,219	$ 23,158	12000	$ 694,740	$ 3,195,060	$ 3,889,800	802,570	4,692,370	$ 6,522,370
6	Vendor #2 2 stage (cogen)	1000	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	4,183,595	$ 6,013,595
7	Vendor #2 2 stage (base)	1000	Redacted	2400	2,400,000	1.43	7.54	26,219	$ 127,288	72000	$ 2,863,979	$ -	$ 2,863,979	882,570	3,746,549	$ 5,576,549
8	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	588,676	5,065,580	$ 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

LCA of existing electric chiller (peak)

$ 5,175,844

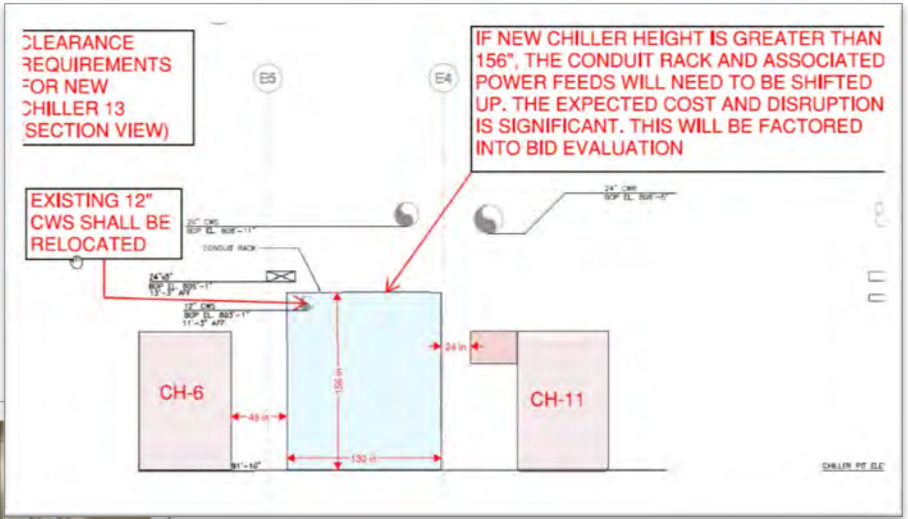
LCA of new absorber (baseload)

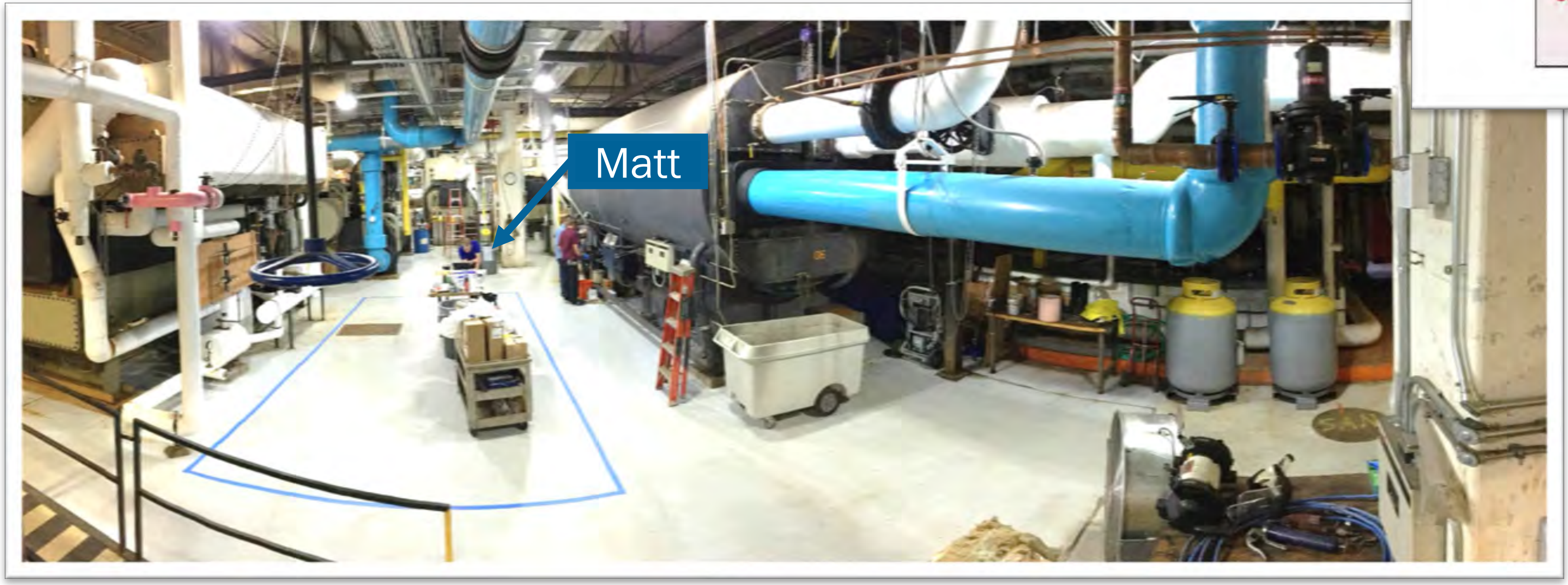
$ 4,975,538

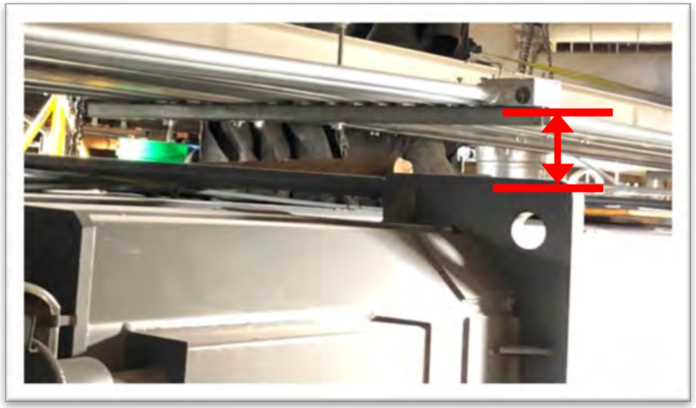
LAYING OUT THE PROJECT

Chiller Procurement

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







LAYING OUT THE PROJECT

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.

Performance Map		Evap. Delta T	Lvg Evap	Steam PPH CND Ent. Temp. (deg F)				COP Tolerance	
Load	Tons	deg F	deg F	85	80	75	70	Upper Limit	Lower Limit
100.0%	1000	18	40					none	ZERO @ 85F
100.0%	1000	12	40					none	AHRI 560
80.0%	800	12	40					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!	####		

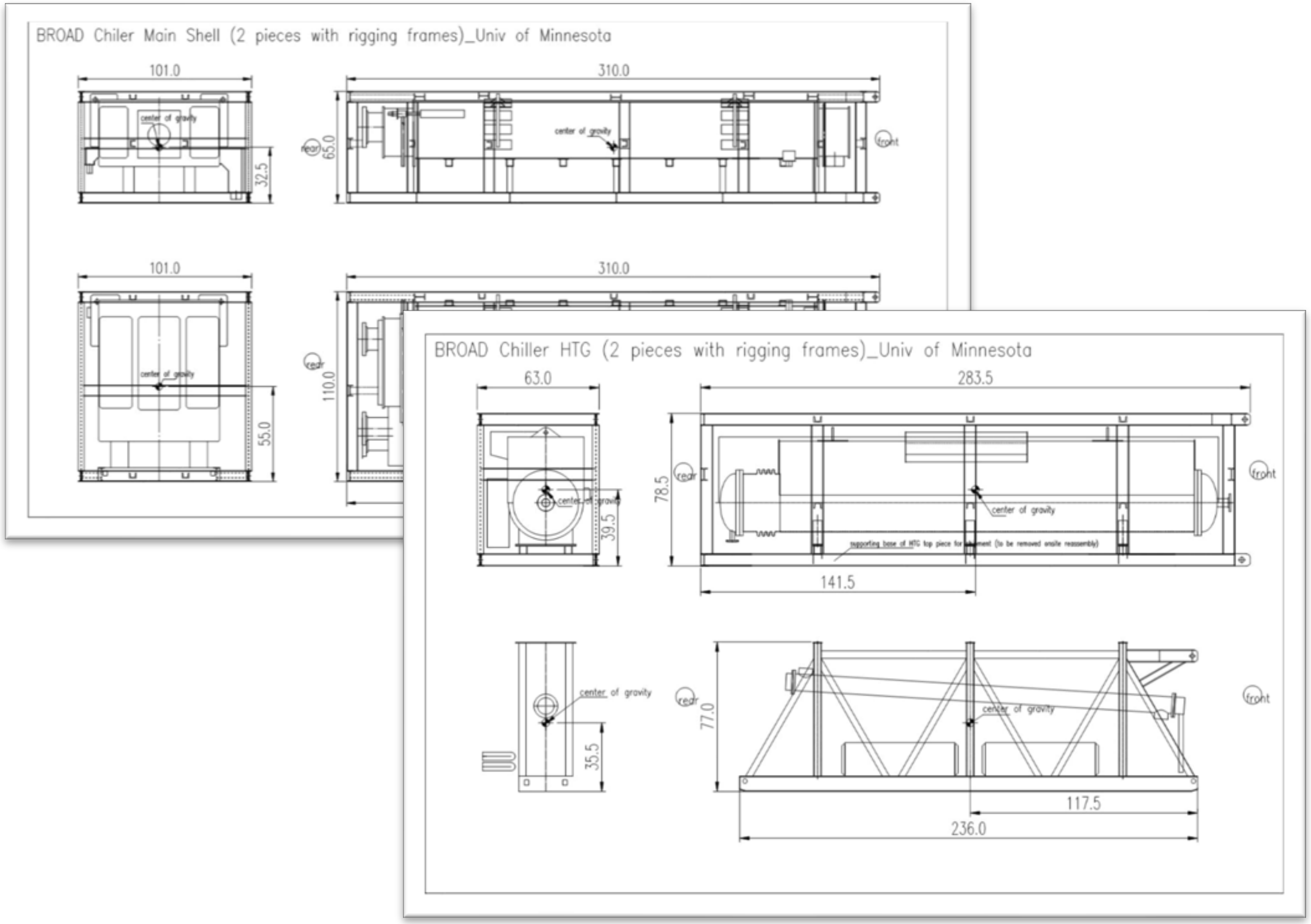
Non-Mandatory Factory Condenser Flow Performance Test

CND Pump Energy		Evap. Delta T	Lvg Evap	CND/ABS Flow (gpm)				CND/ABS dp (ft H20)			
Load	Tons	deg F	deg F	85	80	75	70	85	80	75	70
100.0%	1000	18	40								
100.0%	1000	12	40								
80.0%	800	12	40								
60.0%	600	12	40								
40.0%	400	12	40								
	Average			#DIV/0!	#DIV/0!	#DIV/0!	####	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

LAYING OUT THE PROJECT

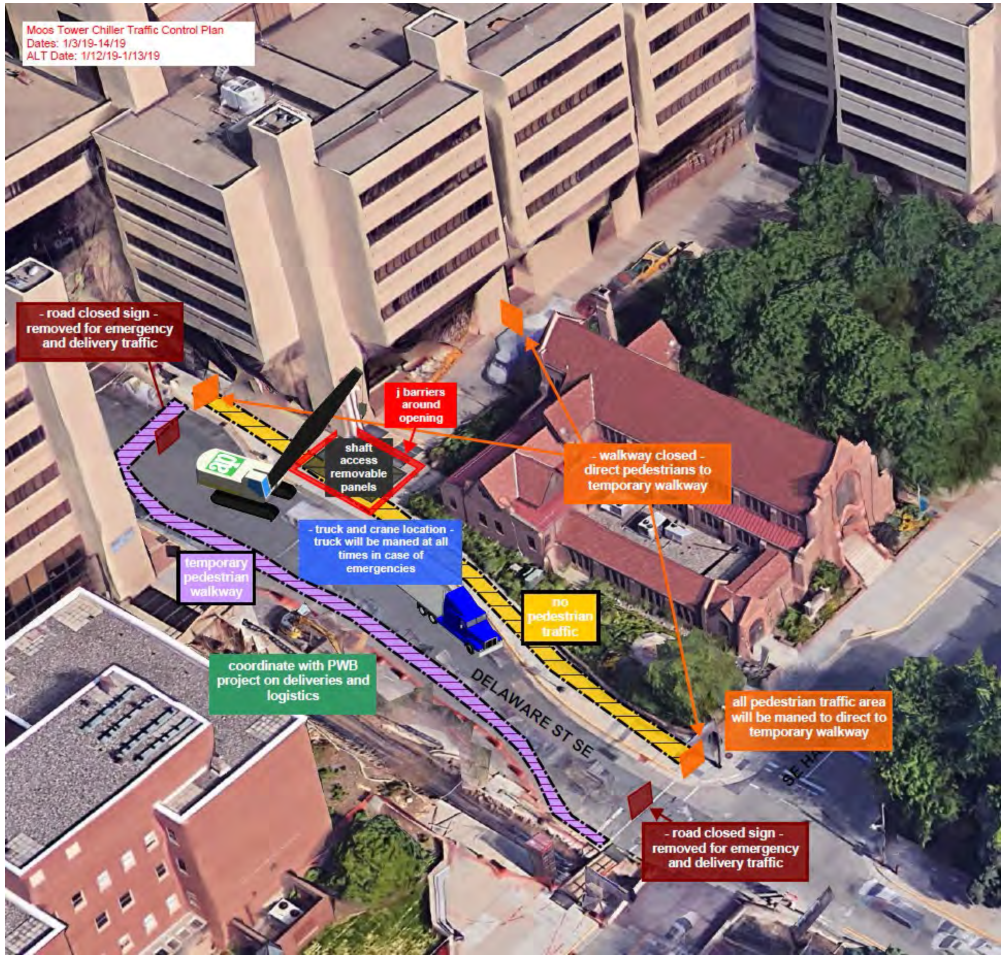
Chiller Selection

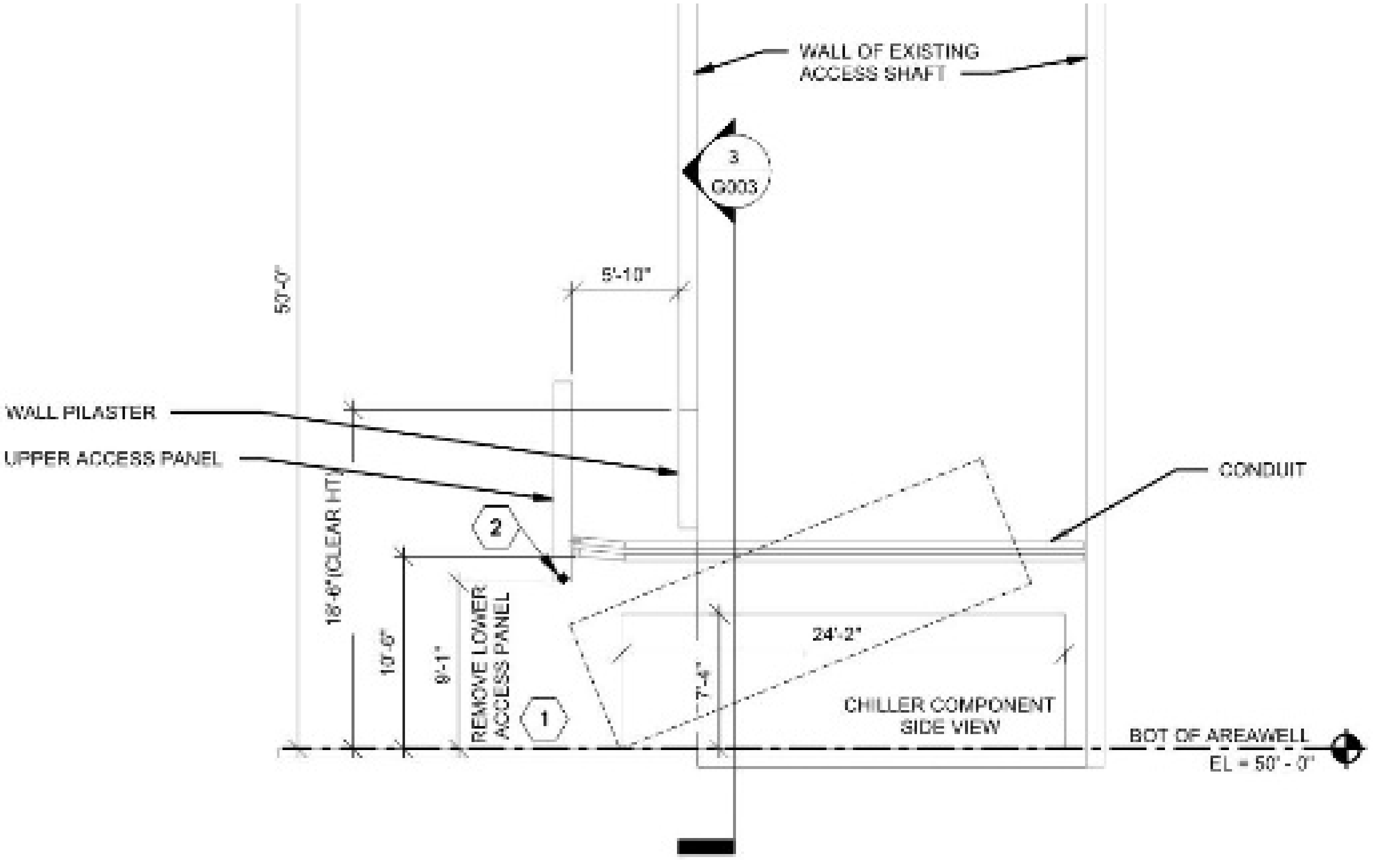
- Broad Model BS400
- Design Conditions:
  - 1,000 tons capacity
  - Evaporator: 40°/58°F
  - Condenser: 85°/97°F
  - Inlet Steam Pressure: 125 psig, saturated
  - Steam Consumption: 8,385 lb/hr
  - COP: 1.4
  - Steam powered condensate pump
- Tube Materials:
  - Evaporator: Copper
  - Condenser: Cupronickel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



LAYING OUT THE PROJECT

Equipment Install – Shaft Access

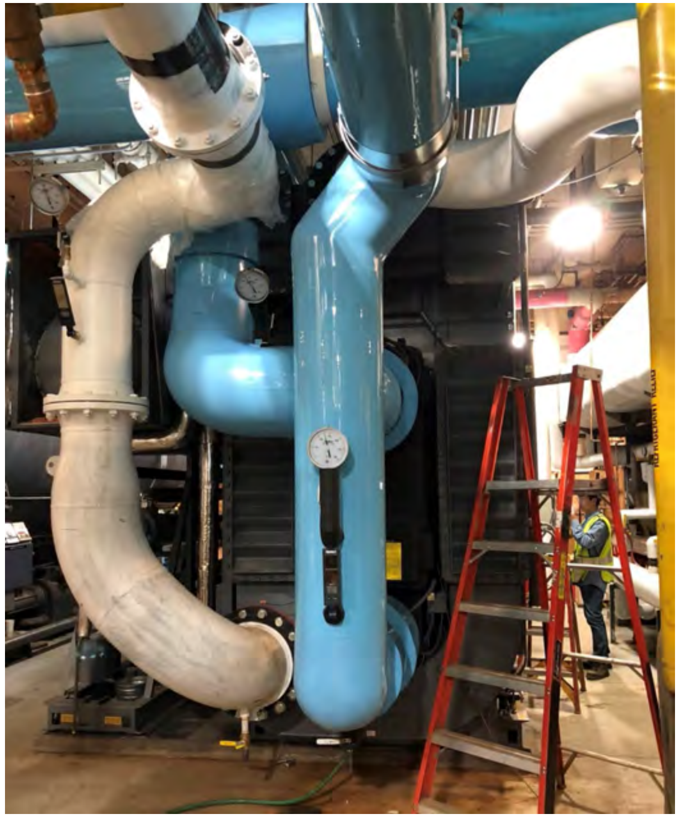




LAYING OUT THE PROJECT

Moos Tower Chiller Layout and Installation

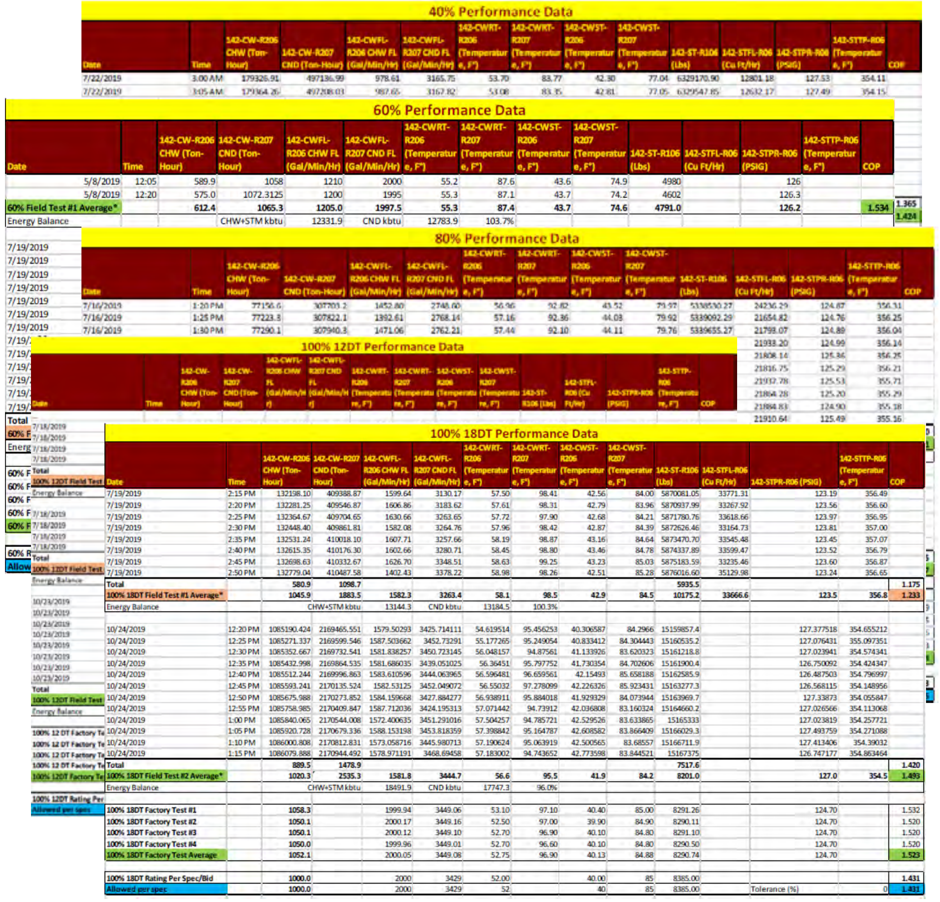
- Laser scan was essential for adequate clearance for piping, tube pull and chiller service
- Existing single stage absorption chiller was shifted 3' to provide additional clearance
- Careful scheduling of outages, then proceeded with assembly



END RESULTS

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



END RESULTS

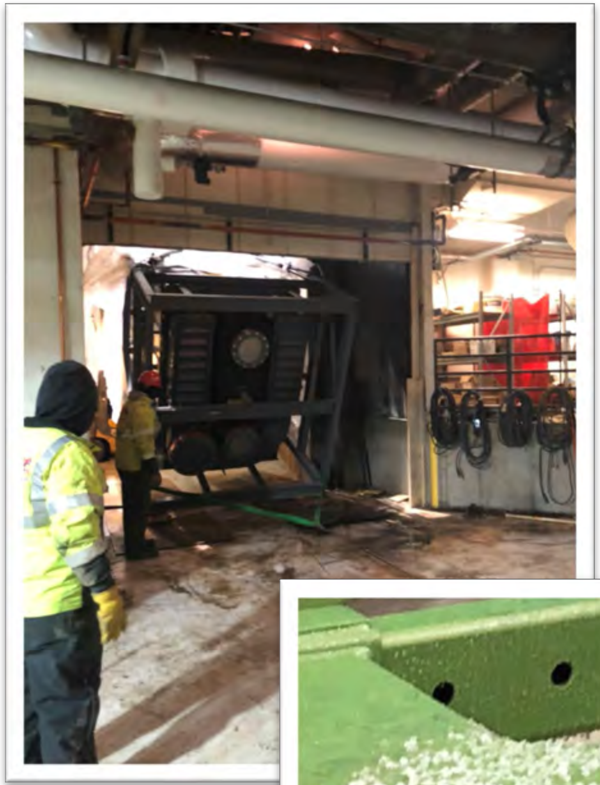
Chiller Operation

- 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

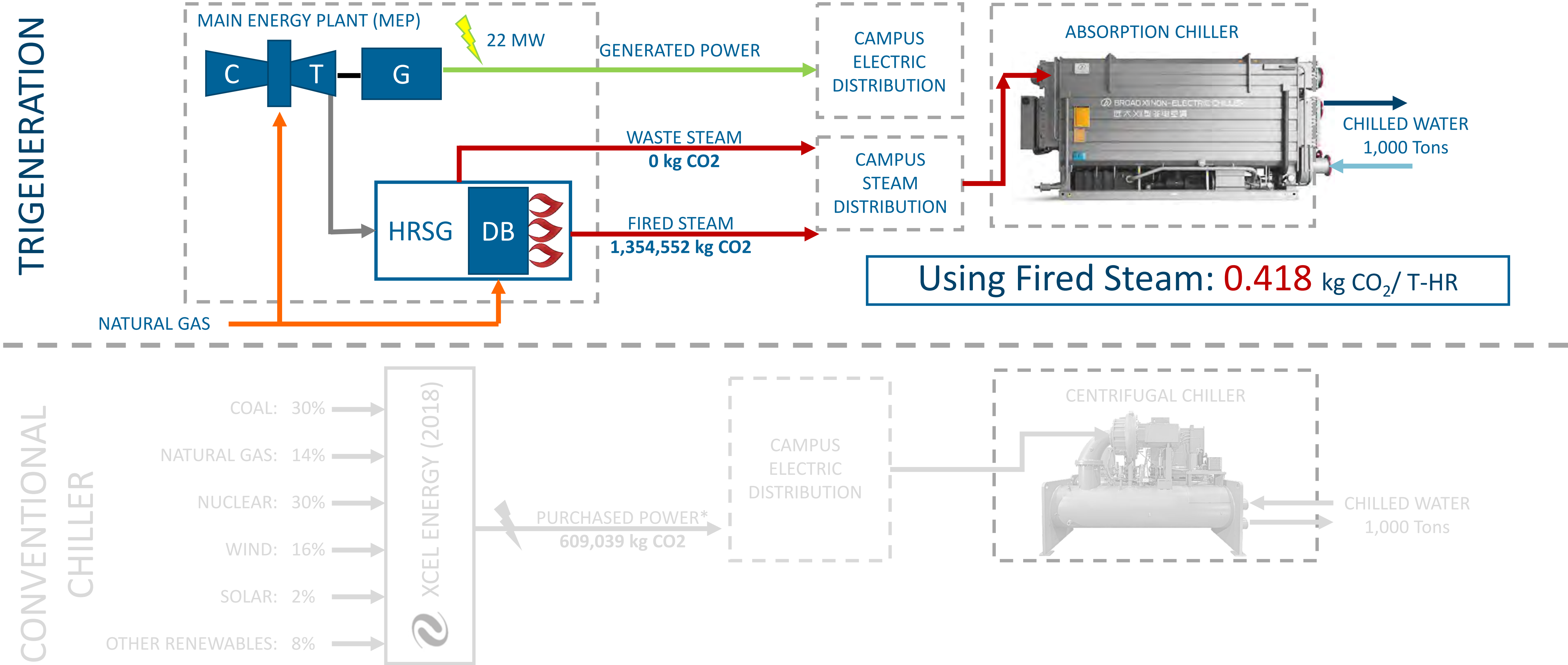
END RESULTS

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 time-saver in such a crowded plant
- Highly recommend detailing out each pipe support location when possible to avoid extra costs from field-routing
- Chiller delivery in -20F windchill is not fun. . .



ANNUAL CHILLER CO_2 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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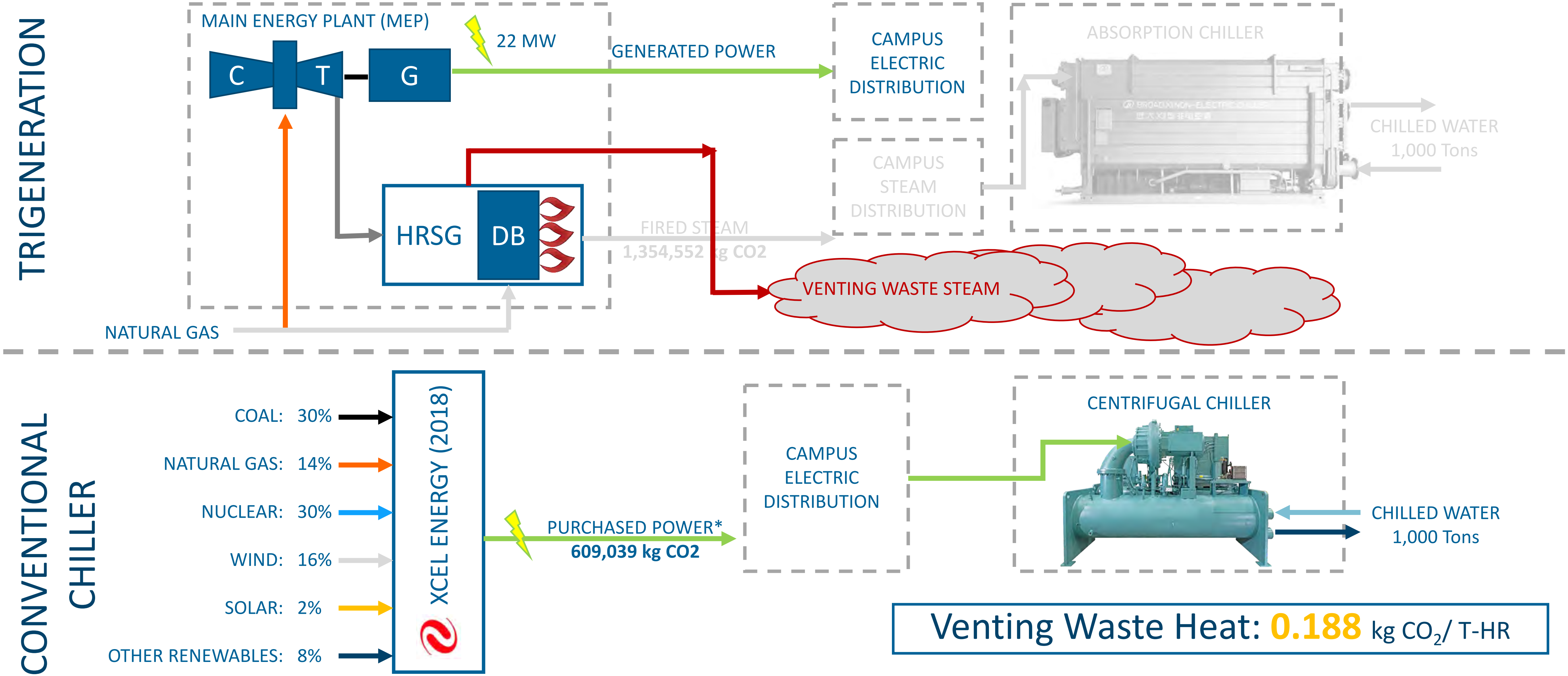

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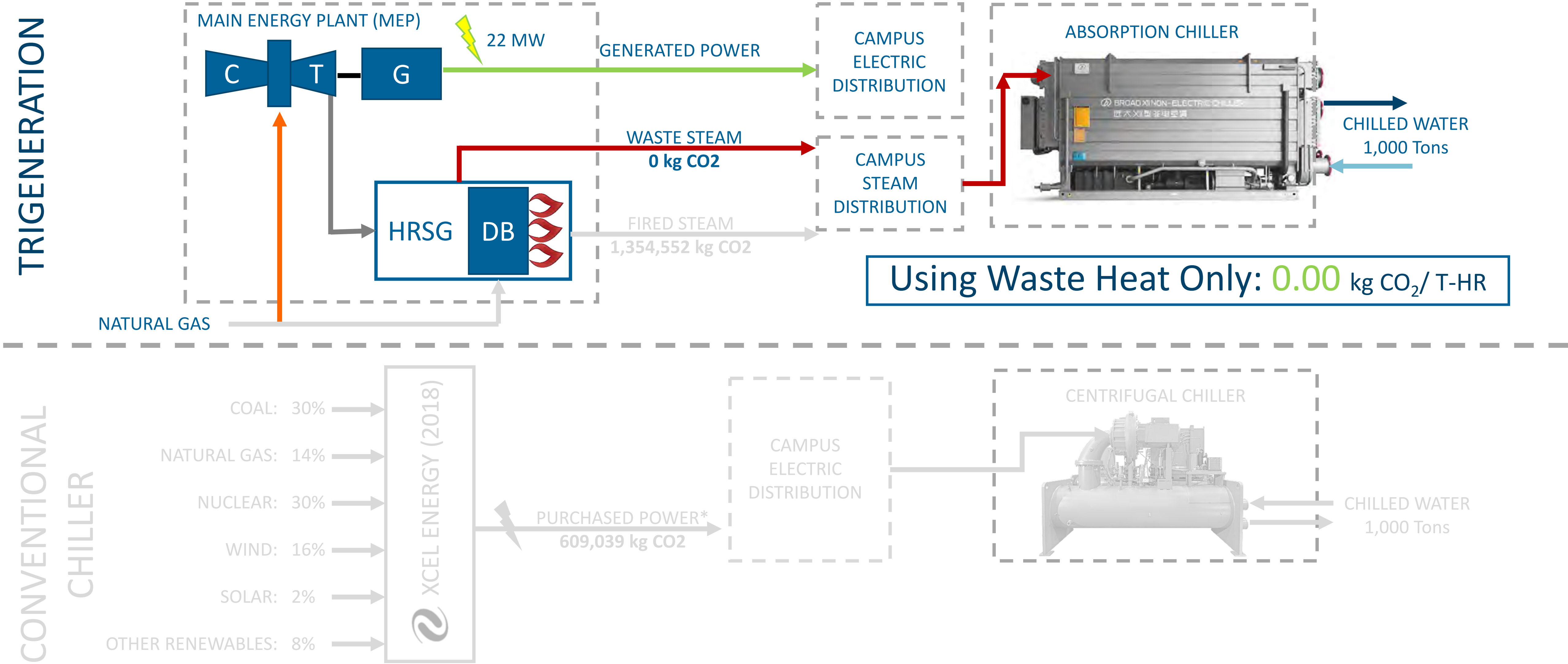

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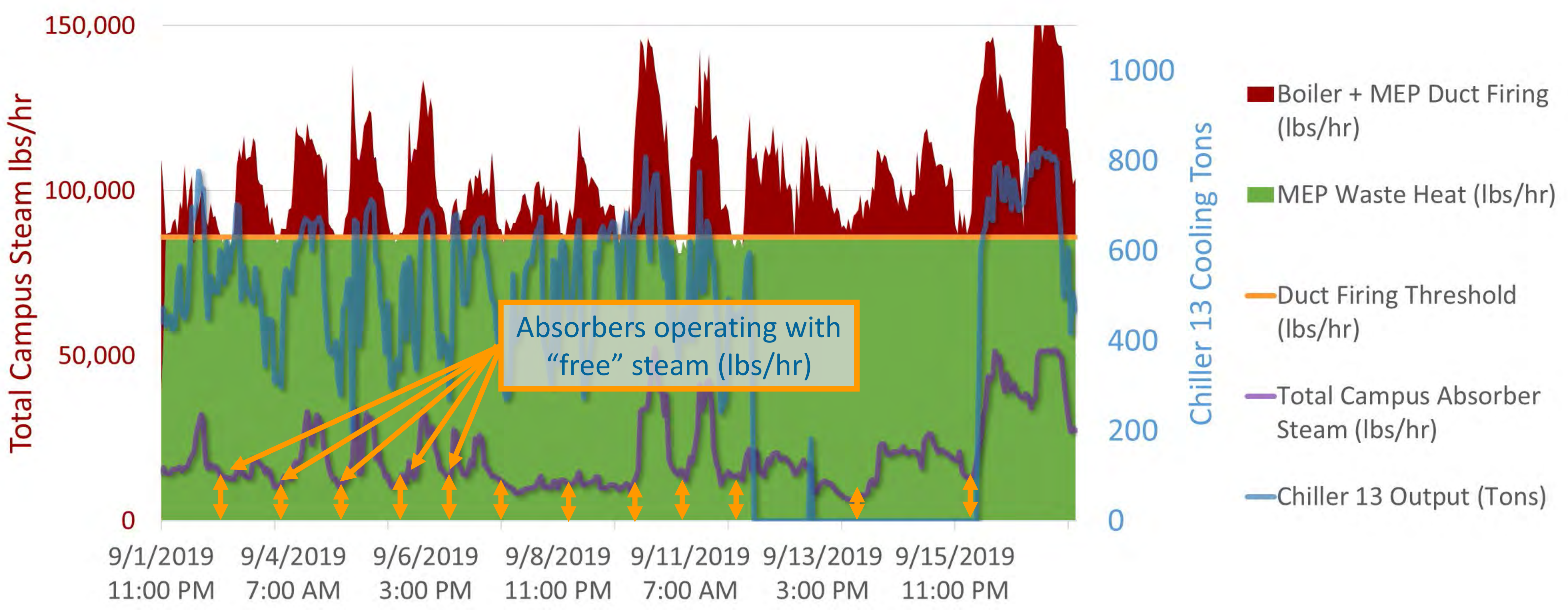
END RESULTS

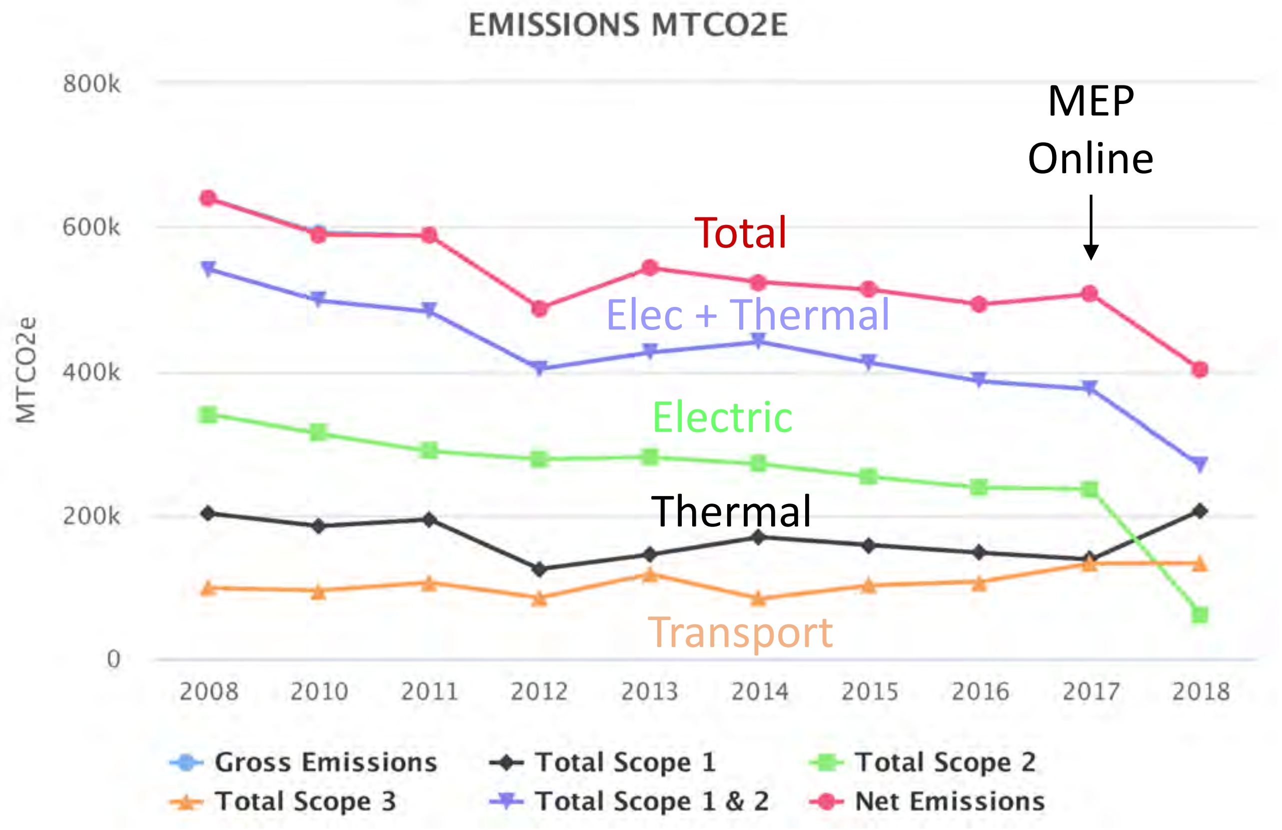
Moos Chiller 13 Operation vs. MEP Operation



END RESULTS

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**



QUESTIONS?

NV5

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