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Techno-Economic Analysis of Geothermal Deep Direct-Use Systems for District Heating and Cooling in West Point, NY, and Detroit, MI

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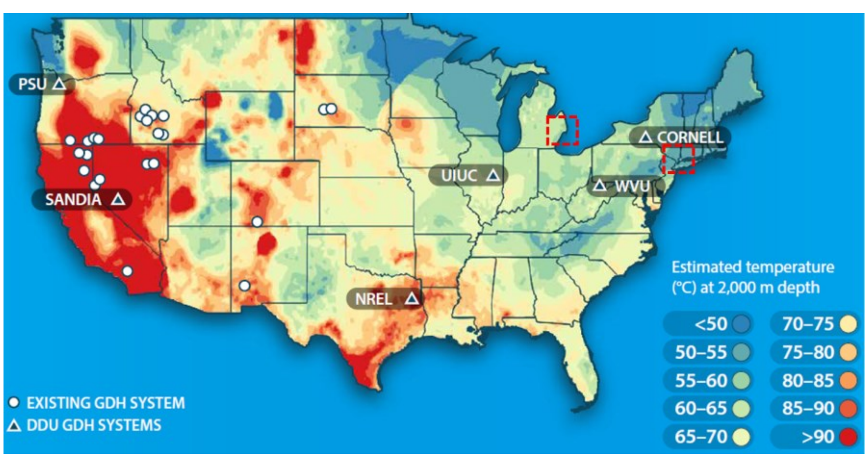
ABSTRACT

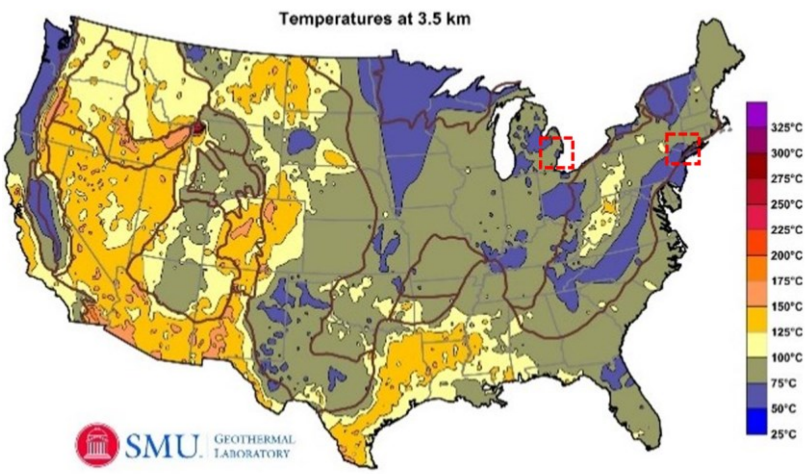
This study evaluated techno-economic potential of geothermal deep direct-use (DDU) systems for district-scale heating and cooling systems in West Point, NY, and Detroit, MI. Regional geological formation, lithology, and bottomhole temperature data were collected through the literature review to characterize geothermal resource potential in the two study areas. The two study areas mainly consist of igneous and metamorphic rocks at target reservoir depths of 3 km to 4 km. Average geothermal gradients in the West Point and Detroit areas were estimated as 19.7 °C/km and 21.2 °C/km, respectively. The characterized reservoir properties and temperature were incorporated in the GEOPHIRES techno-economic analysis tool for levelized costs of geothermal energy production for direct-use heating at 3 km, direct-use heating and cooling at 4 km, and district heating coupled with peaking boiler at 3 km. Average heat production during a 20-year lifetime in the West Point site was 5.5 MW_{th} at 3 km and 9.2 MW_{th} at 4 km, with average production temperatures of 66 °C and 84 °C, respectively. Similarly, the average heat production in the Detroit site was 6.4 MW_{th} at 3 km and 10.4 MW_{th} at 4 km, with average temperatures of 71 °C and 90 °C, respectively. The reservoir thermal drawdown in the two study areas was approximately 7% to 8% after 20 years of operation. With the increase in production depth from 3 km to 4 km, the levelized cost of heating (LCOH) of direct-use applications was significantly decreased from $54/MWh to $41/MWh in West Point and from $47/MWh to $36/MWh in Detroit, respectively. The levelized cost of cooling (LCOC) was generally higher than the LCOH due to additional capital and lifetime operational costs and 80% to 90% efficiency of absorption chiller for cooling. LCOHs of district heating systems were significantly higher than those of direct-use applications, with lower utilization factors and optimized with a 30-year system lifetime, 5% discount rate, and 3.5-MW baseload as $37/MWh with utilization factor of 87.4% in West Point and $36/MWh with utilization factor of 80.2% in Detroit Arsenal. These results imply that the geothermal DDU systems in the two study areas are techno-economically feasible and comparable when the systems are operated with additional baseloads.

1. INTRODUCTION

Mullane et al. (2016) demonstrated that low-temperature geothermal resources below 150 °C are widespread in relatively shallow subsurface (≤3 km) in the United States (Figure 1(a)) and estimated the low-temperature geothermal energy as 30,000 EJ and 6 million EJ for hydrothermal and enhanced geothermal systems, respectively. Similarly, Blackwell et al. (2011) estimated that geothermal resources at temperatures above 75 °C are broadly available at 3.5 km depth (Figure 1(b)). The low-temperature geothermal resources have been developed and utilized since the 1890s for geothermal deep direct-use (DDU) applications including district heating systems. Currently, 23 geothermal district heating systems are in operation in the United States, particularly in the western United States due to higher-grade geothermal resources (see white circles in Figure 1(a)). On the other hand, due to relatively lower-grade geothermal resources, the development of geothermal DDU energy systems has been limited in the South, Midwest, and Northeast regions.



(a)



(b)

Figure 1: Geothermal resource potential in the United States: (a) at 2 km depth from the surface with locations of 23 existing geothermal district heating systems marked with white circles and six deep direct-use geothermal district heating projects in development marked with triangles (Robins et al. (2021), updated from Mullane et al. (2016)) and (b) at 3.5 km depth from the surface (Tester et al. (2023) updated from Blackwell et al. (2011)). The two red-colored dashed boxes represent the study areas, Detroit Arsenal in Michigan and West Point in New York.

In addition to the resource temperature, subsurface geology, especially permeability, plays an important role in the development of geothermal DDU systems. For example, hot "permeable" rocks, such as coarse sandstones in a sedimentary layer, may be exploited for a hydrothermal system where water (e.g., existing groundwater, water injected from well(s)) is heated by convective heat transfer through pore spaces and conductive heat transfer in the hot permeable rock. On the other hand, hot "impermeable" rocks (e.g., granite) may be developed for a human-made reservoir with engineered fracture network (i.e., enhanced geothermal system (EGS)). While the subsurface temperature directly addresses the geothermal resource potential, subsurface geology is more closely related to the system performance and efficiency in terms of heat and mass transfer based on the reservoir properties including porosity, permeability, and thermal conductivity.

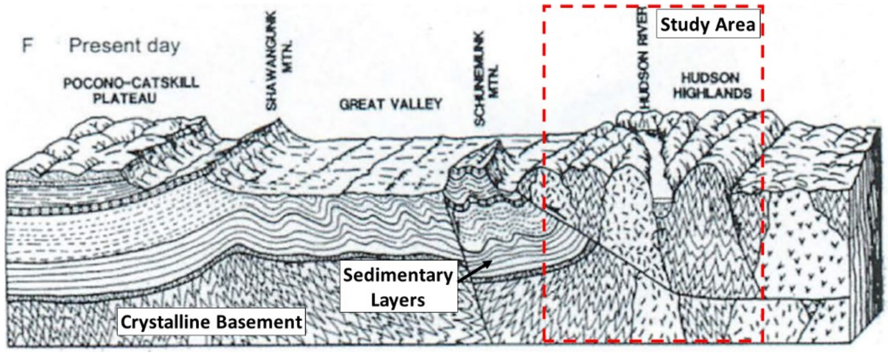
Feasibility of geothermal DDU systems in the United States has been extensively studied by previous researchers. In particular, the Department of Energy Geothermal Technologies Office (DOE GTO) has recently granted six projects to evaluate the feasibility of geothermal DDU systems in the United States: 1) geothermal district heating system at University of Illinois Urbana-Champaign (Stumpf et al. 2018), 2) geothermal district heating system in Nevada (Lowry et al. 2020), 3) geothermal district heating system at Cornell University (Tester et al. 2019), 4) geothermal district heating system at West Virginia University (Nagasree 2021), 5) geothermal direct-use for chilled water using an absorption chiller in Texas (Turchi et al. 2020), and 6) subsurface storage for solar thermal energy at Portland State University (Bershaw et al. 2021). The levelized costs of heat (LCOH) of the six systems widely ranged from $13/MWh to $345/MWh depending on subsurface conditions, surface configurations, and cost assumptions (Beckers et al. 2021). Beckers et al. (2021) concluded that geothermal DDU systems are cost-competitive. More recently, the DOE GTO awarded $6 million to expand geothermal heating and cooling at federal sites nationwide under the Federal Geothermal Partnerships (FedGeo) initiative. As a part of the FedGeo project, this study evaluated techno-economic feasibility of geothermal DDU systems in the United States Military Academy, West Point, NY, and the Detroit Arsenal, MI. Subsurface geology and thermal gradient were characterized for the two study areas with the information collected from the literature review. Then, levelized costs of geothermal energy production for direct-use heating and cooling were evaluated using GEOPHIRES model tool.

2. GEOTHERMAL RESOURCE POTENTIAL IN WEST POINT, NY, AND DETROIT, MI

2.1. Geological Formation and Lithology

West Point is located on a fault where the subsurface geology and its thermal conductivity, permeability, and heat flow may be critically different from location to location and depth to depth (Figure 2(a)). According to Johnson and Gellasch (2004), granite and gneiss are dominant in the West Point area, while Great Valley (west of West Point) consists of sedimentary bedrock (Paleozoic sediments) (Figures 2(a) and (b)). That is, igneous and metamorphic rocks that typically have low permeability and high density and thermal conductivity may be dominantly existing in the study area and then sedimentary bedrock layers (e.g., Hudson River shales and sandstones, Wappinger limestone) may be presented below a certain depth approximately 3 to 4 km from the ground top surface. Although Tester et al. (2021) and Homman et al. (2022) estimated the thickness of adjacent sedimentary layer as 4 km, it is difficult to accurately estimate subsurface geology in the study area without regional-specific geology data at depth (e.g., borehole logs), due to the complicated geological events (e.g., continental collision, folding and faulting).

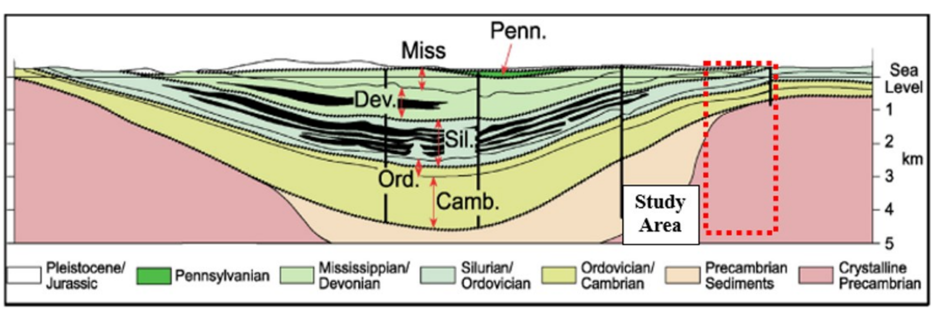
On the other hand, Detroit Arsenal is located on Michigan sedimentary basin and the local bedrock geology is Ellsworth and Antrim shales (Figures 2(c) & (d)). The thickness of the sedimentary layer in the study area is approximately 1 km and then Precambrian crystalline basement is expected below 1 km where geothermal energy production is targeted for the DDU applications. This implies that deep geothermal resources in the Detroit study area may have relatively lower permeability at the targeted depth (e.g., 3 to 4 km) and thus an enhanced geothermal system (EGS), which artificially creates fractures (and/or expands pre-existing fractures) for increasing permeability, may be considered for the geothermal energy production.



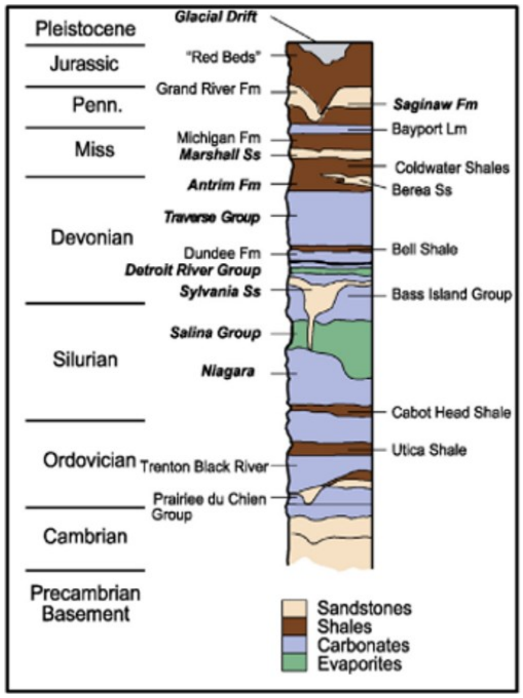
(a)

ERA	PERIOD	MAJOR UNITS		EVENTS
Cenozoic	Quarternary		Moraines, kames, eskers, and lake deposits	Several glacial advances with depositional and erosional features. Glacial Lake Fairchild formed.
Mesozoic	Triassic		Palisades sill and other basaltic intrusions	Rifting, separation of Pangea, opening of present Atlantic Ocean.
Paleozoic	Permian & Penn.			Gondwana collided with Laurentia causing the Alleghanian Orogeny
	Devonian		Schunemunk conglomerate, Bellvale shales and sandstones	Laurentia collided with Baltica causing the Acadian Orogeny.
	Silurian		Rondout limestone, Binnewater sandstone, High Falls shale, Shawangunk conglomerate	Clastic sediments deposited from ancestral Taconic Mountains to east of present day Hudson River.
	Ordovician		Hudson River shales and sandstones	Marine deposition continues. Convergence and subduction east of this area caused the Taconic Orogeny.
	Cambrian		Wappinger limestone	Orogeny ceased and tensional forces dominate. Shallow seas cover region.
Precambrian			Storm King and Canada Hill granites, Hudson Highlands gneisses	Grenville Orogeny ~1000 – 1200 Ma. Intrusions 1140 and 1000 Ma.

(b)



(c)



(d)

Figure 2: Subsurface geology in Southeastern New York and Eastern Michigan: (a) schematic geology diagram for West Point in New York (modified from Johnson and Gellasch 2004), (b) simplified stratigraphic column (Johnson and Gellasch 2004), (c) schematic cross-section for Detroit area in Michigan (modified from Wen et al. 2015), and (d) schematic stratigraphy of the Michigan Basin (Wen et al. 2015)

2.2 Reservoir Permeability

Permeability is an intrinsic property of the reservoir that describes how quickly groundwater can flow through the porous media (e.g., rock, soil) and depends on pore structures of the material. Jasim et al. (2018) described that the permeability of sandstone ranges from 10E-17 m^2 to 10E-13 m^2, while Wang and Park (2002), Tanikawa and Shimamoto (2009), and Zhang et al. (2016) reported a broader range of sandstone permeabilities depending on the composition. In general, the permeability of sandstones widely ranges from 7.63E-20 m^2 for fine sandstone to 3.90E-14 m^2 for coarse sandstone. Similarly, mudstones have relatively lower permeability ranging from 3.59E-21 m^2 to 2.73E-17 m^2 due to the smaller particle size (e.g., silt and clay particles are much smaller than sand grains). The permeability of crystalline basement ranges from 10E-20 m^2 to 10E-17 m^2, with respect to the origin of igneous rocks originated by cooling and solidification of magma or lava and metamorphic rocks originated by physical and/or chemical changes in rock compositions from high temperature and pressure. Deo et al. (2013) described the sufficient rock permeability for hydrothermal systems is greater than 10E-15 m^2, approximately equivalent to 1 millidarcy. That is, hydraulic fracturing may be needed in certain levels of sedimentary layer, as well as in the crystalline basement, to increase the permeability. Stober and Bucher (1999; 2007) and Ceccato et al. (2021) reported that the permeability of fractured and weathered crystalline basement (e.g., granite) ranges from 5.11E-15 m^2 to 1.00E-12 m^2.

2.3. Geothermal Gradient

Subsurface temperature in the two study areas was linearly estimated using regional average soil temperature measured at 0 to 10 cm depth and bottomhole temperature data obtained from Southern Methodist University (SMU) Geothermal Lab. The SMU Geothermal Lab has collected and analyzed bottomhole temperature (BHT), thermal conductivity (λ), and heat flow on a national scale (Blackwell et al. 1990; Wisian et al. 1999; Blackwell and Richards 2004). Eight and four BHT measurements were collected from SMU's database for West Point and Detroit areas, respectively. The eight wells were located approximately 29 miles away from the West Point study area, and the four wells were located approximately 11 miles away from the Detroit study area. The BHT measurement depths widely ranged from 762 m to 3 km with an average of 1.9 km in the West Point study area (average BHT = 51.5 °C), while those were relatively consistent as 1.1 km in the Detroit study area (average BHT = 33.35 °C). The average BHTs in the two study areas were then incorporated with annual average soil temperatures of 10 °C (50 °F) for estimating geothermal gradients in the West Point and Detroit study areas. The estimated geothermal gradients in the West Point and Detroit study areas were 19.7 °C/km (Equation 1) and 21.2 °C/km (Equation 2), respectively. The subsurface temperature estimations indicated that geothermal resources around 88.7 °C and 94.7 °C may be available at 4 km depth in the West Point and Detroit areas, respectively (Figure 3). The subsurface temperature estimation for the Detroit area was also crosschecked with the temperature estimated using an empirical equation (Equation 3). Vugrinovich (1989) proposed an empirical equation based on linear regression of 405 BHTs in Michigan's Lower Peninsula to estimate BHT at depth. The temperature at 4 km depth in the Detroit area was similarly estimated as 91.3 °C.

$$BHT_{West\ Point}\ (°C) = 10\ (°C) + 19.7\ (°C/km) \times depth\ (km) \quad (1)$$

$$BHT_{Detroit}\ (°C) = 10\ (°C) + 21.2\ (°C/km) \times depth\ (km) \quad (2)$$

$$BHT_{Vugrinovich\ (1989)}\ (°C) = 14.5 + 0.0192 \times depth\ (m) \quad (3)$$

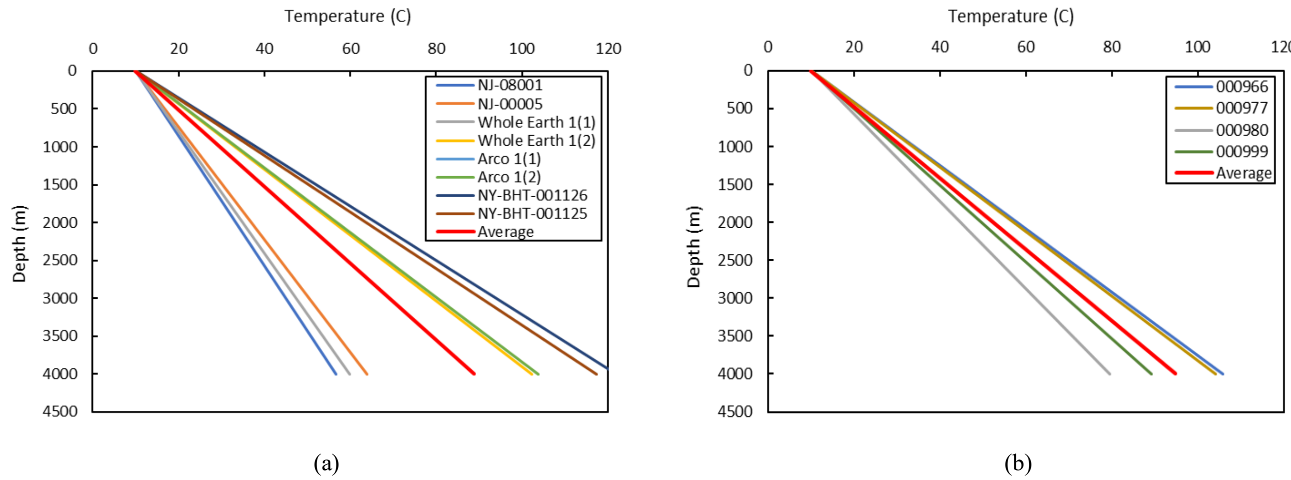


Figure 3: Subsurface temperature estimation at depth in: (a) West Point area and (b) Detroit area

3. LEVELIZED COST OF GEOTHERMAL ENERGY PRODUCTION FOR DIRECT-USE APPLICATIONS

Levelized cost of energy is defined as lifetime system costs (e.g., capital and operation and maintenance (O&M) costs) divided by lifetime energy production of the system and has been used to compare the cost-effectiveness of energy produced by different technologies and scenarios. In this study, levelized costs of geothermal energy production for deep direct-use (DDU) applications in the United States Military Academy, West Point, and the Detroit Arsenal were compared with four scenarios: 1) geothermal energy production from 3 km depth for direct-use heating, 2) geothermal energy production from 4 km depth for direct-use heating, 3) geothermal energy production from 4 km depth for cooling with an absorption chiller, and 4) geothermal energy production from 3 km for district heating. While those simulations for the direct-use end uses did not consider demand side and distribution network economics, the district heating end-use simulations incorporated load profiles and district distribution piping costs. The characterized regional geothermal gradients and geological characteristics were incorporated in GEOPHIRES v.3 for the simulation. GEOPHIRES is a python code-based simulation tool for techno-economic analysis of geothermal applications, including direct-use heating and cooling and district heating systems. GEOPHIRES models lifetime thermal drawdown in the reservoir, estimates geothermal energy production with user-defined configurations, and calculates capital and operational costs using empirical cost correlations, and LCOH or LCOC.

3.1. Reservoir Performance Modeling

As the first step, long-term thermal drawdown in the reservoir was modeled in GEOPHIRES over a 20-year lifetime. Considering the characterized geothermal gradient (i.e., 19.7 °C/km in the West Point area and 21.2 °C/km in the Detroit area), geothermal energy production depths were set at 3 km and 4 km with bottomhole temperatures of 69.1 °C and 88.8 °C in West Point and 73.6 °C and 94.8 °C in Detroit Arsenal, respectively (Table 1). The built-in multiple parallel fractures model was selected for the reservoir modeling to represent infinite series of parallel, equidistant, and vertical fractures with uniform aperture (Gringarten et al. 1975). In addition to the reservoir modeling, the wellbores were modeled for a doublet system (one well for injection and another well for production) using the built-in wellbore transient heat transmission model calculating the temperature drop from bottom to top in the production well (Ramey 1962). Table 1 summarizes the reservoir properties and dimensions used in the simulations.

Table 1: Reservoir model parameters for long-term thermal drawdown simulation

Models	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Application	Direct-use heating	Direct-use heating	Direct-use cooling with absorption chiller	District heating with peaking boiler
Well Depth (m)	3,000	4,000	4,000	3,000
Geothermal Gradient (°C/km)	West Point: 19.7 °C/km, Detroit Arsenal: 21.2 °C/km			
Reservoir Model	Multiple parallel fracture model (Gringarten et al., 1975)			
Wellbore Heat Transfer Model	Ramey wellbore model (1962)			
Flow Rate (kg/s)	50			
Fracture Geometry	Rectangular parallel and equidistant fractures with uniform aperture			
Fracture Length (i.e., spacing between injection and production lateral)	300			
Fracture Width (m)	200			
Fracture Separation (m)	30			
Number of Fractures (m)	46			
Reservoir Density (kg/m^3)	2,730			
Thermal Conductivity (W/m/K)	2.83			
Heat Capacity (J/kg/K)	825			
Discount Rate (%)	7			

Figure 4 represents the simulated 20-year production temperature profiles of geothermal systems in West Point and Detroit Arsenal at 3 km and 4 km depths. With the given flow rate of 50 kg/s and reservoir dimensions in Table 1, the lifetime thermal decline was estimated between 5 °C and 10 °C that can be reduced with flow rate (i.e., decreased flow rate) and/or reservoir dimension (e.g., increased number of fractures). The reservoir modeling results also indicated that 5.5 MWth of heat can be extracted using any production scenario with average production temperature ranging from 66.1 °C to 89.7 °C (Table 2).

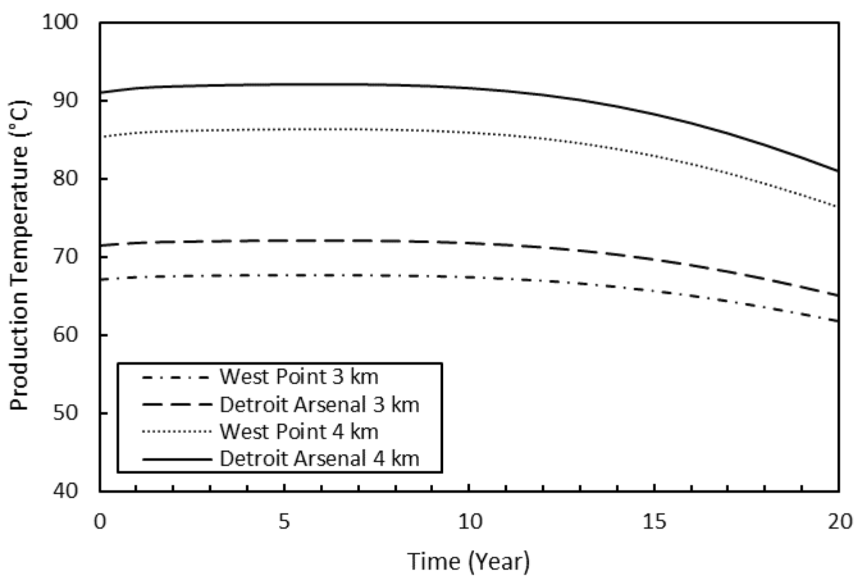


Figure 4: Thermal drawdown in the reservoirs at two production depths for a 20-year lifetime

Table 2: Production temperatures and thermal energy extraction from the reservoir with four scenarios

Models	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	NY	MI	NY	MI	NY	MI	NY	MI
Initial Reservoir Temperature (°C)	69.1	73.6	88.8	94.8	88.8	94.8	69.1	73.6
Initial Production Temperature (°C)	67.1	71.4	85.3	91	85.3	91	66.6	70.9
Maximum Production Temperature (°C)	67.7	72.1	86.3	92.1	86.3	92.1	67.4	71.8
Avg. Production Temperature (°C)	66.4	70.6	84.1	89.7	84.1	89.7	66.1	70.3
Avg. Reservoir Heat Extraction (MW_{th})	5.51	6.39	9.23	10.39	9.23	10.39	5.46	6.34

3.2. Levelized Costs of Geothermal Energy Production for Direct-Use Heating, Direct-Use Cooling, and District Heating at Two Production Depths

GEOPHIRES provides modules to calculate LCOH or LCOC of geothermal DDU applications (direct-use module) and LCOH of geothermal district heating systems (district heating module) (Beckers and Ross 2023). For the LCOH and LCOC calculations, system capital and lifetime operational costs were divided by the modeled geothermal energy lifetime production. The lifetime operational costs and energy production incorporated a discount rate assumed as 7% in this study to address the present value of a future payment. The system key components considered in the capital and operational cost estimations included borehole drilling and completion cost, stimulation cost, surface equipment capital cost (e.g., heat exchanger, field gathering system), and wellfield and surface equipment maintenance cost. Capital and operational costs for an absorption chiller and a natural gas-fired peaking boiler were also incorporated for supplying cooling in Scenario 3 and for supplying peak heating loads in Scenario 4, respectively. These cost components were estimated using built-in empirical cost correlations. For example, the drilling costs were estimated using cost correlations from Lowry et al. (2017) for 3 or 4 km doublet. More details on the model structures and cost correlations can be found in Beckers (2016) and Beckers and McCabe (2019).

The direct-use module simulates the geothermal energy production for direct-use applications (Scenarios 1, 2, and 3) with pre-assigned utilization factor, which is a ratio of the energy production to the system size, regardless of the end users' demand. On the other hand, the district heating module models the geothermal energy production to supply the user-provided heating demand profile through a distribution network. In the literature (e.g., Robins et al. 2021; Beckers et al. 2021), the utilization factor broadly ranged from 23% to 98%, mainly because of the frequent operation at less than full capacity and the seasonality of heating needs (e.g., low production for low heating demand during summer). In this study, 90% of the utilization factor was assumed in Scenarios 1, 2, and 3, while the utilization factor was calculated in GEOPHIRES for Scenario 4 with the given load profile and simulation results. For the district heating system modeling (Scenario 4), this study assumed that the new geothermal DDU systems supply the heating and/or cooling for five buildings in West Point and Detroit Arsenal. An example heating load profile at Cornell University, where heating demand patterns might be similar in terms of similar climate conditions in New York State, was processed for thermal demand profile in West Point Academy. Similarly, this study refined an average of 11 years' natural gas monthly loads in a nearby steam plant for heating load profiles in Detroit Arsenal. This study also assumed that existing distribution pipes can be reused for the future geothermal systems (i.e., capital cost for distribution network is zero).

The modeling results are summarized in Table 3. The production depth (e.g., 3 km in Scenario 1 or 4 km in Scenario 2) significantly affected both energy production and costs. For example, annual heat production of about 26.4 GWh increment (67.5 % increment) was expected with the increased production depth from 3 km to 4 km in West Point primarily due to the increased production temperature. At the same time, the drilling cost increased greatly from $10.97 million to $16.64 million (51.7% increment). However, even with the higher drilling cost for 4 km production depth, LCOHs of 4 km production scenarios were generally lower than those of 3 km production scenarios. LCOHs of geothermal DDU heating at 3 km and 4 km production depths were $54/MWh and $41/MWh in West Point and $47/MWh and $36/MWh in Detroit Arsenal, respectively. The absorption chiller in Scenario 3 increased overall capital and operational costs. LCOCs in Scenario 3 were generally higher than LCOHs due to the relatively lower cooling production, as well as the higher capital and operational costs (LCOC in West Point = $75/MWh, LCOC in Detroit Arsenal = $65/MWh). The coefficient of performance of a single-stage absorption chiller is typically less than 1 at low temperature below 150 °C (DOE 2018; Nikbakhti et al. 2020; El Haj Assad et al. 2021).

Table 3: Levelized costs of geothermal energy production for direct-use applications with four scenarios

Models	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	NY	MI	NY	MI	NY	MI	NY	MI
Avg. Heat Production (MW_{th})	4.96	5.75	8.31	9.35	9.23	10.39	4.92	5.7
Avg. Cooling Production (MW_{th})	N/A	N/A	N/A	N/A	5.48	6.41	N/A	N/A
Avg. Annual Heat Production (GWh_{th}/yr)	39.14	45.36	65.54	73.79	72.82	81.99	8.1	10.2
Avg. Annual Cooling Production (GWh_{th}/yr)	N/A	N/A	N/A	N/A	43.26	50.6	N/A	N/A
Total System Capital Cost (million $)	15.44	15.73	22.35	22.73	27.7	28.96	15.4	15.69
Total System Operations and Maintenance Cost (million $/yr)	0.8	0.78	0.76	0.71	0.87	0.83	0.45	0.46
LCOH ($/MWh)	54	47	41	36	N/A	N/A	224	181
LCOC ($/MWh)	N/A	N/A	N/A	N/A	75	65	N/A	N/A
Utilization Factor (%)	90	90	90	90	90	90	18.8	20.4

LCOHs of Scenario 4 for district heating systems were generally higher than those for DDU heating or cooling scenarios in Scenarios 1 to 3. This is mainly because of the relatively low utilization factor in Scenario 4. While the systems in Scenario 1 (DDU at 3 km) produced average annual heat of 39.14 GWh/yr in West Point and 45.36 GWh/yr in Detroit Arsenal with a utilization factor of 90%, the systems in Scenario 4 (district heating at 3 km) produced average annual heat of 8.1 GWh/yr in West Point and 10.2 GWh/yr in Detroit Arsenal with utilization factors of 18.8% and 19.5%, respectively. This underutilization of the available heat supply will be further discussed in the next section with a sensitivity analysis.

3.3. Sensitivity Analysis of LCOH in District Heating Scenario

There are several factors that affect LCOH, including the lifetime production, discount rate, and utilization factor. To optimize the system size and LCOH, additional modeling was conducted for Scenario 4 with 30-year lifetime, 5% discount rate, and baseloads of 0.5 MW, 2 MW, and 3.5 MW. In the 30-year lifetime simulations for a comparison with 20-year lifetime operation, the number of fractures increased from 46 (used in 20-year operation) to 62 (30-year operation) in terms of the optimal thermal drawdown approximately between 5 °C and 10 °C. With a 30-year lifetime and 62 fractures, the LCOHs decreased from $224/MWh to $199/MWh in West Point and $181/MWh to $161/MWh in Detroit Arsenal, respectively. The decreased $199/MWh in West Point and $161/MWh in Detroit Arsenal were then further decreased to $174/MWh and $140/MWh, respectively, with the decreased discount rate changed from 7% to 5%. However, the utilization factors were the same as 18.8% in West Point and 20.4% in Detroit Arsenal because the district thermal loads were the same. With baseloads of 0.5 MW, 2 MW, and 3.5 MW, the LCOHs and utilization factors were optimized as $113/MWh (utilization factor = 28.9%), $55/MWh (utilization factor = 59.1%), and $37/MWh (utilization factor = 87.4%) in West Point and $97.2/MWh (utilization factor = 29.4%), $50.7/MWh (utilization factor = 56.3%), and $34.7/MWh (utilization factor = 82.6%) in Detroit Arsenal, respectively. Figure 5 represents the LCOH decrements in West Point and Detroit with the variables, and Figure 6 compares demand and supply profiles in West Point with different baseloads visualizing the different system utilizations. These results indicate that additional applications for the base heating loads (e.g., greenhouse heating, low-temperature process heating in nearby industrial facilities) may be considered in future geothermal DDU systems.

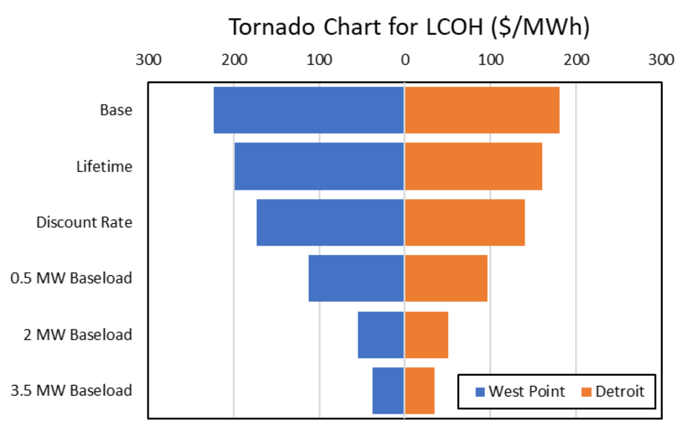


Figure 5: Impact of system lifetime, discount rate, and baseloads on the LCOHs of district heating systems in West Point and Detroit

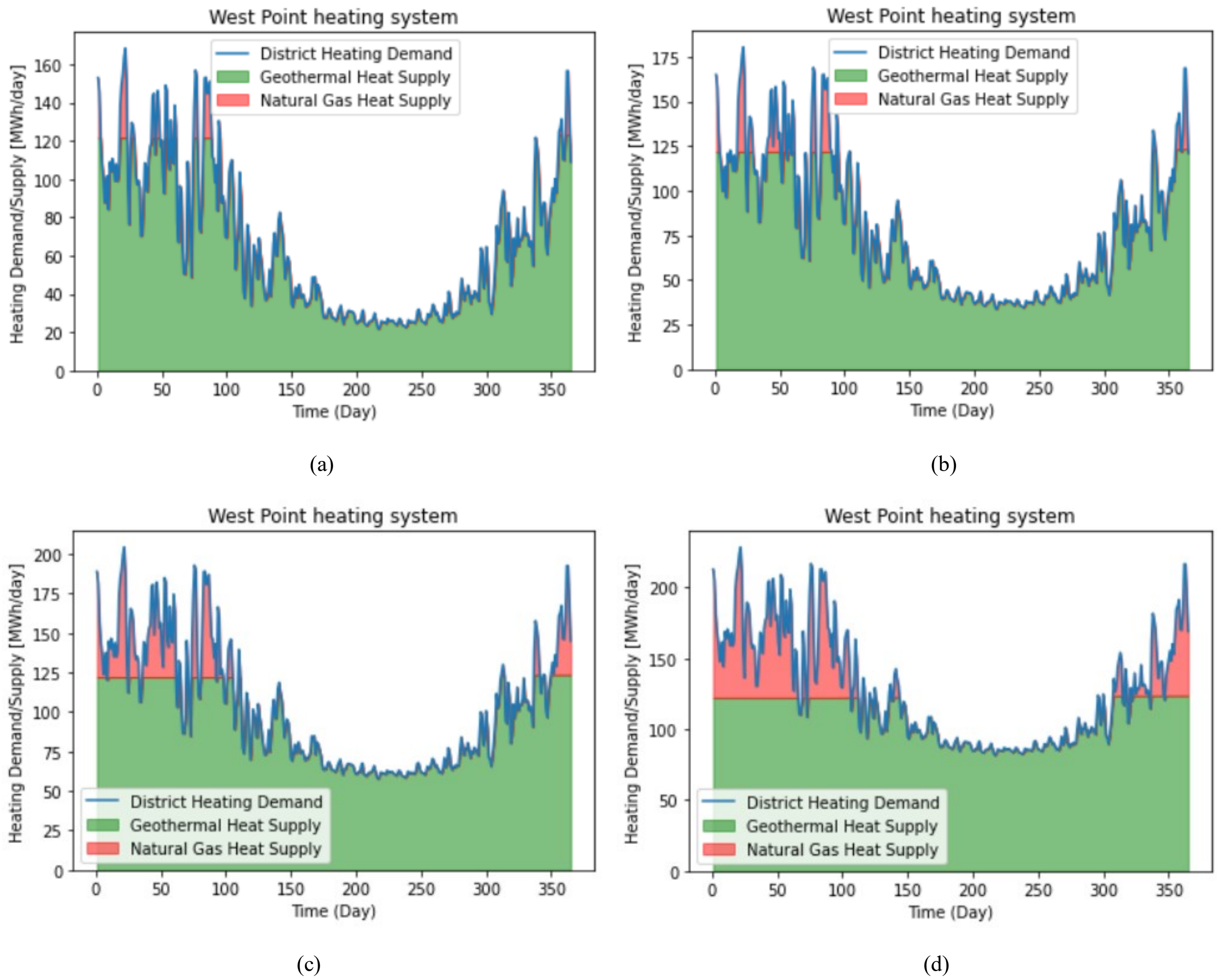


Figure 6: District heating demand and supply profiles in West Point incorporated with (a) 0 MW baseload, (b) 0.5 MW baseload, (c) 1.5 MW baseload, and (d) 2.5 MW baseload.

4. SUMMARY AND CONCLUSION

Geothermal direct-use district energy systems are developed in places where low-temperature geothermal resources below 150 °C are available at affordable depths. In the United States, geothermal direct-use applications have been developed in the West, with limited development elsewhere due to relatively lower-grade geothermal resources. In this study, the techno-economic potential of geothermal DDU systems in the United States Military Academy, West Point Academy in New York and the Detroit Arsenal in Michigan was evaluated. Geological formations and lithologies in the two study areas were identified as igneous and metamorphic rocks near the target reservoir depth from 3 km to 4 km. Using a bottomhole temperature database, the regional geothermal gradients were estimated as 19.7 °C/km and 21.2 °C/km in the West Point and Detroit areas, respectively.

The GEOPHIRES simulation for reservoir lifetime performance indicated that average heat productions during a 20-year lifetime were 5.5 MW_{th} at 3 km (average production temperature = 66 °C) and 9.2 MW_{th} at 4 km (average production temperature = 84 °C) in West Point and 6.4 MW_{th} at 3 km (average production temperature = 71 °C) and 10.4 MW_{th} at 4 km (average production temperature = 90 °C) in Detroit Arsenal, with about 7% to 8% thermal drawdown in the reservoir. While operation and maintenance costs in the four scenarios were similar, capital costs varied significantly depending on the drilling cost for 3 km or 4 km depth ($15 million for 3 km drilling versus $23 million for 4 km drilling). The LCOH decreased generally with the production depth (from 3 km to 4 km). LCOCs in Scenario 3 were generally higher than the LCOHs due to additional capital and lifetime operational costs for an absorption chiller that has 80% to 90% efficiency with low-temperature resources. LCOHs of district heating systems (Scenario 4) were significantly higher than those of direct-use applications (Scenarios 1 and 2), as the system is not fully operated during the summer season (i.e., lower utilization factors). The sensitivity analysis results showed that the LCOHs of the district heating systems can be optimized from $224/MWh in West Point and $181/MWh in Detroit Arsenal to $37/MWh in West Point and $35/MWh in Detroit Arsenal with a 30-year system lifetime, 5% discount rate, and 3.5-MW baseload. These results provide high-level comparisons of technical and economic performance of geothermal DDU applications in the two study areas and imply that geothermal DDU systems can be optimized with additional baseloads.

DISCLOSURE

This study evaluated the feasibility of geothermal deep direct-use applications in the two regions, not specific buildings. The information, model parameters, and load profiles were obtained from the literature review, not actual data provided by Detroit Arsenal and West Point Academy.

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