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Central Energy Plant – Green Globes Campus

CEP and Site Energy Initiatives

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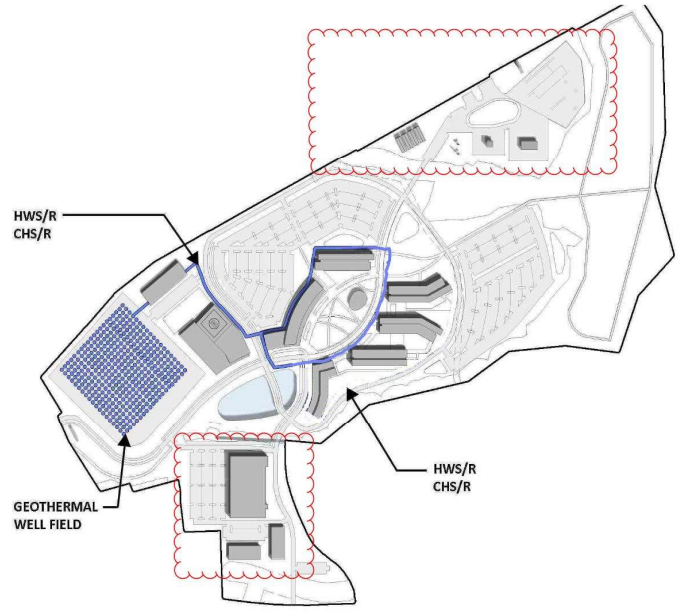
- Hybrid Geothermal Central Energy Plant
  - 105°F HHW supply temperature
  - 44°F CHW supply temperature
  - 1580 Tons (Phase 1, 2, 3)
  - 297 Wells at 500 ft, 650 Tons: Phase 1
  - (1) 500 Ton Heat Pump Centrifugal Chiller & (1)80 Ton Heat Pump Scroll Chiller: Phase 1
  - (1) 500 Ton Heat Pump Centrifugal Chiller/Cooling Tower: Phase 2
  - (1) 500 Ton Heat Pump Centrifugal Chiller/Cooling Tower: Phase 3
- CEP Solar PV System
  - Size: 110kW, 283 Panels
  - Annual Production: 146,898 kWh
  - Net meter with power grid
- Campus Solar PV Site Lighting
  - No wired fixtures
  - No Hybrid fixtures (40+) year payback

Central Energy Plant

- Clouded areas are not connected to CEP. Connected buildings and assumed SF with phasing:

Phase	Building	SF
1	CEP	20,000
	Public safety	70,000
	Technology 4.0	80,000
	General education w/ student services	110,000
2	General classroom	80,000
	General classroom	80,000
3	Academic building 4	80,000
	Academic building 5	80,000
	Total	600,000

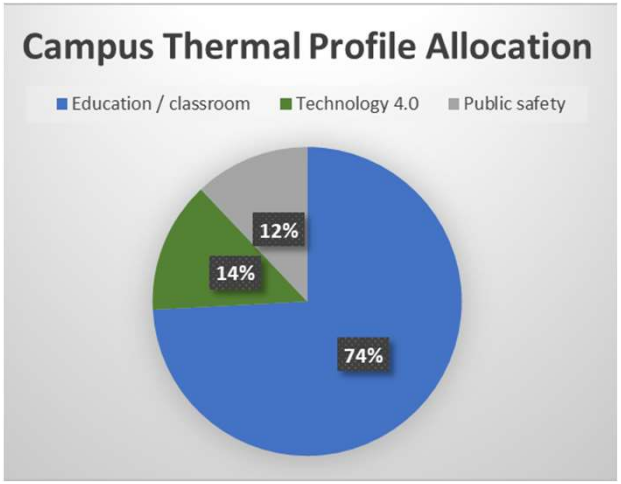


Section 5C.1: Geothermal Utility Diagram

Thermal Models

- Thermal profiles and peak loads for the various phasing

			Annual	Peak	Peak	Campus area	Heating peak	Cooling peak
Phase	**Energy Recovery**		**kBtu**	**kBtu**	**Tons**	**SF**	**Btu/SF**	**SF/ton**
1 + 2 + 3	No	Heating	11,088,387	10,825	902	600,000	18.04	
	Yes	Cooling	22,306,951	13,341	1,112	600,000		539.67
1 + 2	No	Heating	7,763,604	7,747	646	440,000	17.61	
	Yes	Cooling	12,759,857	9,447	787	440,000		558.91
1	No	Heating	4,438,821	4,668	389	280,000	16.67	
	Yes	Cooling	8,468,762	6,153	513	280,000		546.11



- Percentage of thermal profile allocation fore each thermal model

Plant Design Options

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Description:	Traditional gas fired boiler, conventional chiller with cooling tower	Full geothermal (sized for 100% of the heating and cooling loads)	Geothermal with ASHP (sized for 100% of the heating, use ASHP for favorable conditions and maintain a balanced borefield) 130°F HHW supply temperature	Geothermal with ASHP (sized for 100% of the heating, use ASHP for favorable conditions and maintain a balanced borefield) 105°F HHW supply temperature	Geothermal with cooling tower (sized for 100% of the heating, balanced borefield) 130°F HHW supply temperature	Geothermal with cooling tower (sized for 100% of the heating, balanced borefield) 105°F HHW supply temperature	Chilled water thermal energy storage (with option #4A parameters)

Equipment Capacity

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Natural gas fired boilers	(4) 4,000 MBH	(2) 3,000 MBH	(2) 3,000 MBH	(2) 3,000 MBH	(2) 3,000 MBH	(2) 3,000 MBH	(2) 3,000 MBH
Chillers / heat pumps	(4) 500-ton	(4) 500-ton	(3) 500-ton	(3) 500-ton	(4) 500-ton	(4) 500-ton	(4) 500-ton
Closed circuit evaporative cooling tower	(4) 500-ton	-	-	-	(1) 500-ton	(1) 500-ton	(1) 500-ton
Simultaneous heat pump	-	(1) 80-ton	(1) 80-ton	(1) 80-ton	(1) 80-ton	(1) 80-ton	(1) 80-ton
Modular ASHP	-	-	(9) 60-ton	(9) 60-ton	-	-	-
Geothermal borefield (at depth of 400')	-	810	390	390	390	390	390
TES tank	-	-	-	-	-	-	5,000 ton-hr

Electricity, gas, water consumption

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Simulatneous (kWh)	0	229,456	229,456	152,953	229,456	152,953	124,914
ASHP CLG (kWh)	0	0	971,032	971,032	0	0	0
ASHP HTG (kWh)	0	0	0	0	0	0	0
GEO CLG (kWh)	0	982,260	260,830	260,830	224,130	224,130	232,176
GEO HTG (kWh)	0	584,814	584,814	429,467	584,814	429,467	455,580
HYB CLG (kWh)	1,165,472	0	0	0	821,609	821,609	831,112
HYB HTG (therms)	119,230	0	0	0	0	0	0
Water (gallons)	4,345,901	0	0	0	1,286,179	1,286,179	1,299,556

Energy (MMBTU)

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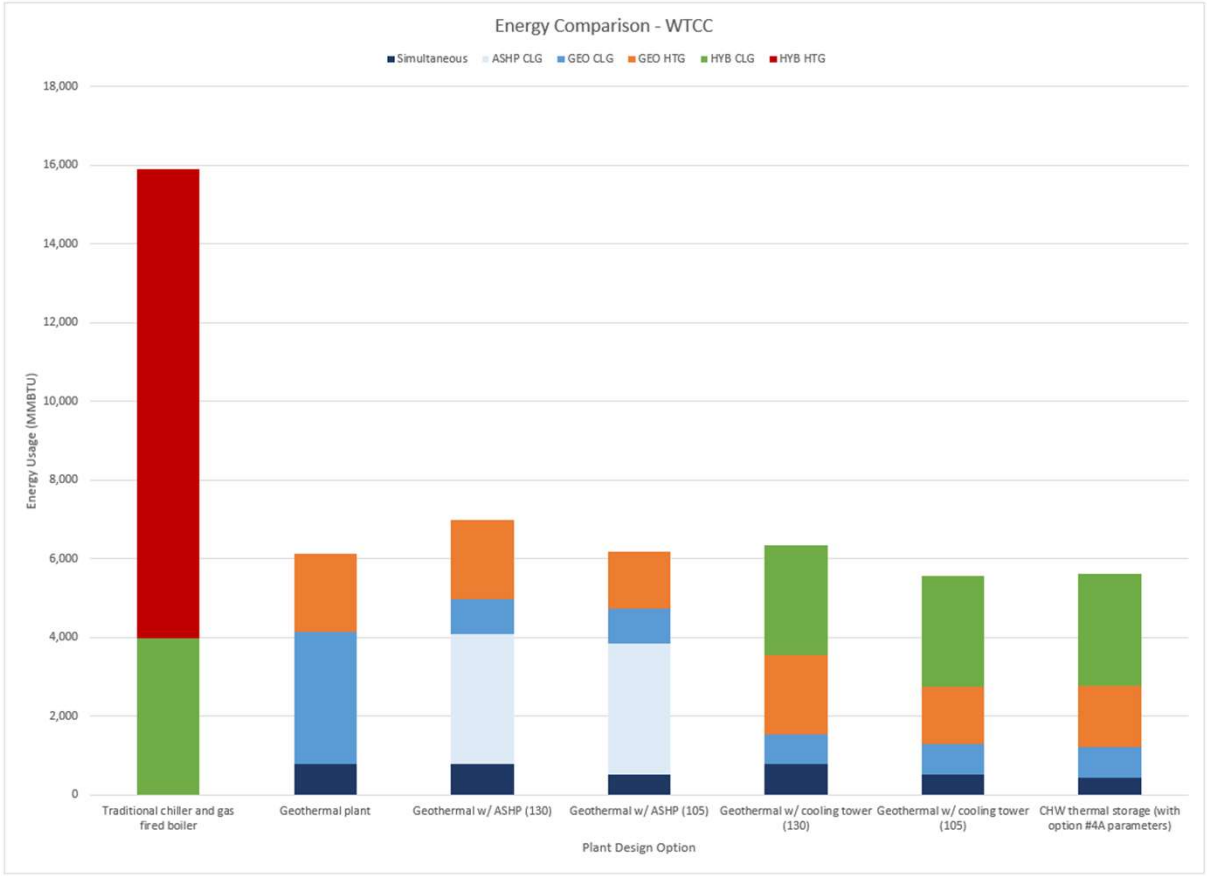
	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Simultaneous	0	783	783	522	783	522	426
ASHP CLG	0	0	3,313	3,313	0	0	0
ASHP HTG	0	0	0	0	0	0	0
GEO CLG	0	3,351	890	890	765	765	792
GEO HTG	0	1,995	1,995	1,465	1,995	1,465	1,554
HYB CLG	3,977	0	0	0	2,803	2,803	2,836
HYB HTG	11,923	0	0	0	0	0	0
Total	**15,900**	**6,130**	**6,981**	**6,190**	**6,346**	**5,555**	**5,609**
Savings over baseline		9,770	8,918	9,709	9,553	10,344	10,291
% savings		61%	56%	61%	60%	65%	65%

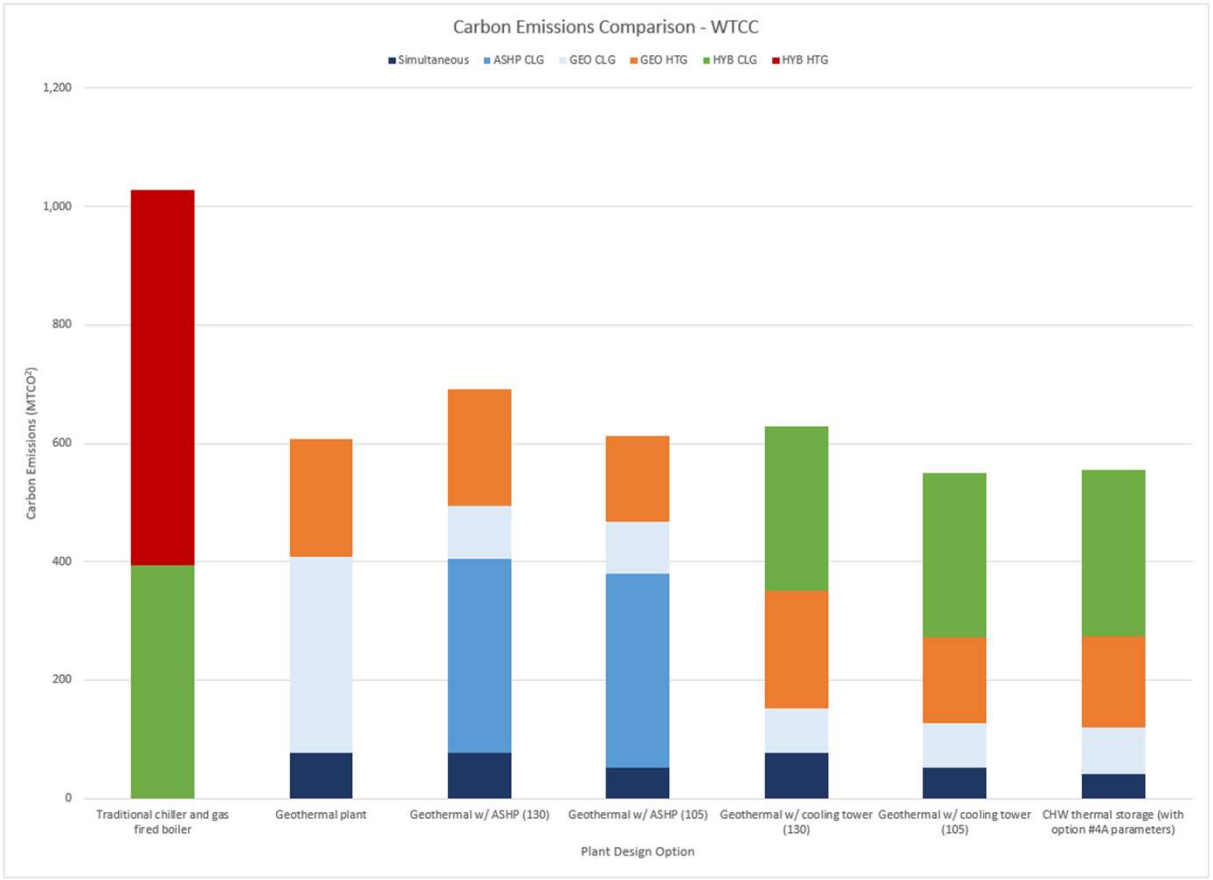
Energy


Energy Comparison - WTCC
Simultaneous
ASHP CLG
GEO CLG
GEO HTG
HYB CLG
HYB HTG
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Energy Usage (MMBTU)
Traditional chiller and gas fired boiler
Geothermal plant
Geothermal w/ ASHP (130)
Geothermal w/ ASHP (105)
Geothermal w/ cooling tower (130)
Geothermal w/ cooling tower (105)
CHW thermal storage (with option #4A parameters)
Plant Design Option

Carbon ($MTCO_2$)

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Simultaneous	0	78	78	52	78	52	42
ASHP CLG	0	0	328	328	0	0	0
ASHP HTG	0	0	0	0	0	0	0
GEO CLG	0	332	88	88	76	76	78
GEO HTG	0	198	198	145	198	145	154
HYB CLG	394	0	0	0	278	278	281
HYB HTG	634	0	0	0	0	0	0
Total	**1,028**	**607**	**691**	**613**	**628**	**550**	**555**
Savings over baseline	0	421	336	415	399	478	472
% savings		41%	33%	40%	39%	46%	46%
Cost of carbon savings ($100/$MTCO_2$)	$0.00	$42,076.65	$33,643.51	$41,476.90	$39,931.94	$47,765.32	$47,237.45

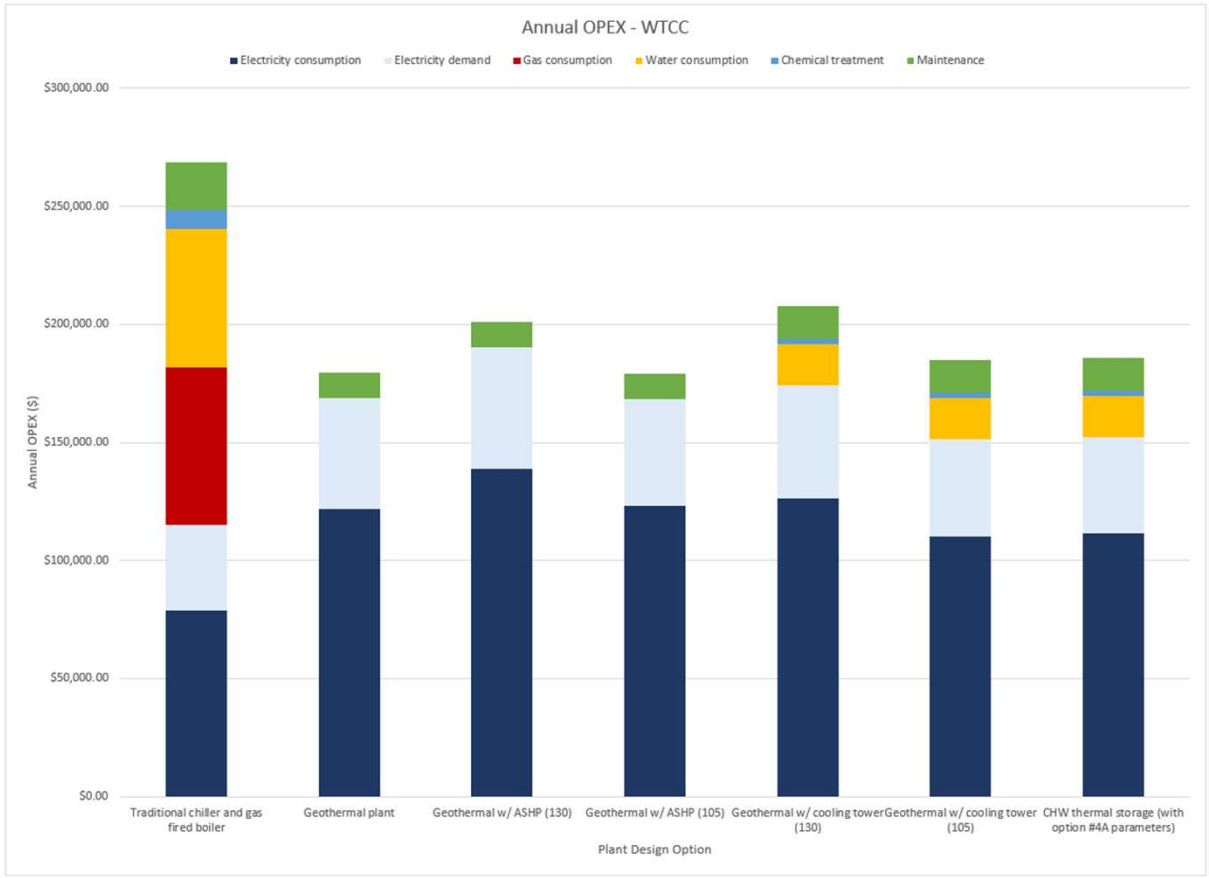
Carbon


Carbon Emissions Comparison - WTCC
Simultaneous
ASHP CLG
GEO CLG
GEO HTG
HYB CLG
HYB HTG
1,200
1,000
800
600
400
200
0
Carbon Emissions (MTCO²)
Traditional chiller and gas fired boiler
Geothermal plant
Geothermal w/ ASHP (130)
Geothermal w/ ASHP (105)
Geothermal w/ cooling tower (130)
Geothermal w/ cooling tower (105)
CHW thermal storage (with option #4A parameters)
Plant Design Option

Operating Cost Expenditure (OPEX) - MGS

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Electricity consumption	$79,007.33	$121,786.79	$138,707.31	$122,990.16	$126,090.01	$110,372.87	$111,432.01
Electricity demand	$36,147.36	$47,206.10	$51,772.47	$45,358.44	$48,135.48	$41,087.14	$40,690.64
Gas consumption	$66,768.78	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Water consumption	$58,582.75	$0.00	$0.00	$0.00	$17,337.69	$17,337.69	$17,518.02
Chemical treatment	$7,773.82	$0.00	$0.00	$0.00	$2,300.68	$2,300.68	$2,324.61
Maintenance	$20,163.35	$10,686.51	$10,686.51	$10,686.51	$13,936.51	$13,936.51	$13,936.51
Total	**$268,443.39**	**$179,679.39**	**$201,166.28**	**$179,035.11**	**$207,800.36**	**$185,034.89**	**$185,901.79**
Savings over baseline	$0.00	$88,763.99	$67,277.11	$89,408.28	$60,643.02	$83,408.50	$82,541.60
Savings over baseline including social cost of carbon	$0.00	$130,840.65	$100,920.62	$130,885.18	$100,574.96	$131,173.82	$129,779.05

OPEX - MGS


Annual OPEX - WTCC
Electricity consumption
Electricity demand
Gas consumption
Water consumption
Chemical treatment
Maintenance
$300,000.00
$250,000.00
$200,000.00
$150,000.00
$100,000.00
$50,000.00
$0.00
Annual OPEX ($)
Traditional chiller and gas fired boiler
Geothermal plant
Geothermal w/ ASHP (130)
Geothermal w/ ASHP (105)
Geothermal w/ cooling tower (130)
Geothermal w/ cooling tower (105)
CHW thermal storage (with option #4A parameters)
Plant Design Option

Initial Investment Costs

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A	Option # 5
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*	*CHW thermal storage (with option #4A parameters)*
Natural gas fired boilers	$1,725,061	$780,455	$780,455	$780,455	$780,455	$780,455	$780,455
Chillers / heat pumps	$2,891,138	$6,875,559	$4,874,026	$4,874,026	$6,875,559	$6,875,559	$6,875,559
Closed circuit evaporative cooling tower	$3,025,107	$0	$0	$0	$748,684	$748,684	$748,684
Modular ASHP	$0	$0	$2,349,870	$2,349,870	$0	$0	$0
Glycol & HX	$0	$0	$197,378	$197,378	$0	$0	$0
Geothermal borefield (at depth of 400')	$0	$5,433,333	$2,600,000	$2,600,000	$2,600,000	$2,600,000	$2,600,000
TES tank	$0	$0	$0	$0	$0	$0	$963,515
Total	**$7,641,306**	**$13,089,347**	**$10,801,729**	**$10,801,729**	**$11,004,698**	**$11,004,698**	**$11,968,213**
Incremental over baseline	$0	$5,448,041	$3,160,423	$3,160,423	$3,363,392	$3,363,392	$4,326,907

Life Cycle Cost Assessment (LCCA)

- LCCA input parameters
- Equipment life expectancy
  - Conventional chillers
    - 25 years
  - Condensing boilers
    - 15 years
    - 25 years (geothermal options in which boilers are only used as emergency backup)
  - Evaporative cooling tower
    - 20 years
  - Water-source heat pumps
    - 25 years
  - ASHP
    - 25 years
  - Geothermal borefield
    - > 50 years

LCCA Input parameters	
General inflation	2.7%
Discount rate	3%
Bond rate	5%
Bond period	20 years
LCCA period	25 years

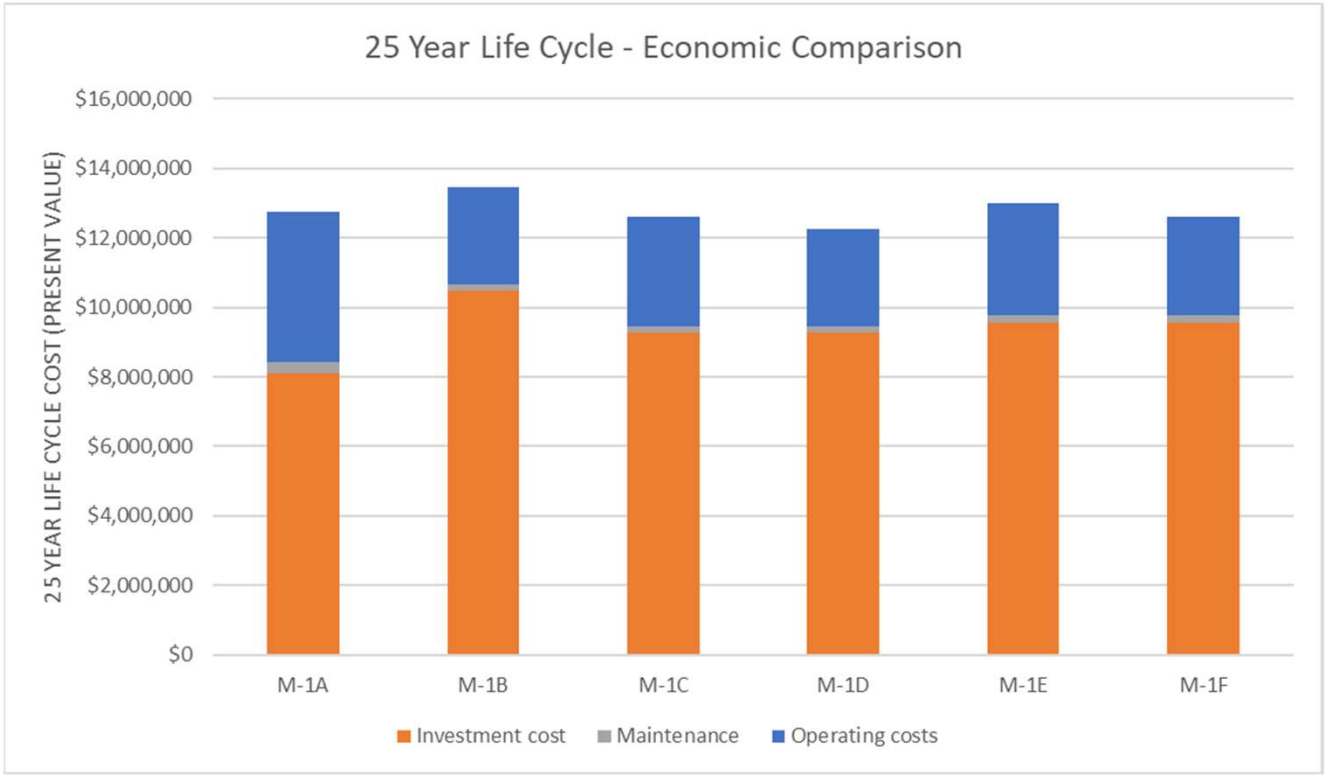
Life Cycle Cost Assessment (LCCA)

- 25-year life cycle economic costs (listed in present value)
- No incentives on geothermal options included yet

	Option # 1	Option # 2	Option # 3	Option # 3A	Option # 4	Option # 4A
	M – 1A	*M – 1B*	*M – 1C*	*M – 1D*	*M – 1E*	*M – 1F*
	Traditional chiller and gas fired boiler	*Geothermal plant*	*Geothermal w/ ASHP (130)*	*Geothermal w/ ASHP (105)*	*Geothermal w/ cooling tower (130)*	*Geothermal w/ cooling tower (105)*
Electric utility cost	$1,899,713	$2,787,878	$3,142,349	$2,777,254	$2,874,207	$2,498,636
Gas utility cost	$1,289,871	$0	$0	$0	$0	$0
Water & chemical treatment	$1,125,106	$0	$0	$0	$332,986	$332,986
Total operating costs	$4,314,690	$2,787,878	$3,142,349	$2,777,254	$3,207,193	$2,831,622
Maintenance	$341,888	$181,202	$181,202	$181,202	$236,307	$236,307
Investment cost	$7,159,637	$12,233,029	$10,120,843	$10,120,843	$10,311,018	$10,311,018
Replacement costs	$2,530,879	$0	$0	$0	$377,086	$377,086
Residual value	-$1,593,725	-$1,745,439	-$840,396	-$840,396	-$1,142,299	-$1,142,299
Net Investment cost*	$8,096,791	$10,487,591	$9,280,446	$9,280,446	$9,545,805	$9,545,805
Total 25-year cost	**$12,753,369**	**$13,456,671**	**$12,603,998**	**$12,238,902**	**$12,989,305**	**$12,613,734**
25-year savings	$0	-$703,302	$149,371	$514,466	-$235,936	$139,634

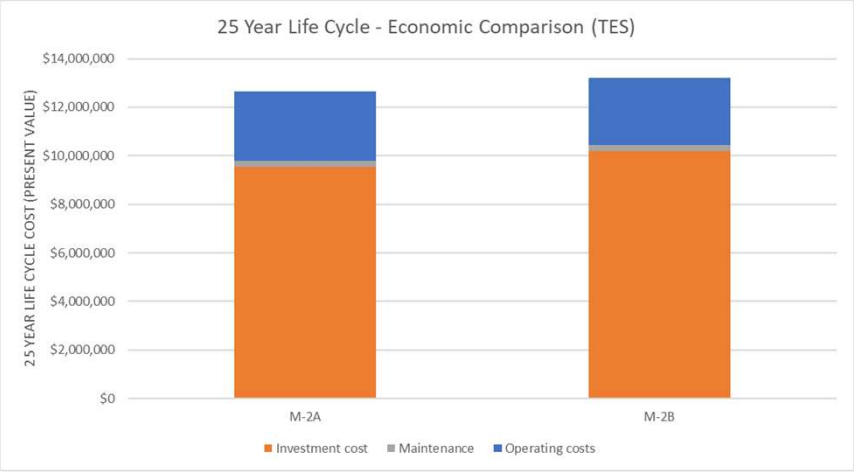
* Net investment cost includes initial investment cost, replacement costs during the 25-year study period, minus the residual value of all assets

Life Cycle Cost Assessment (LCCA)



Life Cycle Cost Assessment (LCCA) - TES

- Thermal energy storage (TES)
- No savings over 25-year period



	Option # 4A	Option # 5
	M – 2A	*M – 2B*
	Geothermal w/ cooling tower (105)	*Geothermal w/ cooling tower (105) – CHW thermal energy storage tank*
Electric utility cost	$2,541,594	$2,416,828
Gas utility cost	$0	$0
Water & chemical treatment	$332,986	$332,986
Total operating costs	$2,874,581	$2,749,814
Maintenance	$236,307	$236,307
Investment cost	$10,311,018	$11,213,798
Replacement costs	$377,086	$377,086
Residual value	-$1,142,299	-$1,379,965
Investment cost*	$9,545,805	$10,210,919
Total 25-year cost	**$12,656,692**	**$13,197,039**
25-year savings (over option #4A)	$0	-$540,347

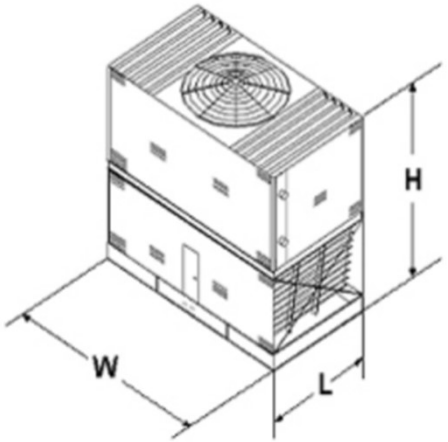
Cooling Tower

Pros:

- Efficiency improvement in low enthalpy conditions
- Reduce outdoor space requirements (compared to air-cooled equipment)
  - 14’ x 26’ x 20’
  - (L x W x H)
- Can pre-cool geothermal borefield in spring season
  - Don’t need to run a compressor to pre-cool ground
- Allows greater flexibility in maintain a healthy balanced ground temperature on the long term
- Better performance during cooling season over ASHP due to lower geo temperatures (not accounted for currently)

Cons:

- Water quality checks necessary to preserve life of equipment
- Water consumption and chemical treatment costs



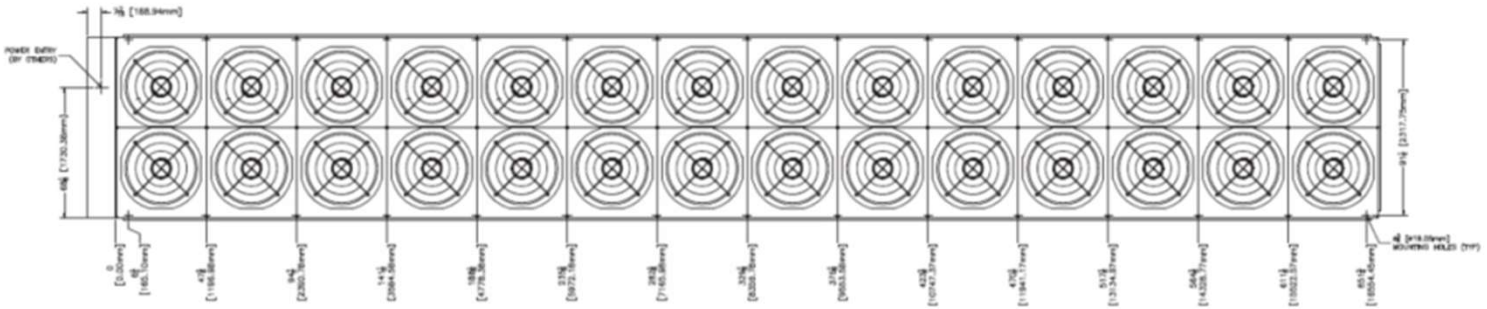
Air-Source Heat Pump (ASHP)

Pros:

- No water or chemical treatment costs
- Lower overall installed cost at plant vs geothermal w/ cooling tower
  - ASHP plant equipment:
    - (3) 500-ton chillers, (1) 80-ton simultaneous, (1) 460-ton ASHP
  - Geothermal w/ cooling tower equipment:
    - (4) 500-ton chillers, (1) 80-ton simultaneous, (1) 500-ton cooling tower
  - Need (1) less 500-ton chiller in ASHP plant option since the ASHP can serve as a redundant chiller when a 500-ton chiller goes offline
- Lower overall operating cost (including water & chemical treatment)

Cons:

- Large footprint required
  - 56’ x 8’ x 8.5’
  - (L x W x H)
- Less efficient at high enthalpy conditions (need to run ASHP during peak hours)
- Higher annual electricity peak demand charges
- Higher annual electricity consumption charges
- Less flexibility in maintaining healthy ground temperature
- Requires plate and frame heat exchanger and glycol loop in ASHP



130°F vs 105°F HHW Supply Temperature

- 130°F vs 105°F HHW supply temperature:
  - ~37% increase in heating efficiency
  - kWh and $MTCO_2$ savings at the plant
  - **$26K** savings at the plant
- Equipment manufacturers:
  - Limited manufacturers for centrifugal heat pumps capable of producing 130°F HHW
  - More competitive bid opportunities for centrifugal heat pumps capable of producing 105°F HHW supply
- Domestic hot water:
  - Need to boost water temperature from 100°F (temp after heat exchanger) to 118°F with electric boost
    - Cost associated with this is less than $6,000 annually for 5,000 gallons of hot total hot water usage for the entire campus

	Simultaneous efficiency (kW/ton)	Heating efficiency (COP)	Heating electricity (kWh)	CO_2 emissions – Total Plant ($MTCO_2$)	Annual OPEX – Total Plant ($)
130°F HHW	1.29	4.30	814,270	628	$ 222,906.80
105°F HHW	0.8599	5.92	582,419	550	$ 196,891.32
Savings	**33%**	**37%**	**231,850**	**79**	**$26,015.48**

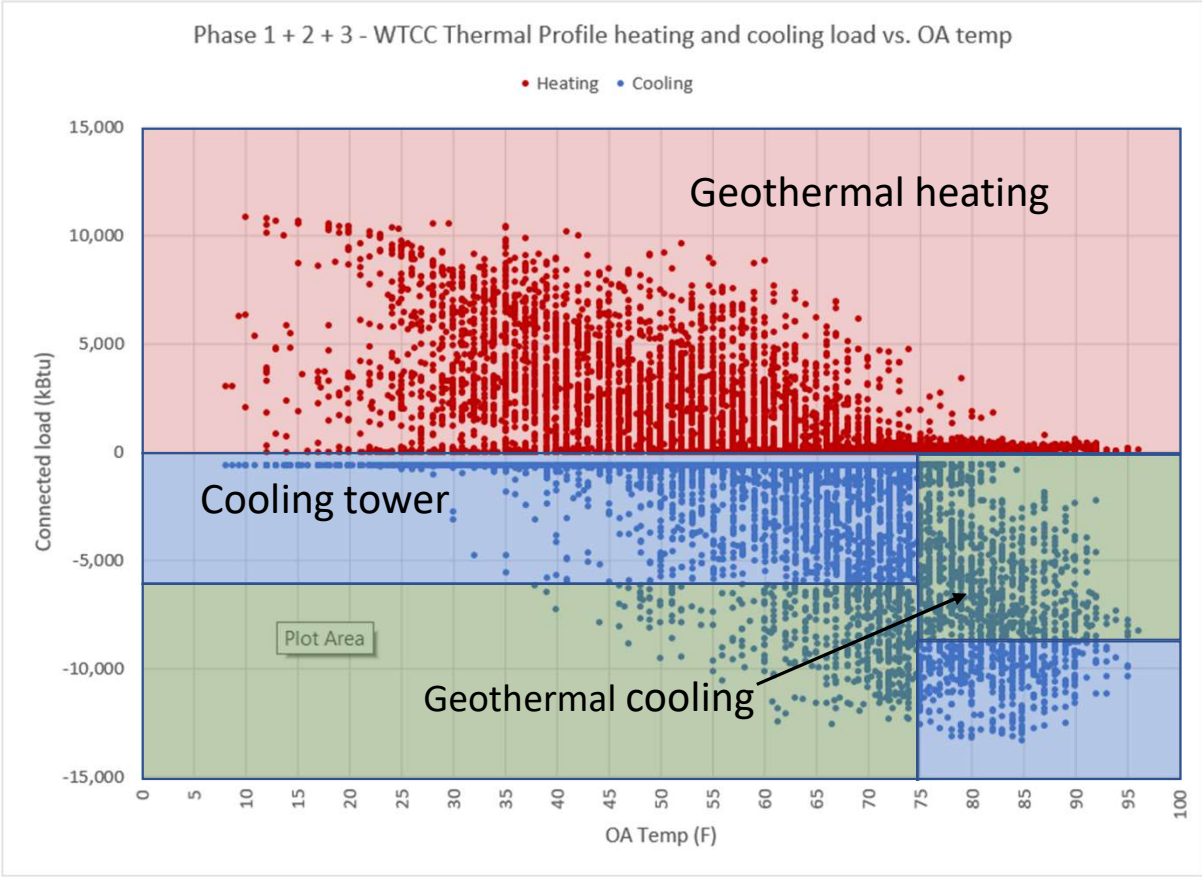
Conclusions / Recommendations

- 105°F HHW supply temperature
  - Benefit in heating efficiency will lead to savings annually for the CEP
  - More competitive bid offers on equipment manufacturers
  - Allows for flexibility at building level to select standard or new coil technologies
  - No difference in leaving air temperature on air handlers or VAV boxes (95F)
- Cooling tower
  - Smaller footprint than ASHP
  - Greater flexibility in maintaining healthy geothermal borefield temperature
    - Can pre-cool geothermal borefield and lead to lower operating temps in the summer → (additional savings)
- No CHW TES tank
  - Not viable financially, 25-years worth of operating costs savings won't pay for the tank
- Geothermal w/ cooling tower (105°F HHWS) is preferred solution
  - Lower 25-year cost to baseline
  - Lowest EUI & greatest carbon emissions savings compared to all plant options
  - Environmental stewardship
    - 11,950 $MTCO_2$ savings over 25-year period compared to traditional plant options

Cooling Tower & Geothermal (Full Buildout Balanced)

- Combination of cooling tower and geothermal cooling and heating
- Utilized cooling tower in cooler ambient conditions for all cooling load that is less than 75°F OA temperature up to 500 tons capacity
- Utilize cooling tower in high OA ambient temperatures over 650 tons to minimize GLHE size
  - Unbalanced heating peak ~650 tons (what GLHE is sized for)
- Balanced GLHE
  - Minimizes GLHE size
  - No temperature creep of GLHE
  - Maximizes GLHE performance

	Annual load	Heat rejected/extracted from borefield
Geothermal cooling	4,937,580	6,418,854
Geothermal heating	8,313,573	6,395,056



Central Energy Plant Phased Buildout

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