Department of Biosystems
and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

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Biosystems Design Projects

A Networked Geothermal Energy System for Residential and Industrial Consumption: Design and Analysis

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Background

What is networked geothermal heating and cooling?

- Series of buried pipes that circulate a fluid heated or cooled by subsurface temperatures, shown in Figure 1.

What are geothermal heat pumps?

- Heat pumps fueled by the consistent subsurface temperatures of the earth, shown in Figure 2.

Geothermal technology has been used for heating and cooling but has seldom been implemented at a utility scale.

Reasons for Implementation

- Carbon neutrality by 2050 [1]
- Environmentally conscious heating and cooling system
- Energy efficient system

Consumers Energy Project Sponsorship

- Commitment to sustainability
- Target of carbon neutrality by 2050

Problem Statement

Create a comprehensive model to evaluate the efficiency, cost, and carbon emissions of a utility scale networked geothermal energy system.

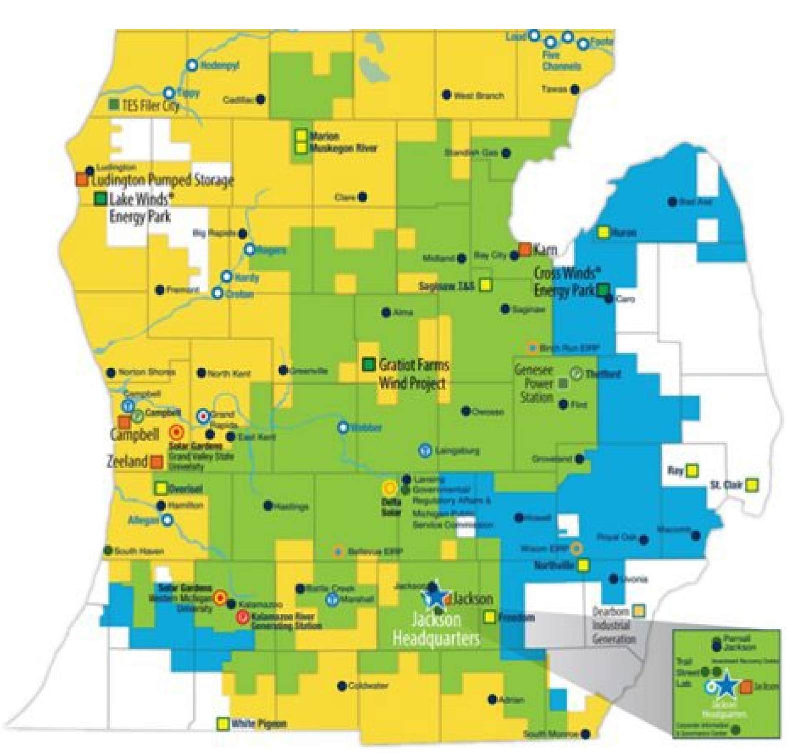

Figure 3. Consumers Electrical and Natural Gas Utility Zones [2]

Location

The model was required to include residential and industrial heating and cooling loads. Factors evaluated at potential sites included:

- Proximity to combination service territory
- Green initiatives in the area
- Well logs
- Type of industrial site

Three locations were proposed to the client. After consultation, KTM Industries in Holt, MI was selected. The designated service area is shown in Figure 4 and included an industrial site and 32 homes.

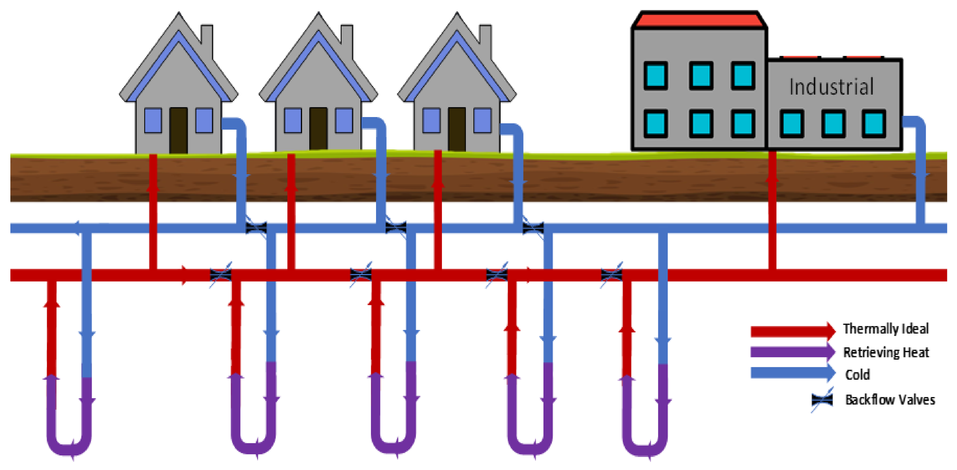

Figure 1. Networked Geothermal System Setup

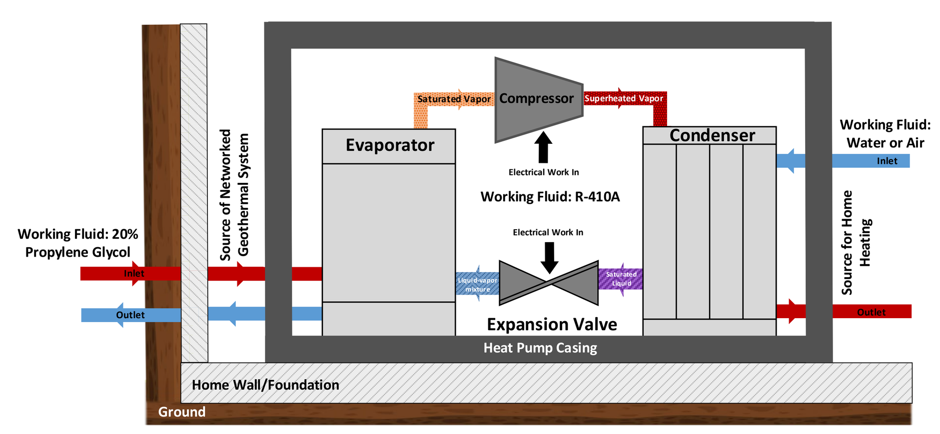

Figure 2. Heat Pump Diagram: Heating Cycle

Objectives

- Determine 3 locations in Michigan
- Identify required system components
- Develop a model for the energy output and economics of the system

Constraints

- Must be within Consumers Energy current combination service area, shown in Figure 3
- Must utilize existing right-of-way owned by Consumers Energy
- Must be able to support the area of service

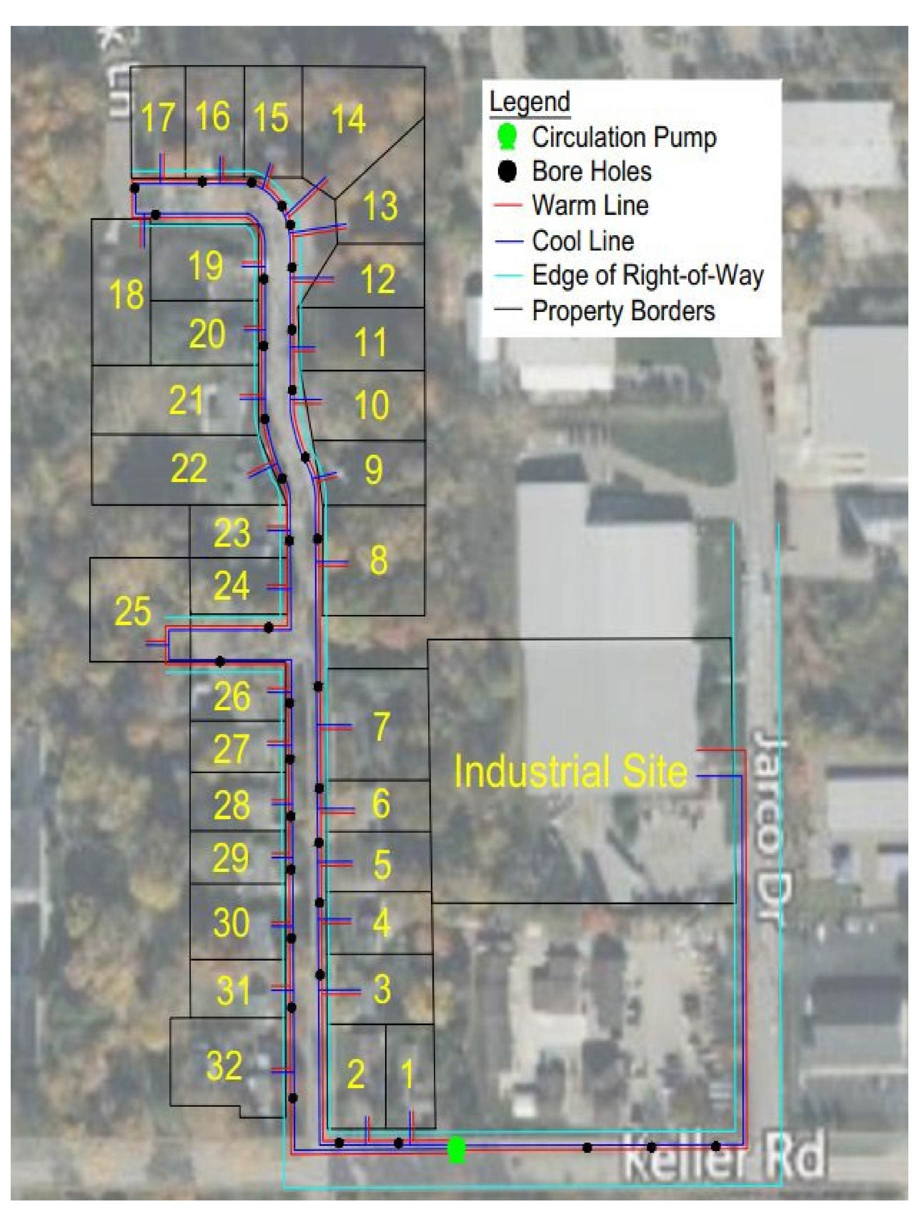

Figure 4. Project Site Map

Case Study

Model Overview

- The excel model was designed to be responsive and adapt to site specific conditions.
- The model contains an inputs table that automatically updates an outputs table of calculated key values. The inputs and outputs tables are shown in Tables 1 and 2.

Table 1. Model Inputs Table

Inputs		
Classification	**Value**	**Unit**
# of Homes	32	
Single Home Heating Load	90.2	mmBtu
Single Home Cooling Load	8	mmBtu
County Wide Residential Natural Gas Usage	[redacted]	mmBtu
Number of Residential Customers	[redacted]	
# of Industrial Sites	1	
Square Footage of Industrial Site	44,000	ft^2
Industrial Site Heating Load	286	mmBtu
Industrial Site Cooling Load	132	mmBtu
County Wide Industrial Natural Gas Usage	[redacted]	mmBtu
Number of Industrial Customers	[redacted]	
Depth of Boreholes	400	ft
Route Distance	5,300	ft

Table 2. Model Outputs Table

Outputs		
Classification	**Value**	**Unit**
Total Length of Piping	40,500	ft
Piping for a Single Home	1,100	ft
Piping for Industrial Site	4,100	ft
Number of Boreholes Needed	51	
Capital Cost	$ 2,688,000	
Net Present Value	$ (3,094,600)	
Levelized Cost of Energy	$ 48	$/mmBtu
CO2 Emissions	85	tons

Table 3. Piping Length Key Equations

Key Equations	
Overall Heat Transfer Coefficient	$U = \left(\frac{1}{h} + \frac{dx_{pipe}}{k_{pipe}}\right)^{-1}$
Convective Heat Transfer Coefficient	$h = \frac{k_{20\%\,glycol}}{D_{pipe}} \times Nu$
Nusselt number	$Nu = 0.023 \times (Re)^{.8} \times (Pr)^{.3}$
Heat Transfer	$Q = UA\Delta T_{LM}$
Surface Area of Pipe	$A = 2\pi\left(\frac{d}{2}\right)L$

Key Calculations

- Heating and cooling loads were used to find the necessary length of piping.
- Length of pipe differed for each load; the longer length determined the system size.
- Heat and mass transfer concepts were used in these calculations, their equations are shown in Table 3.

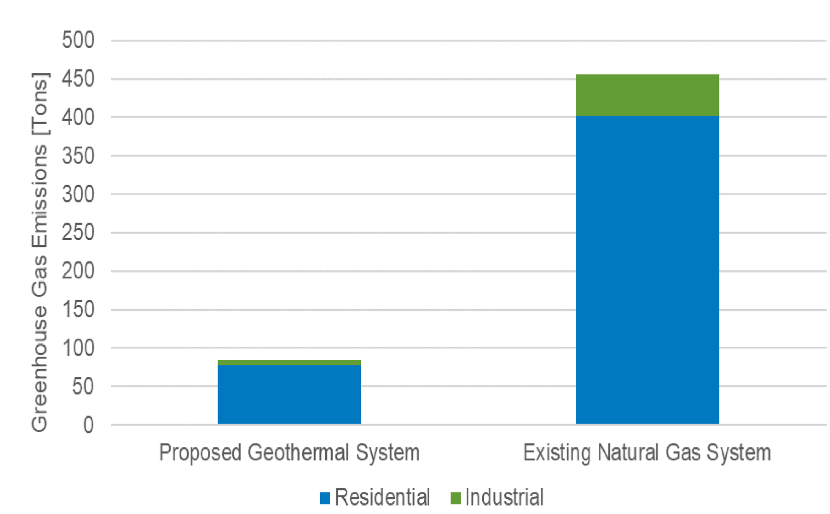

Figure 5. System CO_2 Emissions (Tons)

Sensitivity Analysis

- This sensitivity analysis, in Figure 6, compares the impact different variables have on the levelized cost of energy.
- The slope of the heating and cooling load line is the steepest. It has the largest impact because it relates to the demands of each respective site.
- Economic factors such as natural gas cost, electric cost, and discount rate are the next most influential variables. Each of these factors directly contribute to the cost of the system.

Environmental Analysis

- Figure 5 shows the carbon emissions from the proposed geothermal network to an existing natural gas system.
- The geothermal system's carbon emissions were calculated based on electricity demand of the heat pump.
- The natural gas system's carbon emissions were calculated based on county wide natural gas usage.
- Emissions were reduced by approximately 80%.

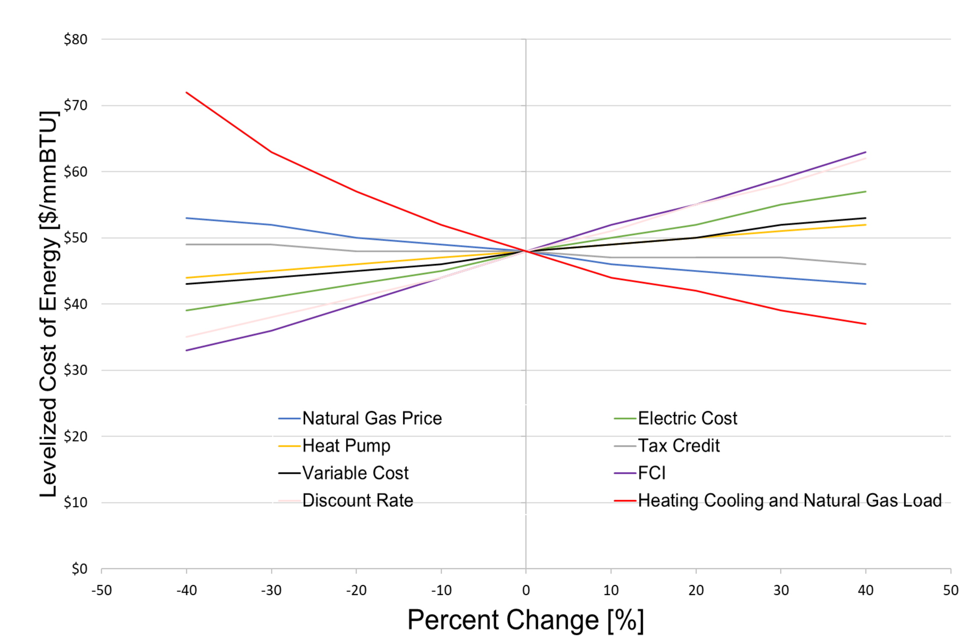

Figure 6. Sensitivity Analysis

Assumptions

1. The model is based on an average residential and industrial heating load in Ingham County.
2. There is ideal heat transfer from the ground to the subsurface piping.
3. No thermal interference between boreholes.
4. The heat pumps run for 12 hr/day and 216 days/year. The heat pumps will heat for 155 days and cool for 61 days.
5. The distance from each house to the main line is 45 feet.
6. The subsurface ground temperature below 6 feet is 55°F. [3]

Economic Analysis

Cost

- Fixed capital investment and annual operation and maintenance, in Table 4.

Table 4. Fixed Capital Costs and Annual O&M Costs

Costs	Amount	Costs	Amount
Direct Cost	$1,642,000	Variable Cost	$44,900
Indirect Cost	$1,046,000	Fixed Cost	$524,200
Fixed Capital Cost	**$2,688,000**	**Annual O&M Cost**	**$569,100**

Revenue

- The difference between the annual operating costs of the geothermal and the existing natural gas systems, shown in Table 5.

Table 5. Annual Savings

Annual Costs	Amount
Geothermal Electric	$44,870
Natural Gas	$59,300
Total Annual Savings	**$14,430**

Analysis

- Net present value and levelized cost of energy, shown in Table 6.
- The analysis was done over a 50-year system lifespan.

Table 6. Profitability Metrics

Net Present Value (NPV)	**$(3,094,600)**
Levelized Cost of Energy (LCOE)	**$48**

Levelized Cost of Energy

The levelized cost of energy represents the cost for the system to produce one mmBtu of energy.

Key Takeaways

- The system can be further optimized by including government benefits, including revenue from the customer, expanding calculations to include thermal grout, and by performing a full life cycle analysis.
- The model is flexible and responsive to site specific conditions.
- Utility scale geothermal energy with diverse heating loads is achievable in Michigan's climate due to the significant reduction in greenhouse gas emissions.

Select References

[1] Carey, K. (2022, March 30). *CMS Energy to combat climate change by achieving net zero greenhouse gas emissions from entire natural gas system by 2050.* Consumers Energy. https://www.consumersenergy.com/news-releases/news-release-details/2022/03/30/13/14/cms-energy-to-achieve-net-zero-greenhouse-gas-emissions-from-natural-gas-system-by-2050

[2] Consumers Energy. (2020). *Consumers Energy service territory map.* https://www.consumersenergy.com/-/media/CE/Documents/company/service-territories/consumers-energy-servie-territory-map-2020.pdf

[3] Otwell, B. (2016, December). *Groundwater – Invisible but precious.* For Love of Water. https://forloveofwater.org/groundwater-invisible-precious/