PROCEEDINGS, 45th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2020
SGP-TR-216

Feasibility Analysis of Deep Direct-Use Geothermal on the West Virginia University Campus-Morgantown, WV

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Keywords: Deep direct-use, hybrid geothermal system, economic analysis, ASPEN, ChemCAD, West Virginia University.

ABSTRACT

The Morgantown campus of West Virginia University (WVU) is uniquely positioned to host the first geothermal deep direct-use district heating and cooling (GDHC) system in the eastern United States. While most formations of the eastern United States do not have elevated heat flow, Morgantown, WV lies within a unique region with a formation exhibiting sufficient temperatures at a depth expected to support a desirable flow rate of geofluid. Temperature and flow rate were identified to be the two most critical factors in minimizing the cost of geothermal energy in “The Future of Geothermal Energy Report”, by a Massachusetts Institute of Technology (MIT)-led interdisciplinary panel (2006). The WVU campus site offers surface demand coupled with the potential subsurface viability. Specifically, the existing district heating and cooling system that is in use year-round will be leveraged. Absorption chilling systems are used to cool the campus in the summer and hot water circulation to heat the campus in the winter. In this work, the surface plant and economic analysis of the GDHC system is evaluated for two cases: 1) using the existing steam district heating and cooling facilities, and 2) converting the current campus steam infrastructure to a hot water system. In the first case, a hybrid geothermal-natural gas system is considered to provide steam at the required conditions for the entire WVU campus. For the second case, a geothermal system enhanced with a heat pump is used to provide hot water for the entire WVU campus. The surface demand is characterized by year-round steam consumption data. Surface plant performance and capital cost analyses are performed using ASPEN/ChemCAD simulation software and the economic analysis of levelized cost of heat (LCOH) is performed using GEOPHIRES. The feasibility of both cases will be determined by comparing estimated energy costs and benefits with current energy costs of the existing coal-fired system (~$15/MMBTU). The LCOH for the steam hybrid GDHC system for entire campus (i.e., case one) is in the range of $7.9/MMBTU - $12.4/MMBTU, which is below the current heating cost, while the preliminary LCOH estimated for the hot water GDHC system (i.e., case two) is in the range of $15.9/MMBTU-$19.8/MMBTU, which is higher than the current cost. Based on techno-economic analyses completed, the hybrid GDHC is a feasible replacement for the existing coal-fired system.

1. INTRODUCTION

Low-temperature Geothermal Play Fairway Analysis of the Appalachian Basin (GPFA-AB) estimated a region of elevated heat flows in northcentral West Virginia (Cornell University 2017). The Morgantown campus of West Virginia University (WVU) is located within this region, and offers a desirable and unique combination of critical factors necessary to develop a deep direct-use geothermal system in the eastern United States. In terms of achieving deep direct-use geothermal in the eastern U.S., the practical application of our work is compelling in that it fills a critical infrastructure management need for WVU. Steam to the WVU campus is currently provided by an external coal-fired facility, owned and operated by Morgantown Energy Associates (MEA) that is in process of being decommissioned. The WVU Facilities Management Team is actively pursuing options to provide heating and cooling to the campus which spans 245 buildings on 1,892 acres with a population of about 33,000 students, faculty, and staff. Geothermal energy is considered to be a potential option that will significantly advance the efforts of WVU to achieve a reliable and clean energy source for their central district heating and cooling system, as part of the Sustainability Plan managed under the Office of Sustainability and the WVU Energy Institute.

The techno and economic analysis of the geothermal deep direct-use district heating and cooling (GDHC) surface plant is evaluated for two cases: 1) using the existing steam district heating and cooling facilities, and 2) converting the current campus steam infrastructure to a hot water system. In the first case, a hybrid geothermal-natural gas system is considered to provide steam at the required conditions for the entire campus. While for the second case, a geothermal system enhanced with heat pump is used to provide hot water for the entire campus. The surface demand is characterized by year-round steam consumption data for the campus. Surface plant performance and capital cost analysis is performed using ASPEN (Aspentech 2017) and ChemCAD (Chemstations 2016) simulation software and the economic analysis of the levelized cost of heat (LCOH) is calculated using GEOPHIRES [GEOthermal energy for the Production of Heat and electricity (IR) Economically Simulated, with “IR” representing electric current and resistance and referring to the electricity mode], developed at Cornell University (Beckers 2016; Beckers and McCabe 2018, 2019).

2. GEOTHERMAL SITE LOCATION

In coordination with the WVU Real Estate Office, a geothermal site location on campus is selected and Figure 1 provides a more detailed view of the location. This location provides a short-run connection to the WVU Hospitals Complex, a 690-bed academic medical center of roughly 500,000 square feet. This site also has existent high-pressure steam and natural gas lines and connect to a retired steam plant. Right of ways/conduit for historical steam lines connect from this site, and the in-use steam line is in the vicinity. The recreation field in the upper left corner of this site has no major utility lines buried in this space, and overall the site provides good access to a major highway (WV Route 705 – 5-lanes adjacent) and adequate laydown room.

Figure 1: The aerial view of the proposed geothermal well site location on WVU Campus.

3. CHARACTERIZE ENERGY DEMAND

The energy consumption data for the WVU campus is measured to characterize the energy demand. Five main energy distribution points across the campus (Figure 2) are metered:

1. Medical Center: Health Sciences campus and Ruby Memorial Hospital
2. Towers: Residential area
3. Ag. Science: Engineering and Agriculture Science buildings
4. Life Sciences: Life Sciences building
5. Downtown: Buildings in downtown area.

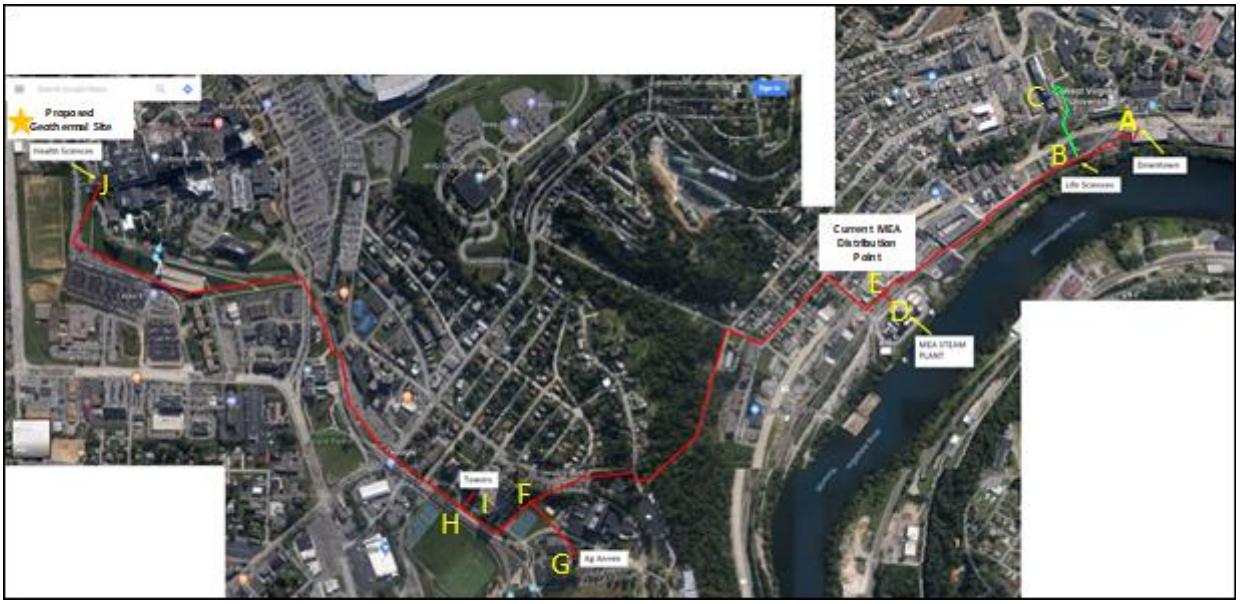


Figure 2: Google map showing the current locations of meter points and the distribution pipeline path. Pipelines in red are owned by Morgantown Energy Associates (MEA) and pipelines in green are owned by WVU. (Not to the scale).

Servers are installed at the five distribution meter points to record steam temperature, pressure, and flow rate, and return condensate temperature and flow rate in 5-minute intervals. The data is downloaded monthly from the servers to a desktop. The data is collected from January 2018 - September 2019. Steam temperature and pressure for the Health Sciences campus and Ruby Memorial Hospital (i.e., Medical Center meter point) during January 2019 is shown in Figure 3. The average steam temperature and pressure are 341°F (171.7°C), and 91.14 PSIG (6.21 atm gauge), respectively. The steam demand fluctuates based on the daily weather. The average steam flow rates for all distribution points for the period of October 2018 - September 2019 is shown in Figure 4 with peak usage observed in the month of January during winter and minimum usage observed in July during summer.

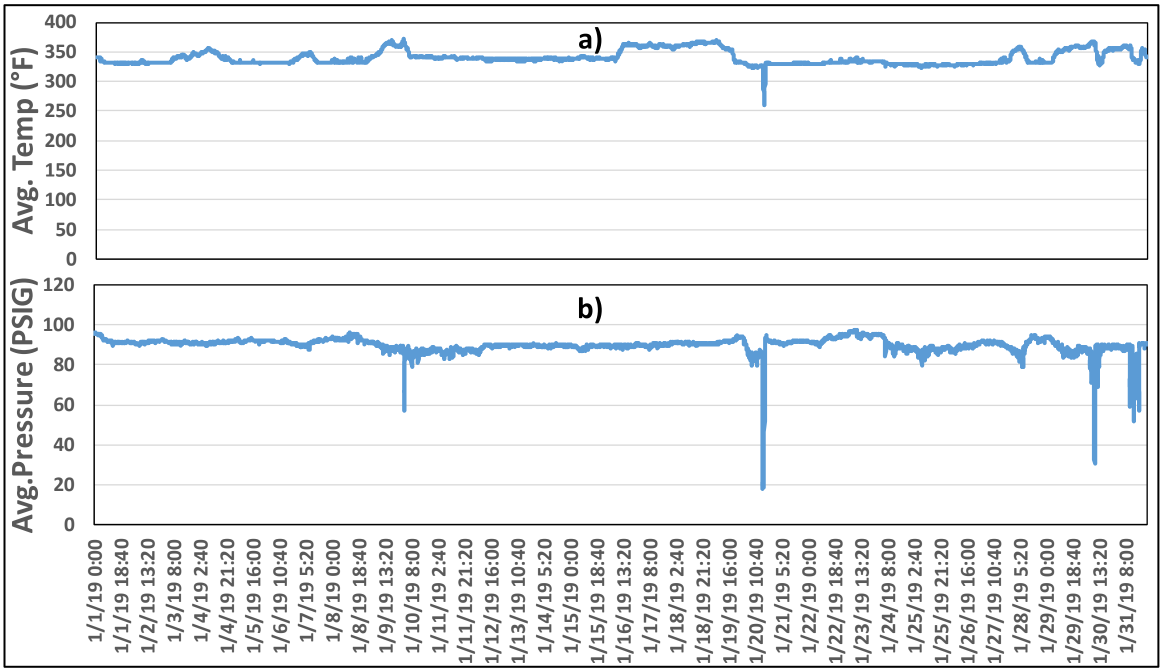


Figure 3: Steam temperature (a) and pressure (b) for Health Sciences campus and Ruby Memorial Hospital (i.e., Medical Center meter point) during January 2019.

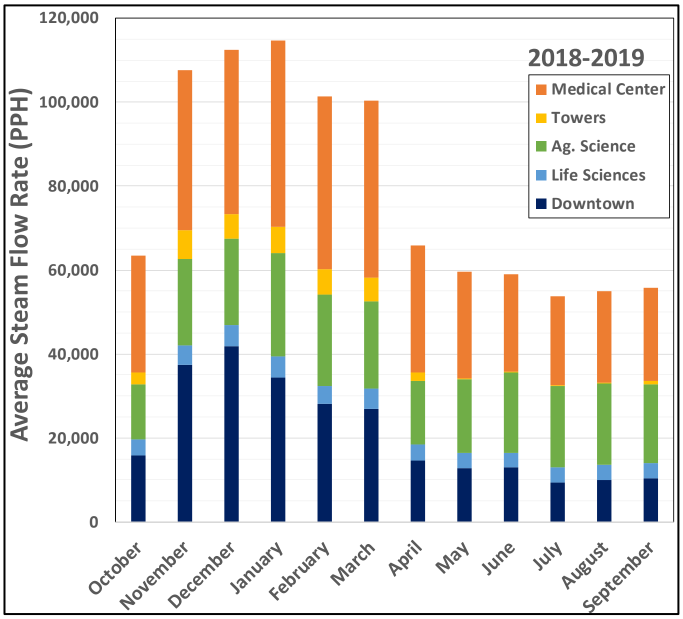
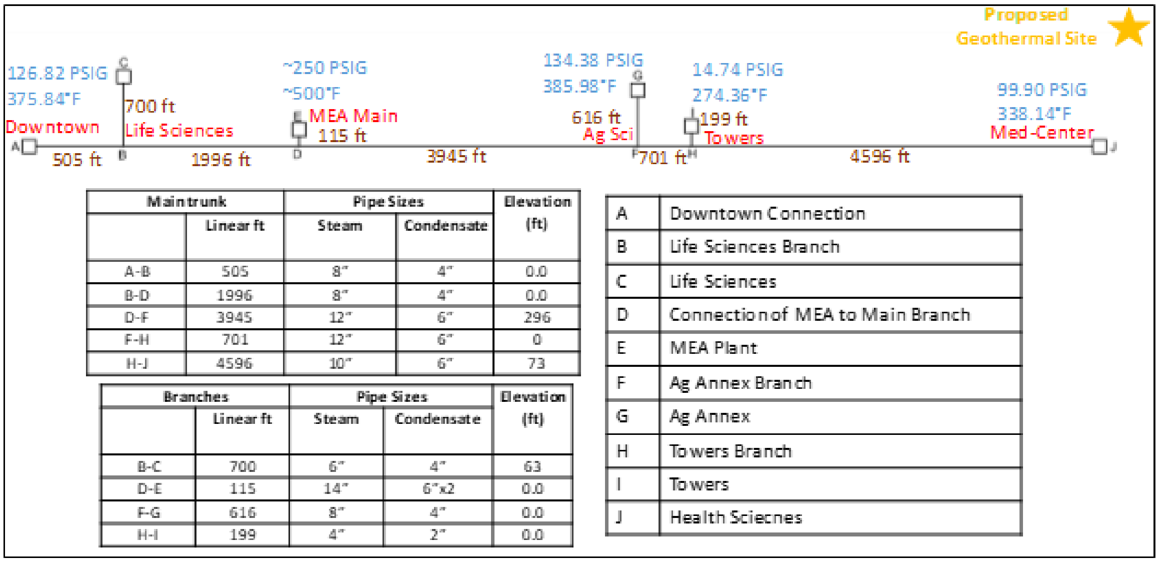


Figure 4: The average steam flow rate in pounds per hour (PPH) for 2018-2019.

4. STEAM-BASED HYBRID GEOTHERMAL DISTRICT HEATING AND COOLING SYSTEM

The current district heating and cooling distribution system (Figure 2) will be used because it doesn't require any changes. In order to supply the required steam, a centralized hybrid GDHC system is proposed with natural gas fired boilers as a secondary heat source, integrated with the geothermal system.

A one-line sketch of the piping information includes pipe sizes and lengths from the MEA facility to individual distribution point is shown in Figure 5. The pipeline elevations between the distribution points are estimated using Google Maps. The water loss between steam and condensate return is assumed to be 10%, based on WVU's current agreement with MEA.



Maintrunk		Pipe Sizes		Elevation (ft)
	Linear ft	Steam	Condensate	
A-B	505	8"	4"	0.0
B-D	1996	8"	4"	0.0
D-F	3945	12"	6"	296
F-H	701	12"	6"	0
H-J	4596	10"	6"	73

Branches		Pipe Sizes		Elevation (ft)
	Linear ft	Steam	Condensate	
B-C	700	6"	4"	63
D-E	115	14"	6"x2	0.0
F-G	616	8"	4"	0.0
H-I	199	4"	2"	0.0

A	Downtown Connection
B	Life Sciences Branch
C	Life Sciences
D	Connection of MEA to Main Branch
E	MEA Plant
F	Ag Annex Branch
G	Ag Annex
H	Towers Branch
I	Towers
J	Health Sciecnes

Figure 5: One-line drawing of MEA's pipelines with distribution meter points along with linear pipe distances, elevations, and pipe sizes.

Currently, the return condensate flows freely due to gravity from the individual meter points to the MEA facility based on current distribution lines (as shown in Figure 2). However, with a required change in the central plant location to the proposed geothermal site, pumps will be required at meter points D and H to assist return condensate flow to the central plant location. We considered two scenarios based on the new proposed geothermal site located on Health Science campus:

1. Scenario 1: Supply steam at 18.25 bar (250 psig) and 260°C (500°F) to entire WVU campus (all five-distribution meter points) and the flow rate is considered to be 15.2 kg/s (120,000 PPH) based on peak usage in January.
2. Scenario 2: Supply saturated steam at 12.5 bar (166 psig) to the Ag. Science, Towers Medical center meter points at a flow rate of 10.1 kg/s (80,000 PPH). While steam for the Downtown and Life Science meter points will be provided by natural gas boilers and is not considered in the analysis.

4.1 Surface Plant Modeling

The central surface plant facility designed to produce steam at required conditions and distributed to the individual distribution points using existing pipelines is shown in Figure 6. The surface plant components consist of a geothermal heat exchanger, heat pump, natural gas boiler, condensate receiver tank, pumps, and distribution pipeline units. The hot geothermal fluid (Geo-In) at a fixed temperature and flow rate from the production well is first sent to the centralized geothermal plate heat exchanger (PHE) where heat from the geothermal fluid is transferred to the condensate entering the heat exchanger (Cold-In) and the spent geothermal fluid (Geo-Out) is reinjected back into the reservoir. The PHE in Figure 6 isolates the geothermal fluid from the surface equipment and distribution system to prevent scaling and corrosion. In order to improve the utilization of heat, a heat pump is used to extract heat from the low temperature return condensate and is used to heat the geothermally preheated hot water before sending to the boiler, thereby enhancing the utilization of heat and improving the geothermal heat extraction. The standard components of a heat pump system include a condenser, compressor, evaporator, and an expansion valve. The heat is extracted from the low temperature heat source in the evaporator where refrigerant is evaporated, and the refrigerant condenses and rejects heat to produce high temperature water with a compressor efficiency is 75%. Ammonia (NH_3) is considered as a refrigerant and based on the temperature of the return condensate, commercial NH_3 water source heat pumps can produce hot water at a maximum temperature of 90°C. Therefore, geothermally preheated water is heated to 90°C before sending it to natural gas fired boiler, where it is further heated to produce steam at the required conditions. The natural gas (95% methane, 2.5% ethane, 2.5% propane (Nasir et al. 2014)) at 65°C and 10% excess air at 25°C is supplied to the boiler at a fixed efficiency of 85%.

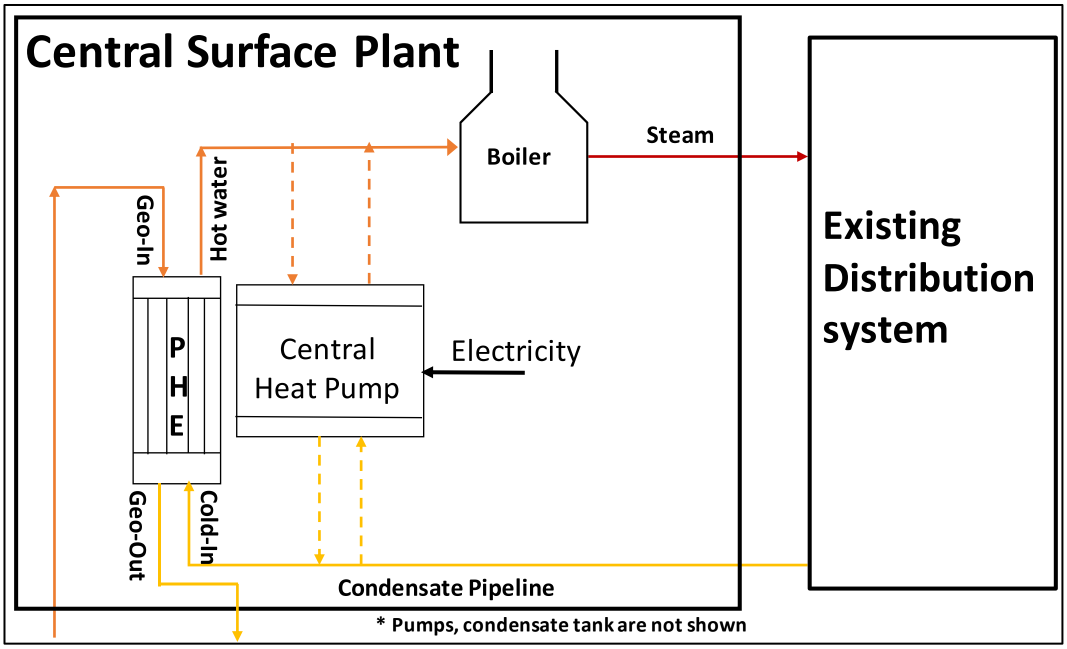


Figure 6: Schematic of the hybrid geothermal-natural gas system with heat pump to provide steam at required conditions for WVU campus.

The steam produced is distributed to the entire WVU campus through the five main distribution points using the existing piping network. The condensate from the buildings is returned to the main five distribution points and is finally recycled to the central plant through condensate pipelines. New pipelines are added to connect the central plant to the existing distribution lines.

1. New steam pipeline: transports steam from the boiler outlet to the main MEA pipeline that connects to existing distribution pipeline at the Medical Center meter point.
2. Two new condensate pipelines: from point J to the central geothermal plant, one transports all the condensate return from the Downtown, Life Sciences, Ag. Sciences, and Towers meter points while the other transports condensate return from the Medical Center meter point.

A hot water pump is used to raise the pressure of hot water to that of the steam produced. Return condensate is returned to the central plant by using pumps at distribution points D and H, to overcome pressure losses due to elevations and pipeline losses. The efficiency for all pumps is assumed to be 80%. The model along with the distribution pipelines and pumps is simulated using ASPEN HYSYS tool (Aspentech 2017).

4.1.1 Results

The heat duty from the PHE, the heat pump and the boiler are given in Table 1, the geothermal contribution to the proposed hybrid GDHC system was calculated using Equation [1]. The pumping power required for hot water and condensate pumps along with the pressure head is tabulated in Table 2.

$$\%\,Geo = \frac{Q_{Geo}}{Q_{Geo} + Q_{Boiler} + Q_{HeatPump}} \qquad [1]$$

Table 1: The thermal contribution through different units to production of steam at required conditions for Hybrid GDHC system with heat pump.

Unit	Scenario 1	Scenario 2
PHE (Q_{Geo})	1.73 MWth	1.09 MWth
Boiler(Q_{Boiler})	39.33 MWth	23.61 MWth
Heat Pump ($Q_{HeatPump}$)	0.99 MWth	0.67 MWth
Total (Q_{Geo}+Q_{boiler}+$Q_{HeatPump}$)	42.05 MWth	25.37 MWth
%Geo	4.11 %	4.30 %

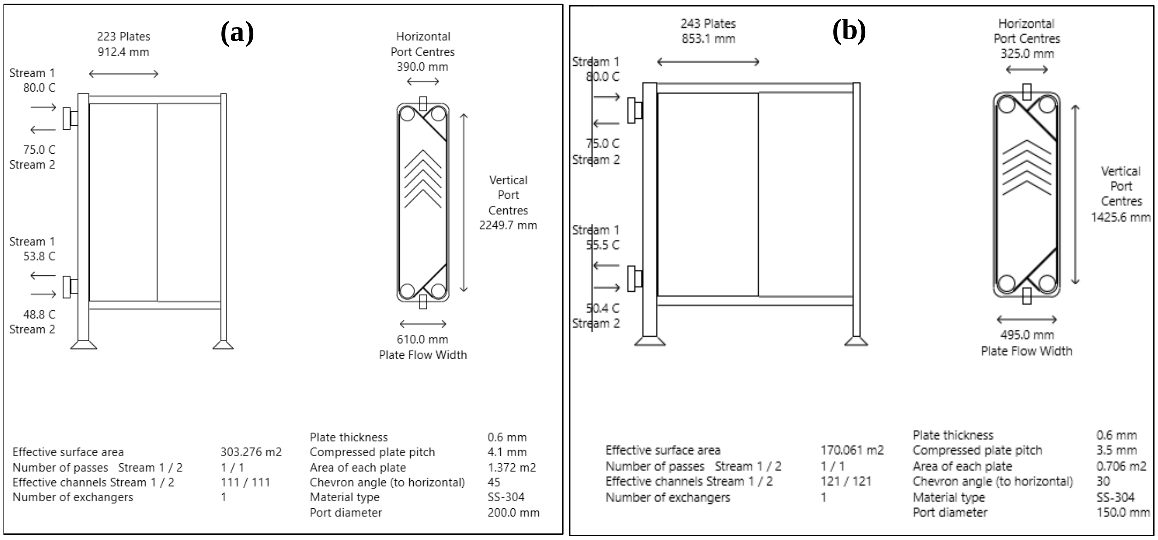
Table 2: The pumping capacity of hot water pump at the central facility and return condensate pumps at distribution points D and H for Hybrid GDHC system with heat pump.

Pump Type	Scenario 1			Scenario 2		
	Mass Flow (kg/s)	Pressure Head (ft)	Power (kW)	Mass Flow (kg/s)	Pressure Head (ft)	Power (kW)
Hot Water Pump	15.20	603.50	34.28	10.10	402.3	15.33
D	4.13	298.40	4.61	-	-	-
H	7.98	83.65	2.50	3.70	75.11	1.038

To carry out a rigorous design of the PHE, make necessary adjustments for fouling, and allowable pressure drop requirements, the process data from HYSYS is exported to Aspen Exchanger Design and Rating (EDR) (Aspentech 2017) where a detailed design is performed to determine the PHE area, plate configuration, and number of plates. Fouling resistance of 0.0007 ft^2-h-°F/BTU (Hernandez-Galan and Plauchu 1989) is used for geothermal fluid to account for geothermal fouling in the heat exchanger while for the condensate fluid a fouling resistance of 0.0001 ft^2-h-°F/BTU (Rafferty and Culver 1998) is used. The PHE geometry obtained for both scenarios along with inlet and outlet temperatures for the geothermal fluid and condensate water is shown in Figure 7 and the parameters are detailed in Table 3.

Table 3: Design of PHE in Hybrid GDHC system with heat pump.

Parameter	Parameter Value	
	Scenario 1	Scenario 2
Heat Duty (kW)	1,726.00	1,086.00
PHE Area (m^2)	303.30	170.10
Number of Plates	223.00	121.00
Plate Length (mm)	2,469.45	1,595.55
Plate Width (mm)	610.00	495.00
Overall Heat Transfer Coefficient U (W/m^2-K)	1,103.00	1,470.20



(a)

Effective surface area	303.276 m2	Plate thickness	0.6 mm
Number of passes Stream 1 / 2	1 / 1	Compressed plate pitch	4.1 mm
Effective channels Stream 1 / 2	111 / 111	Area of each plate	1.372 m2
Number of exchangers	1	Chevron angle (to horizontal)	45
		Material type	SS-304
		Port diameter	200.0 mm

(b)

Effective surface area	170.061 m2	Plate thickness	0.6 mm
Number of passes Stream 1 / 2	1 / 1	Compressed plate pitch	3.5 mm
Effective channels Stream 1 / 2	121 / 121	Area of each plate	0.706 m2
Number of exchangers	1	Chevron angle (to horizontal)	30
		Material type	SS-304
		Port diameter	150.0 mm

Figure 7: Geometry configuration of PHE in Hybrid GDHC system with heat pump.

4.2 Capital Cost for the Centralized Surface Plant

The total capital investment is the sum of fixed and fixed working capital investments.

$$C_{cap} = C_{fixed} + C_{working} \qquad [2]$$

The working capital is the additional cost, apart from fixed capital investment, needed for start-up of the project and to keep the surface plant in operation. The working capital is assumed to be 20% of the total capital investment for the project (Timmerhaus et al., 2003). Therefore, the total capital investment is given as:

$$C_{cap} = 1.25\ C_{fixed} \qquad [3]$$

The fixed capital investment is the sum of direct and indirect costs.

$$C_{fixed} = C_{direct} + C_{indirect} \qquad [4]$$

The direct costs for the heat exchanger, pumps, and new pipelines (connections to existing distribution pipelines) of the surface plant for both scenarios are calculated using ASPEN Capital Cost Estimator (ACCE) (Aspentech 2017) and direct costs for the natural gas-fired boiler and heat pump are obtained as quotes from Johnston Boiler Company and Mayekawa USA, Inc., respectively. For new pipelines, the material is considered carbon steel with a polyurethane insulation to prevent piping corrosion (Rafferty 1989; Rafferty 1998), while for the PHE, the material considered is stainless steel (SS-304). The cost for a boiler is obtained as a quote from a vendor, Johnston Boiler Company.

The indirect costs, including construction expenses, contingency, contractor fees, and engineering expenses, are assumed to be 35% of the fixed capital investment (Timmerhaus and West 2003). Therefore, the fixed capital investment is given as:

$$C_{fixed} = 1.54\ C_{direct} \qquad [5]$$

Hence, the total surface plant capital investment is approximately twice the direct cost.

$$C_{cap} = 1.93\ C_{direct} \approx 2.0\ \ C_{direct} \qquad [6]$$

To determine the cost of purchasing the existing steam distribution pipelines (owned by MEA), three different cases are considered:

1. Case 1: MEA donates the pipelines to WVU at no cost,
2. Case 2: WVU purchases pipelines from MEA for $15M, and
3. Case 3: $25M for installations of new distribution pipelines across the campus.

The surface capital costs calculated for both the scenarios in all the cases are listed in Table 4.

Table 4: Total surface capital costs including central plant and distribution pipelines for Hybrid GDHC system with heat pump.

Equipment type	**Case 1**		**Case 2**		**Case 3**	
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**
Heat Exchanger	0.22	0.17	0.22	0.17	0.22	0.17
Boiler (Vendor quote)*	1.83	1.75	1.83	1.75	1.83	1.75
Heat Pump (Vendor quote)#	0.41	0.41	0.41	0.41	0.41	0.41
Condensate Receiver Tank	0.27	0.24	0.27	0.24	0.27	0.24
Hot water Pump	0.06	0.05	0.06	0.05	0.06	0.05
Condensate Pump	0.09	0.04	0.22	0.16	0.22	0.16
Retrofitted Steam Pipeline	0.72	0.72	0.72	0.72	0.72	0.72
Retrofitted Condensate Pipeline	0.33	0.33	0.33	0.33	0.33	0.33
Natural Gas pipeline	0.18	0.18	0.18	0.18	0.18	0.18
Total Central Plant Direct Costs (C_{direct})	**4.11**	**3.89**	**4.11**	**3.89**	**4.11**	**3.89**
Total Central Plant Capital Cost (C_{cap})	**8.22**	**7.78**	**8.22**	**7.78**	**8.22**	**7.78**
Existing Pipeline Costs	**0.00**	**0.00**	**15.00**	**15.00**	**25.00**	**25.00**
Total Capital Cost	**8.22**	**7.78**	**23.22**	**22.78**	**33.22**	**32.78**

**Vendor quote for 300 psig design pressure at a flow rate of 69,000 lbs/hr (8.7 kg/s) is 9.12 M$, and for 200 psig design pressure at a flow rate of 75,900 lbs/hr (9.5 kg/s) is 8.76 M$, therefore two boilers are considered for both scenarios to account for peak flow rates.*

 # Vendor quote for Mayekawa Plus Heat 4HS water source NH_3 heat pump package with a capacity of 770 GPM (48.6 kg/s) is $414,000, therefore one heat pump is considered for both scenarios.

4.3 Economic Analysis

An economic analysis for the GDHC is performed using GEOPHIRES v2.0 (Beckers 2016; Beckers and McCabe 2018, 2019) and BICYCLE (Hardie 1980, 1981) levelized cost model is used to evaluate LCOH. The current version of GEOPHIRES is open source code written in python and does not include analysis for hybrid system. Therefore, the code is edited to account for a natural gas boiler, its heating duty, and yearly cost for natural gas. The natural gas costs are assumed to be ~$4.12/MCF ($3.702/MCF plus monthly add-ons), the electricity price is considered as $0.067/kWh, and the heat price is estimated based on our current MEA price $15/MMBTU ($0.05/kWh).

The technical parameters used for the subsurface and economic parameters are listed in Table 5. The natural gas boiler duty, heat pump work, and pumping capacity are taken from Table 1 and Table 2, respectively. The well drilling costs are calculated using the default correlations, these values are considered as the upper bound. Horizontal wells with lateral lengths of 500 m are considered. To consider high costs for horizontal well drilling, a cost adjustment factor of 1.5 is used. Since the total capital cost for equipment and distribution pipelines varies between $8M-$33M, LCOH is calculated by varying the total capital cost and surface operating and maintenance costs between $10M-$40M and $2M/year-$4M/year, respectively. Along with the default correlations for well drilling costs, quotes are also obtained from Northeast Natural Energy (NNE) as $2.1M/well and $3.8M/well for vertical and horizontal configurations, respectively. These values are lower bound for well drilling and completion costs. The LCOH results are presented in Figure 8, the LCOH is in the range of $7.9/MMBTU - $12.4/MMBTU, and $9.5/MMBTU - $16.7/MMBTU, for scenarios 1 and 2, respectively.

Table 5: GEOPHIRES input parameters to calculate levelized cost of heat (LCOH) for both vertical and horizontal well configurations.

Parameter	Vertical	Horizontal
Geothermal Fluid Flow Rate (kg/s)	15.0	15.0
Geothermal Gradient (°C/km)	26	26
Ambient Temperature (°C)	13.5	13.5
Well Depth (km)	2.9	2.9
Well Configuration (-)	Doublet	Doublet
Well Inner Diameter (inch)	8.0	8.0
Reservoir Impedance (GPa.s/m^3)	0.82	0.11
Production Wellbore Heat Transfer	Ramey's Model	Ramey's Model
Reinjection Temperature (°C)	50	50
Reservoir Model	User-provided TOUGH2 temperature data	User-provided TOUGH2 temperature data
Reservoir Water Loss Rate	0%	0%
Well drilling cost correlation	1 (vertical, small diameter)	1 (vertical, small diameter)
Well Drilling and Completion Capital Cost Adjustment Factor	1.0	1.5
Plant Lifetime (Years)	30	30
Economic Model	3 (Bicycle (Hardie,1981))	3 (Bicycle (Hardie,1981))
End-Use Option	2.0 (Direct-Use Heat)	2.0 (Direct-Use Heat)
Circulation Pump Efficiency	0.8	0.8
Utilization Factor	0.9	0.9
End-Use Efficiency Factor	0.9	0.9

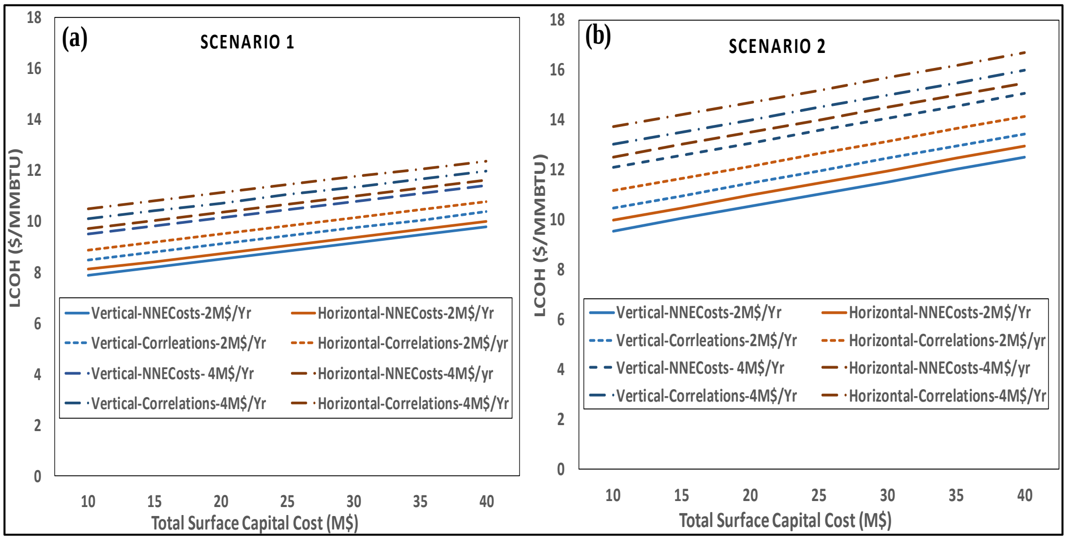


Figure 8: LCOH for hybrid GDHC system with heat pump for scenario 1 (a) and scenario 2 (b), using vertical and horizontal well configurations for different total surface capital and operating costs.

5. HOT WATER-BASED GEOTHERMAL DISTRICT HEATING AND COOLING SYSTEM

A preliminary analysis of conversion of steam infrastructure to a hot water system is also performed. Since there is no access to measure the steam usage and steam vs hot water usage at individual buildings, the best estimate of the total load to be maintained as hot-water to steam (60/40 and 70/30 in summer and in winter, respectively) for the worst-case scenario is considered. In both cases, steam is used for heating domestic water through the existing steam – hot water heat exchangers. If we included conversion of domestic hot water heat exchangers from steam – hot water to hot water – hot water exchangers, we would need approximately 30 heat exchangers for the Ag. Science, Towers), and the Medical center meter points. Each heat exchanger costs about $10,000. In this case, 85% of the peak load would be hot water with the remainder being steam for equipment in winter. The required amount of water flow rate is calculated based on the amount of steam used for heating purposes, latent heat (~ 850 BTU/lb) of steam and the temperature drop (30°F/17°C) at the buildings. Due to the large water flow rates needed for the system (as seen in Table 6), only the Scenario 2 (the Ag. Science, Towers, and Medical Center meter points) are considered for a hot water-based system analysis, while it is assumed that the Downtown and Life Sciences meter point steam requirements will be supplied through natural gas boilers.

The supply temperature at the buildings is around 200°F (93.3°C) and since the geothermal production temperatures are around 187-210°F (86°C-99°F), a heat pump (max. temperature 90°C) is considered to be installed close to the buildings (instead of at the central surface plant) in order to further heat the geothermally heated water and also extract the heat from the return condensate thereby improving the performance of the system. A "new pre-insulated piping system" will be considered to reduce the heat loss during distribution.

Table 6: The required water flow rate estimated using latent heat of steam and the maximum steam flow rate during January.

Hot water/Steam→	**60/40**		**75/25**		**85/15**	
Meter point Location→	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**
Total Amount of Steam (lbs/hr)	70,000	75,000	70,000	75,000	70,000	75,000
Steam Converted to HW (lbs/hr)	42,000	45,000	52,500	56,250	59,500	63,750
Amount of Water (lbs/hr)	1,190,000	1,275,000	1,487,500	1,593,750	1,685,833	1,806,250
Amount of Water (kg/s)	**149.9**	**160.7**	**187.4**	**200.8**	**212.4**	**227.6**

5.1 Surface Plant Modeling

The schematic of the hot-water based system is shown in Figure 9 and is modeled using ChemCAD (Chemstations 2016) for Scenario 2 (the Ag. Science, Towers, and Medical Center meter points).

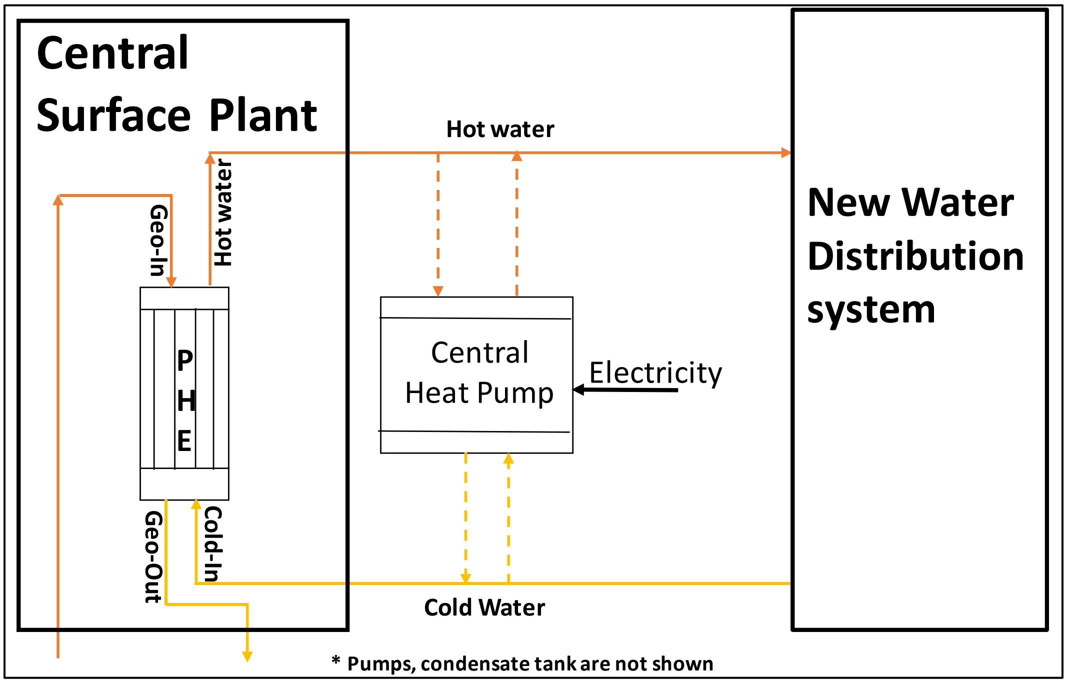


Figure 9: Schematic of the proposed geothermal hot water –based system with heat pump for WVU campus.

The temperature drop at the buildings is considered to be 17°C (30°F). A 5°C temperature drop is considered for distribution heat losses between the heat pump and the PHE. The PHE design is performed using the CCTHERM (CC-Therm 2006) program and direct costs for heat exchanger, pumps are calculated using ACCE (Aspentech 2017) and direct costs for the heat pump is obtained as quotes from Mayekawa USA, Inc. The PHE geometry configuration along with costs obtained for all the cases are tabulated in Table 7.

Table 7: PHE geometry configuration obtained through ChemCAD-CCTHERM and costs from ASPEN Capital Cost Estimator (ACCE).

Water/Steam →	**60/40**		**75/25**		**85/15**	
Meter point Location→	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**
Hot Water Flow Rate (kg/s)	149.94	160.65	187.42	200.81	212.41	227.58
Heat Load MW_{th}	14.20	15.21	17.75	19.01	20.09	21.52
Gross Area (m^2)	768	828	960	1020	1080	1152
No. of Plates	64	69	80	85	90	96
Width (m)	3	3	3	3	3	3
Height (m)	4	4	4	4	4	4
Gap (mm)	2	2	2	2	2	2
Thickness (mm)	0.5	0.5	0.5	0.5	0.5	0.5
Direct Cost ($)	288,400	294,300	359,700	366,700	372,800	380,200

Two options are available for heat pumps through Mayekawa, one with a hot water flow rate of 770 GPM (48.6 kg/s) and the other with a hot water flow rate of 1,140 GPM (72 kg/s). The total number of heat pumps required is calculated based on the required hot water flow rate and rating of the commercially available heat pumps and is tabulated in Table 8. Heat pump coefficient of performance (COP) is found to be 5.69 for all scenarios.

Table 8: Total number of heat pumps required and their corresponding costs.

Water/Steam →	**60/40**		**75/25**		**85/15**	
Meter Point Location→	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**
Hot Water Flow Rate (kg/s)	149.94	160.65	187.42	200.81	212.41	227.58
770 GPM Heat Pumps Required	2	2	1	0	2	2
1140 GPM Heat Pumps Required	1	1	2	3	2	2
Direct Costs[#] (M$)	1.26	1.26	1.28	1.31	1.70	1.70

[#] Vendor quote for Mayekawa Plus Heat 4HS water source NH_3 heat pump package with a capacity of 770 GPM (48.6 kg/s) is $414,000 and 6HS water source NH_3 heat pump package with a capacity of 1140 GPM (72 kg/s) is $435,000.

A central hot water pump is used to deliver hot water to the buildings at a pressure of three bar (30 psig) and return condensate is also pumped back to the central plant at a pressure of three bar using a series of pumps at required distribution meter points, G, F, I, and H. The pumping capacity and costs are provided in Table 9.

Table 9: Pumping capacity and costs for hot water pump and the return condensate pumps for Ag. Science, Towers, and Medical Center meter points.

Water/Steam →	**60/40**					
Meter Point Location→	**Ag. Science + Towers**			**Medical Center**		
Pump	**Head (m)**	**Power (kW)**	**Cost (M$)**	**Head (m)**	**Power (kW)**	**Cost (M$)**
Central Hot Water Pump	21.4	39.3	0.11	22.6	44.5	0.11
G	2.9	4.0	0.08	-	-	-
F	13.5	18.5	0.09	-	-	-
I	18.4	8.7	0.06	-	-	-
H-Ag. Science + Towers	58.3	107.1	0.15	-	-	-
H-Medical Center	-	-	-	23.8	46.9	0.12
Total Cost (M$)			0.48			0.23
Water/Steam →	**75/25**					
Meter Point Location→	**Ag. Science + Towers**			**Medical Center**		
Pump	**Head (m)**	**Power (kW)**	**Cost (M$)**	**Head (m)**	**Power (kW)**	**Cost (M$)**

Central Hot Water Pump	26.1	60	0.13	24.6	60.6	0.14
G	2.9	5.1	0.09	-	-	-
F	15.0	25.6	0.10	-	-	-
I	18.6	11.0	0.06	-	-	-
H-Ag. Science + Towers	67.8	155.8	0.12	-	-	-
H-Medical Center	-	-	-	30.4	74.9	0.14
Total Cost (M$)			0.50			0.28
Water/Steam →	**85/15**					
Meter Point Location→	**Ag. Science + Towers**			**Medical Center**		
Pump	**Head (m)**	**Power (kW)**	**Cost (M$)**	**Head (m)**	**Power (kW)**	**Cost (M$)**
Central Hot Water Pump	29.8	77.7	0.15	26.7	74.6	0.15
G	2.9	5.7	0.10	-	-	-
F	16.2	31.3	0.11	-	-	-
I	18.7	12.5	0.07	-	-	-
H-Ag. Science + Towers	75.3	196.1	0.14	-	-	-
H-Medical Center	-	-	-	35.1	98.0	0.16
Total Cost (M$)			0.56			0.30

5.2 Capital Cost for the Centralized Surface Plant

The total capital costs for surface equipment and distribution pipelines are shown in Table 10 for all the cases considered. However, these costs do not include production of steam by natural gas boiler for Downtown, and Life Sciences meter points and for certain equipment at buildings served by Ag. Science, Towers, and Medical Center meter points.

Table 10: Preliminary equipment costs estimated for hot water-based system.

Water/Steam →	**60/40**		**75/25**		**85/15**	
Meter point Location→	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**	**Ag. Science + Towers**	**Medical Center**
Heat Exchanger Costs (M$)	0.29	0.29	0.36	0.37	0.37	0.38
Heat Pump Costs (M$)	1.26	1.26	1.28	1.31	1.70	1.70
Domestic Hot Water Heat Exchangers (M$)	0.15	0.15	0.15	0.15	0.15	0.15
Pumps (M$)	0.48	0.23	0.50	0.28	0.56	0.30
Pipelines (M$)	5.00	5.00	5.00	5.00	5.00	5.00
Total Direct Cost, C_{direct} (M$)	7.18	6.94	7.29	7.10	7.78	7.53
Total Capital Cost, C_{Cap} (M$)	14.36	13.88	14.59	14.21	15.56	15.06

5.3 Economic Analysis

A Preliminary economic analysis for the hot water system is performed using GEOPHIRES. For geothermal water production from the subsurface, multiple well configurations are considered. Each configuration has two horizontal production wells and one horizontal injection well with a total production rate of either 80 kg/s or 40 kg/s. Based on the hot water requirement, total number of geothermal well configurations are calculated. The LCOH ($/MMBTU) for the central plant for Scenario 2 with operating and maintenance costs of $6M/year and total capital costs of $30M are tabulated in Table 11. The LCOH obtained is in the range of $15.9/MMBTU-$19.8/MMBTU and $21.4/MMBTU - $23.6/MMBTU for a total geothermal flow rate from each configuration of 80 and 40 kg/s, respectively. In all the cases, the estimated LCOH is higher than the current heat price (~$15/MMBTU); therefore, the hot water-based system is not feasible at the current estimations.

Table 11: LCOH calculation for hot water-based system using horizontal well configuration and total surface operating cost of $6M/year and total capital cost of $30M.

Flow Rate from Each Configuration	**Water/ Steam Usage**	**Maximum Water Flow Rate (kg/s)**	**No. of Configurations**	**LCOH ($/MMBTU)**
80 kg/s	60/40	310.6	4	19.75
	75/25	388.2	5	17.47
	85/15	440.0	6	15.95
40 kg/s	60/40	310.6	8	23.58
	75/25	388.2	10	21.38
	85/15	440.0	No.of wells are above the allowable value range	NA

6. CONCLUSION

In this study, we presented a feasibility analysis for the development of a geothermal deep direct-use heating and cooling system at the WVU campus in Morgantown, WV. The surface demand is characterized by year-round steam consumption data across the entire campus. Surface plant performance and capital cost analysis of the GDHC system are performed using ASPEN and ChemCAD simulation software, and the economic analysis of LCOH is performed using GEOPHIRES. A centralized hybrid natural gas geothermal system is proposed to deliver steam to all distribution points at the required conditions; thus, the current distribution system will be used. A heat pump is considered in order to improve the performance of the system and increase geothermal heat extraction. The LCOH for the steam-based hybrid GDHC system for the entire campus (scenario 1) is in the range of $7.9/MMBTU - $12.4/MMBTU, which is below the current cost of $15/MMBTU. The LCOH for a steam-based hybrid GDHC system for scenario 2 is in the range of $9.5/MMBTU - $16.7/MMBTU, which is in the same range as the current cost. Due to the high latent heat needed for conversion of hot water to steam, the geothermal contribution to the current steam-based hybrid system is low. Hence, a preliminary analysis of conversion of the steam-based system to a hot water-based system for scenario 2 is performed. The LCOH obtained for this hot water system is higher than the current cost. However, the LCOH estimated is based on using multiple production wells and well drilling costs for multiple wells are too high for the system to be economical. Therefore, the feasibility of the hot water-based system depends on the ability of producing high volumes of geothermal hot water from the Tuscarora sandstone to meet the peak demand. Based on techno-economic analyses completed in this study, steam-based hybrid GDHC is feasible to replace the existing coal-based system, serving 33,000 students on the campus and Ruby Memorial Hospital, the largest hospital in West Virginia.

ACKNOWLEDGMENT

This manuscript is based upon work supported by the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE) under the Geothermal Technologies Office, under Award Number DE-EE0008105.

DISCLAIMER

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