# Appendix C – Technical, economic, and environmental assessment

The following section outlines the assessments and work completed to determine the technical, economic, and environmental outcomes of installing a community geothermal system within the Bryant Neighborhood. The project goals as part of the SOPO agreement include designing a system that reduces heating and cooling consumption by at least 75% and reduces greenhouse gas emissions by 40%, all while eliminating local energy burden in a low-income, frontline, Justice 40 neighborhood.

Our analysis shows that, with the pairing of home weatherization and rooftop solar PV, our design leads to a 75% reduction in heating and cooling consumption, and greenhouse gas emissions are reduced by 38% with current carbon rates and 75% by 2030 thanks to other initiatives the City and State are working on to decarbonize the electrical grid. At the current rate structure, this combination of strategies projects a 37% reduction in annual energy costs for the neighborhood. This provides a robust solution to significantly lower the energy burden for the Bryant neighborhood, while also providing better indoor air quality and a scalable framework for projects nationwide.

To arrive at these findings, the team undertook the following major steps:

1. Compiled, analyzed, and evaluated existing energy use, energy cost and greenhouse gas emissions for the neighborhood.
2. Created an energy model calibrated to match existing energy consumption.
3. Used load data from the energy model to design and size a geothermal solution.
4. Created a geothermal solution that meets both a focused pilot project and a large-scale deployment.
5. Designed the neighborhood distribution system with input from residents.
6. Analyzed the energy use, energy cost, and greenhouse gas impact for the geothermal solution.
7. Performed a risk assessment to understand project concerns.
8. Assessed efficiency and weatherization options to reduce system size and upfront costs.
9. Explored non-traditional geothermal installation approaches to optimize system size and cost.
10. Provided socio-techno-economic model that includes current and future demand, integrating the results from an optimized geothermal design.

Included in this analysis are the 262 households in the Bryant neighborhood, and 6 commercial buildings. The building energy model results and geothermal data used as part of this analysis have been uploaded to the GDR repository under this project name and number. This data is referenced throughout the following assessment.

**Step One: Compiled, analyzed, and evaluated existing energy use, energy cost, and greenhouse gas emissions for the neighborhood**

To understand the energy usage, cost, and greenhouse gas emissions impacts of community geothermal within the Bryant Neighborhood, the existing energy conditions were compared to a modeled geothermal system. The predictive model assisted in sizing the geothermal bore fields and influenced the choice of installation locations.

The analysis began with an investigation to understand the neighborhood's existing energy usage. The team utilized three main sources of existing energy usage data:

- Home Energy Audits
- Home Utility Data
- Commercial Utility Meter Data

## 1. Home Energy Audits (See App. H, File 1)

40 households took part in an energy audit as part of the ongoing efforts to decarbonize the Byrant neighborhood, which provided an inventory of the HVAC equipment, envelope values, and electricity and gas use profiles of each household. This data was used to better understand the existing conditions and typical settings of the home.


*Figure 1: Energy Audit Data (Data available in GDR under App. H, File 1)*

The homes were equally split into three distinct energy performance groupings: Best (45 – 66 EUI), Middle (66 – 88 EUI), and Worst (88+ EUI). This split was created to more accurately scale the energy model to represent all 262 homes (Figure 2; Data available in GDR under App. H, File 1).

Trends showing occupant activity and habits were pulled from the data to better inform the model. This included:

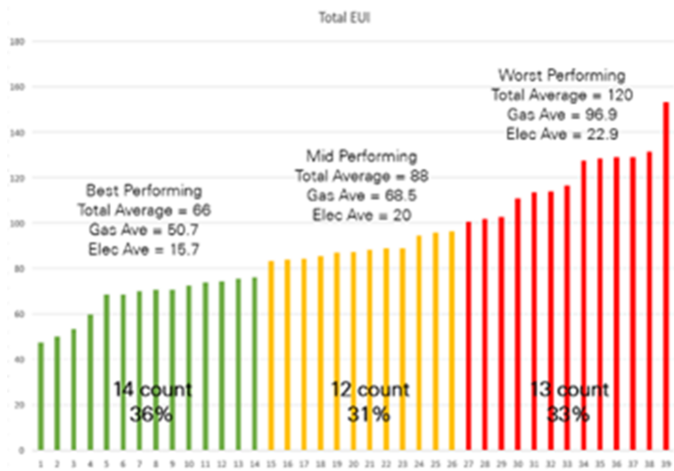



*Figure 1: Figure XX: Energy Performance Buckets (Homes) - Energy Audits*

1. *Infiltration*: The infiltration rate for the Best performing homes was 30 $ft^3/hrft^2$, Middle was 34 $ft^3/hrft^2$, and Worst was 47 $ft^3/hrft^2$. Infiltration has a big effect on small buildings like single-family homes, and energy model inputs are consistent with this pattern (Figure 3).

2. *Roof R-Value*: The Best performing homes had an average roof R-value of 37, Middle was 29, and Worst was 24 (Figure 4). This similarly has a large effect on the homes' energy use and makes a case for weatherization within some of the poorer performing homes.

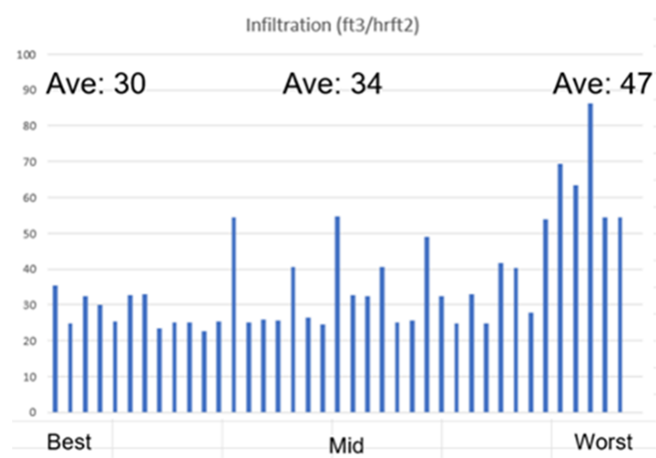



*Figure 2: Energy Audit Home Infiltration Trend (Data available in GDR under App. H, File 29)*

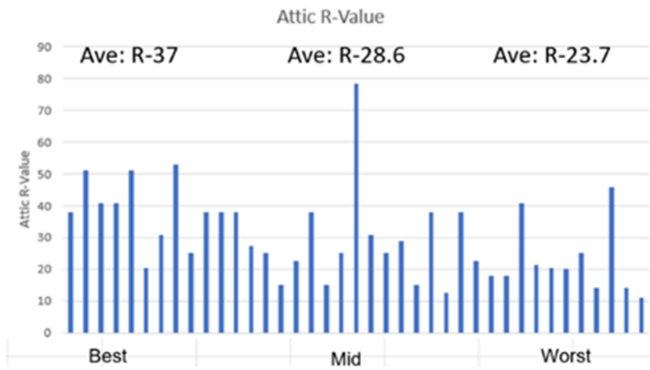
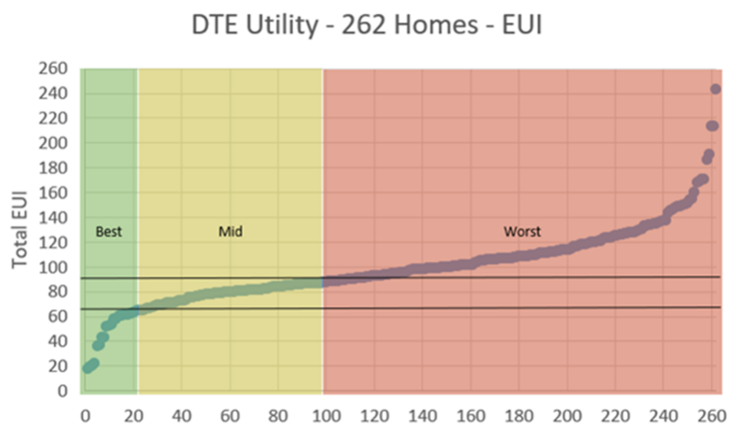



*Figure 4: Energy Audit Home Roof R-Value Trend (Data available in GDR under App. H, File 29)*




## 2. Home Utility Data

The local utility, DTE, provided the daily gas and electric consumption profiles for all 262 households in the neighborhood. This allowed the team to analyze total neighborhood performance. It was determined that 158 households fell in the Worst energy performance group, 79 fell in the Middle category, and 25 in the Best. (Figure 5: Energy Performance Buckets (Homes) – Utility (Data available in GDR under App. H, File 2)).

## 3. Commercial Utility Meter Data

Existing electric and gas meter data was collected for each of the commercial buildings within the project footprint. This data provided the utility profiles and EUIs which were used as targets to calibrate the energy model.

*Figure 3Figure XX: Energy Performance Buckets (Homes) - Utility*

The energy modeling inputs (load profiles and EUI breakdown) for the households was further informed by NREL's ResStock Database and DOE's Prototype Buildings. The below figures depict the EUI breakdown and the consumption profile of a typical single-family home from NREL's ResStock. This summary was based on data of nearly 19,000 homes in Michigan.

| NREL Michigan Data EUI Breakdown | | |
| --- | --- | --- |
| | EUI | % |
| Ceiling Fan | 0.2 | 0.2% |
| Clothes Dryer | 0.9 | 1.0% |
| Clothes Washer | 0.1 | 0.1% |
| Cooling Fans | 0.7 | 0.8% |
| Cooling | 3.5 | 3.7% |
| Dish Washer | 0.3 | 0.3% |
| Freezer | 0.8 | 0.8% |
| Heating Fans & Pumps | 1.2 | 1.3% |
| Exterior Lighting | 0.2 | 0.2% |
| Interior Lighting | 2.3 | 2.5% |
| Mechanical Ventilation | 0.1 | 0.1% |
| Plug Loads | 5.3 | 5.7% |
| Oven (Electric) | 0.6 | 0.6% |
| Oven (Gas) | 2.2 | 2.4% |
| Refrigerator | 1.6 | 1.7% |
| Gas heating | 61.7 | 66.3% |
| Gas Water Heating | 11.5 | 12.3% |
| Total | 93.2 | 100.0% |

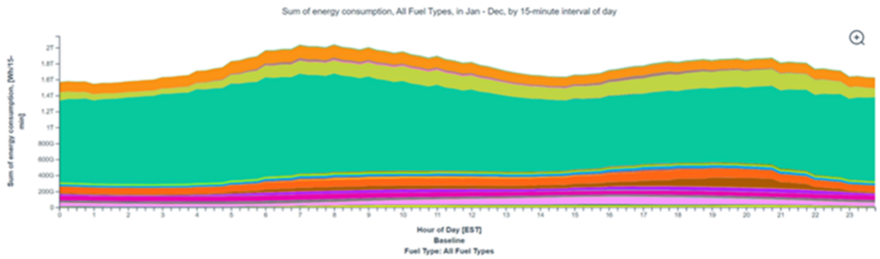



*Figure 6: Benchmark EUI breakdown and profile*
*(Data available in GDR under App. H, File 4-5)*

**Step Two: Created an energy model calibrated to match existing energy consumption**

Using data from above, the team built the geometry, systems, and usage/occupancy profiles for the neighborhood into the Energy Plus simulation engine. Using the above references, the energy model was calibrated to best simulate existing conditions, and the results informed the energy demand/loads for each of the existing buildings. The following figures for the home energy performance groups and Bryant Elementary School are examples of the close correlation between the existing data and the energy model. *(Data available in GDR under App. H, Files 7-9, 16, 18, 20, 22-25)*

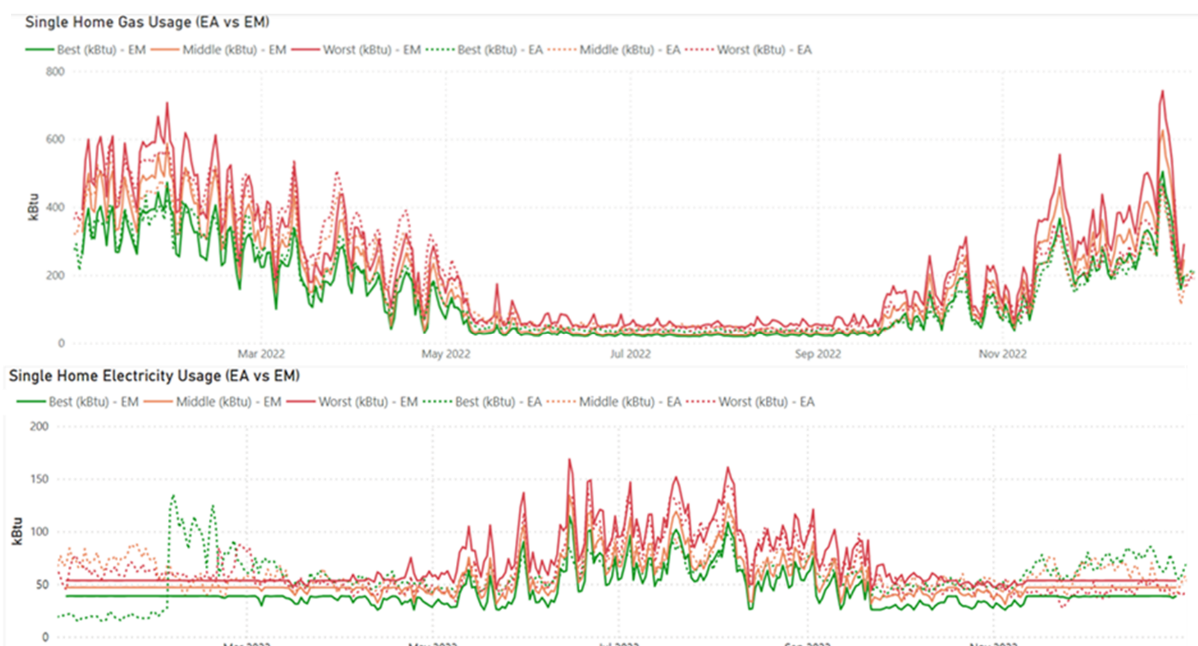



*Figure 7: Electric and Gas Profiles for Home Energy Performance Buckets (Existing vs Energy Model)*

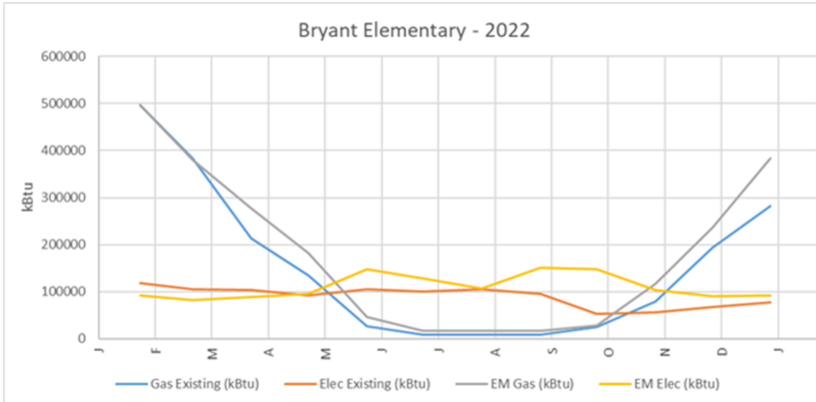
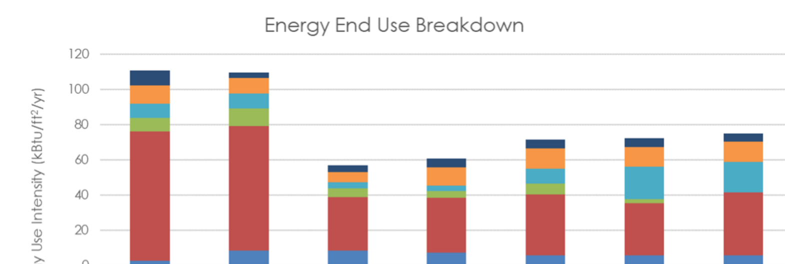


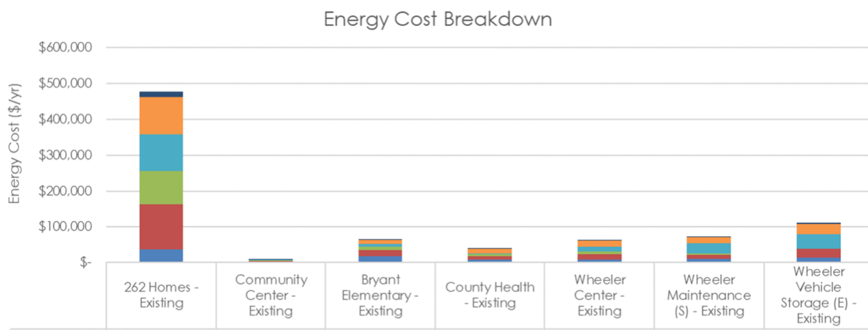

*Figure 8: Electric and Gas Profiles for Bryant Elementary (Existing vs Energy Model) (Data available in GDR under App. H, File 3)*

Next, the team dove deeper into exactly how energy was being used in each household to help determine the impact of weatherization, efficiency, and onsite generation (Figure 9). A cost estimate for each energy source was also estimated (Figure 10) as well as the greenhouse gas emissions associated with existing energy usage profiles (Figure 11). These findings point to significant opportunities to reduce load through energy efficiency and weatherization improvements – an important part of the overall Bryant decarbonization initiative.



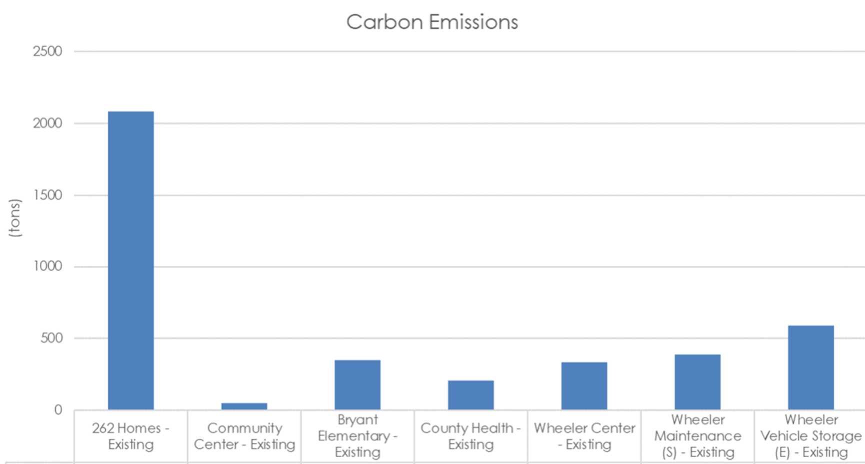

| | 262 Homes - Existing | Community Center - Existing | Bryant Elementary - Existing | County Health - Existing | Wheeler Center - Existing | Wheeler Maintenance (S) - Existing | Wheeler Vehicle Storage (E) - Existing |
|---|---|---|---|---|---|---|---|
| DHW | 8.8 | 2.9 | 3.8 | 5.2 | 5.0 | 5.0 | 5.0 |
| Receptacles | 10.3 | 9.2 | 5.8 | 10.2 | 11.4 | 11.4 | 11.4 |
| Fans | 8.1 | 8.4 | 3.3 | 2.9 | 8.5 | 18.2 | 17.1 |
| Pumps | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cooling | 7.4 | 9.9 | 5.1 | 4.2 | 6.3 | 2.4 | 0.0 |
| Heating | 73.4 | 70.8 | 30.2 | 30.8 | 34.3 | 29.3 | 35.7 |
| Lighting | 2.9 | 8.3 | 8.6 | 7.5 | 5.9 | 5.9 | 5.9 |

*Figure 9: EUI Breakdown for All Buildings (Data available in GDR under App. H, File 29)*




| | 262 Homes - Existing | Community Center - Existing | Bryant Elementary - Existing | County Health - Existing | Wheeler Center - Existing | Wheeler Maintenance (S) - Existing | Wheeler Vehicle Storage (E) - Existing |
|---|---|---|---|---|---|---|---|
| DHW | $15,273 | $126 | $2,098 | $1,579 | $1,981 | $2,072 | $3,262 |
| Receptacles | $103,409 | $1,488 | $11,983 | $11,628 | $17,007 | $17,749 | $28,123 |
| Fans | $101,787 | $1,363 | $6,708 | $3,315 | $12,659 | $28,333 | $42,120 |
| Pumps | $13 | $0 | $1 | $1 | $11 | $7 | $1 |
| Cooling | $93,595 | $1,603 | $10,408 | $4,781 | $9,349 | $3,799 | $0 |
| Heating | $127,215 | $3,065 | $16,466 | $9,360 | $13,628 | $12,150 | $23,430 |
| Lighting | $36,172 | $1,356 | $17,709 | $8,527 | $8,786 | $9,169 | $14,529 |

*Figure 10: Energy Cost Breakdown for All Buildings (Data available in GDR under App. H, File 29)*




| | 262 Homes - Existing | Community Center - Existing | Bryant Elementary - Existing | County Health - Existing | Wheeler Center - Existing | Wheeler Maintenance (S) - Existing | Wheeler Vehicle Storage (E) - Existing |
|---|---|---|---|---|---|---|---|
| Carbon | 2,083 | 48 | 346 | 208 | 336 | 387 | 590 |

*Figure 11: Carbon Emissions for All Buildings (Data available in GDR under App. H, File 29)*

**Step Three: Used load data from the energy model to design and size a geothermal solution**

With the now modeled heating and cooling loads in the table below, the sizing requirements for the geothermal bore fields were performed. The analysis was completed with Gaia Geothermal, GLD (Ground Loop Design) Premier Edition Software. The simulation considers various factors including the heating and cooling loads, ground thermal properties, equipment performance, and piping and fluid variables. The below figures and table show examples of the software's output. The calculation results for the 262 homes shows that 180 wells, each 700' deep, would provide the maximum 7,715 MBH (643 tons) of heating capacity necessary while maintaining a minimum water temperature of 35$^{o}$F as intended. The graph in Figure 12 shows the anticipated supply temperature from the geothermal field throughout the year.

**Calculation Results**

Roughly 196 ft/ton

| Design Method: *Hourly* | COOLING | HEATING |
|---|---|---|
| Total Bore Length (ft): | 126000.0 | 126000.0 |
| Borehole Number: | 180 | 180 |
| Borehole Length (ft): | 700.0 | 700.0 |
| Ground Temperature Change (°F): | N/A | N/A |
| Peak Unit Inlet (°F): | 72.6 | 35.9 |
| Peak Unit Outlet (°F): | 79.3 | 30.0 |
| Total Unit Capacity (kBtu/Hr): | 5300.2 | 7714.9 |
| Peak Load (kBtu/Hr): | 5300.2 | 7714.9 |
| Peak Demand (kW): | 320.9 | 661.2 |
| Heat Pump EER/COP: | 16.4 | 3.4 |
| Seasonal Heat Pump EER/COP: | 18.9 | 3.8 |
| Avg. Annual Power (kWh): | 2.28E+5 | 9.54E+5 |
| System Flow Rate (gpm): | 1325.1 | 1928.7 |

*Table 1: Example of Geothermal Sizing Results (Homes Only – 700 ft) (Data available in GDR under App. H, File 28)*

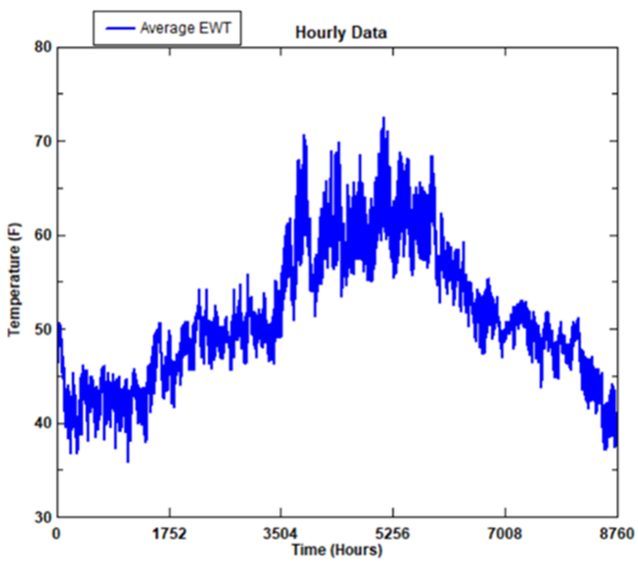



*Figure 12: Example of Geothermal Entering Water Temperature (Homes Only – 700 ft) (Data available in GDR under App. H, File 28)*

The following table (Table 2) provides these loads grouped into different scenarios 1) 262 Homes Only, 2) North Loop Loads, 3) South Loop Loads, and 4) All Buildings. Both 500-ft and 700-ft bores lengths were analyzed for each scenario. The result of this sizing analysis includes the entering water temperature over the year, the capacity of the system, and the system flow rate. This further helped refine the energy model's geothermal simulation and the layout of the geothermal loops.

| | Homes only | All north loads | All south loads | All loads |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Cooling peaks (tons) | 442 | 562 | 160 | 722 |
| Heating peaks (tons) | 655 | 768 | 368 | 1136 |
| # bores (@700') | 180 | 200 | 90 | 280 |
| # bores (@500') | 260 | 280 | 130 | 400 |
| ln ft bore/heating ton | 202 | 185 | 184 | 180 |
| Cooling gpm | 1325 | 1617 | 473 | 1930 |
| Heating gpm | 1928 | 2273 | 1061 | 3334 |
| Min loop temp | 35.6 | 35.5 | 35.5 | 35.2 |
| Max loop temp | 72.9 | 73.5 | 67.2 | 71.2 |

*Table 2: Building Loads and Geothermal Sizing (Data available in GDR under App. H, File 29)*

**Step Four: Created a geothermal solution that meets both a focused pilot project and a large-scale deployment**

To determine the best locations for geothermal in the neighborhood that team began with an overall aerial assessment of the entire neighborhood. The graphic below shows potential locations that were evaluated in total area available to install geothermal.


**Borehole Siting Options**

- ~ 1000 - 1500 ton system
- Goal = 200k - 300k sf

| | Priority/Realistic | Total Area (sf) |
|---|---|---|
| Green | High | 668k |
| Yellow | Medium | 748k |
| Red | Low | 608k |

*Figure 13: Aerial depiction of the Bryant neighborhood and proposed geothermal system.*

This initial site survey demonstrated an abundance of space for installation, but not all spaces were the right fit for the project. Each site was ranked as low, medium, or high priority, with high priority sites being the highest contenders for installation. As indicated in the yellow and red areas, low and medium priority sites face additional restrictions based on ownership, site access, utilities, right of way, and premium cost implications.

The key considerations to guide the field selection of similar future projects include:

- Targeting a centralized location that can minimize pipe runs to homes/buildings.
- Ability for creation of multiple sub-loops by which the piping can be downsized, and this reduces installation costs for utility scale distribution.
- Roadway distribution systems are an outsized component of the cost, potentially higher than installing the geothermal wells themselves. When possible, finding other places for distribution system installation could be beneficial or installing when roads are already under construction can help lower costs.
- Ownership barriers should be considered from the beginning. Installing wells on private property introduces both short- and long-term coordination challenges. Moreover, centralized systems may increase the speed of installation and deployment (versus having a single bore in each backyard).
- Backyard areas are attractive because of lack of utility, but access for ongoing maintenance and the high volume of coordination with homeowners is a very high barrier.
- Easements are a potential location for wells but often contain other existing utilities making space competition, and potentially cost implications, an impediment.
- Installing district geothermal is disruptive. Project sequencing and sustained public engagement is key to minimizing disruption with neighborhood/homes.
- Efficiencies of scale are key and finding ways to align with other construction schedules is a prime way of minimizing disruption while lowering costs (e.g., install loops while water mains are being replaced).
- Sustained engagement is essential, including having a standing place / person that people can go to in order to learn about the project (that was the Bryant Community Center for this project).

Based on these factors, the team narrowed down potential field thermal locations to those shown below. The fields include the central park and school greenspace on the North portion of the site, and commercial building parking areas and greenspace on the South.

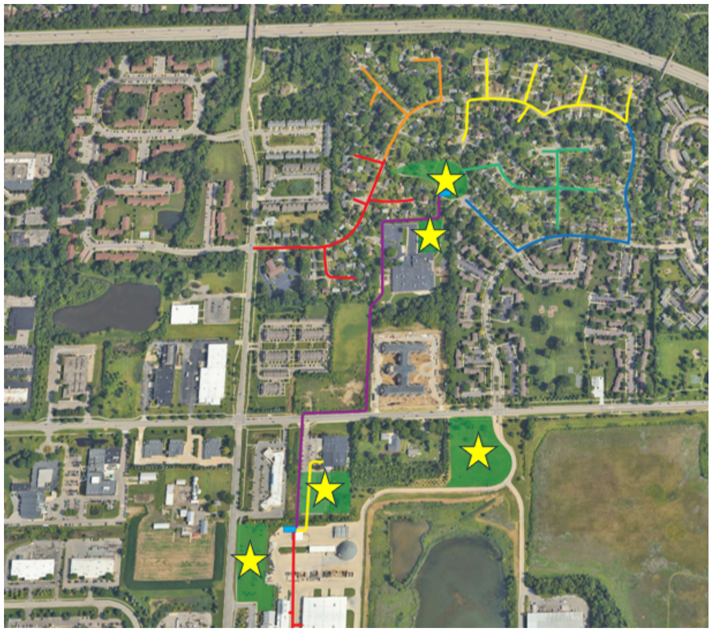


*Figure 14: Planned bore field locations.*

Geothermal Solution Layout - North and South Loops

Based on building load sizing and geothermal bore field availability, it was determined the system can be split into 2 different geothermal loops, with a connection between the loops for shared resources and resiliency. The North loop is located north of E. Ellsworth Road and includes the 262 households within the Bryant neighborhood, Bryant Elementary, and the Bryant Community Center. The South loop is located south of E. Ellsworth Road and includes the County Health Facility and the Wheeler Center buildings. By dividing the neighborhood-scale geothermal system into these two loops, phasing and planning can be achieved on a greater scale to minimize impacts on the neighborhood.


*Figure 15: Graphic of north and south loop.*

<u>Full Loop Design</u>

The figure below showcases the layout for the entire neighborhood in more detail. This includes the placement of pump houses, and a preliminary layout for neighborhood distribution. The detail showcases the distribution system's connection into each individual home. The North loop is a network of multiple smaller, inter-connected loops: Red, Orange, Yellow, Green, Blue, and Purple. These smaller scale geothermal loops are laid out to allow for optimized installation through a phased construction approach.


*Figure 16: Layout of distribution and pump homes.*

<u>North Bore Fields Connection</u>

The feasible spacing and layout of the bores were mapped on the potential field sites, along with the placement of vaults and pump houses.

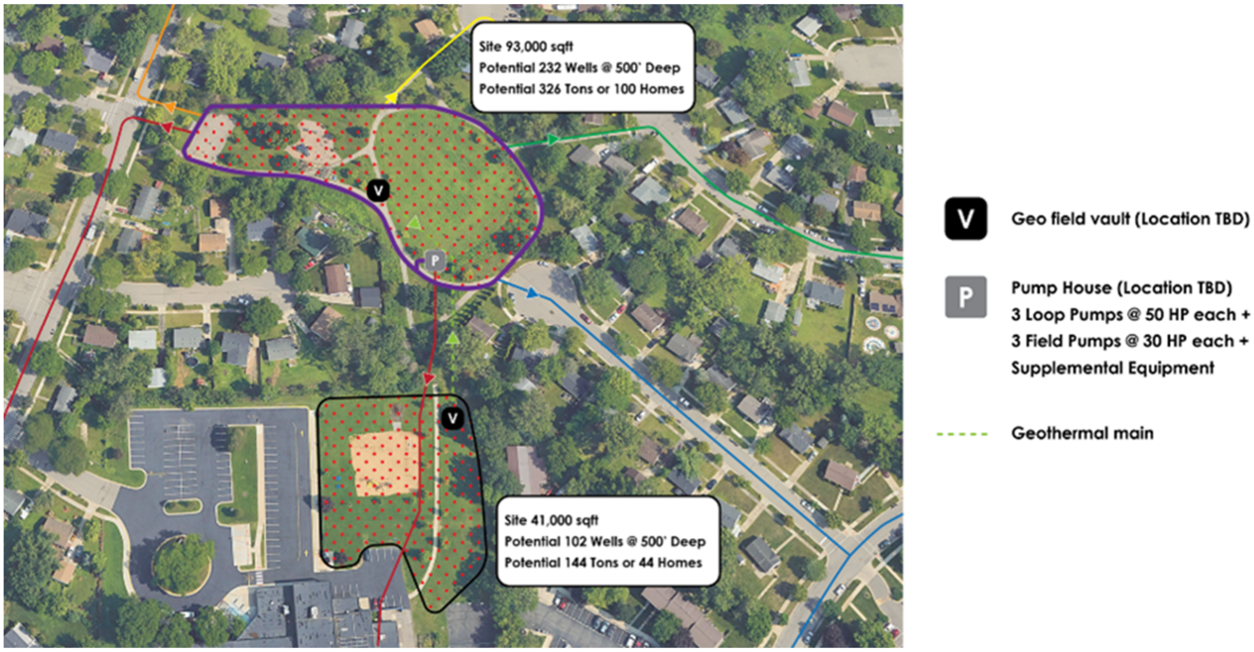



*Figure 17: Layout of geothermal bore field (North loop).*

<u>Geothermal field design</u>

The base system design is a conventional vertical closed loop geothermal system. These systems consist of a series of wells with tubing grouted in place, and these wells are piped and grouped together, and a heat transfer fluid is pumped through the pipes and wells to exchange heat with the ground. The parks and open space adjacent to the school in the center of the residential area within the north loop were chosen as the most suitable location for drilling due to its size, location, and ability to provide the majority of the wells needed for the system, thereby reducing neighborhood disruption and lowering project costs.

**Step Five: Designed the neighborhood distribution system with residents**

The neighborhood distribution design is every bit as important to the project as the geothermal bore design. On paper, routing seems straightforward, but it required major collaboration.

The project team coordinated with the City of Ann Arbor Department of Public Works to figure out pathways both behind the homes and through the main streets to run the distribution system. The graphic below is an overview of the major utilities located in the streets. This includes gas, sanitary, common electricity, and water.

*Figure 18: Distribution of neighborhood piping*

Discussion and review of the plans show that there is adequate space available to route the geothermal in the same corridor as the other utilities. Ultimately, all agreed that routing of mains through the streets would be the most feasible path forward. The image shows general routing for the main piping with lateral extensions to each home. The team agreed that directional boring of this piping is possible to achieve distribution goals, but in some areas open cutting will be required to install valving, work through complicated utility crossing areas, and allow access.

As the fluid travels out of the central bore fields, it will be routed into multiple loops. As shown in the image below (Figure 19), each color represents a different loop. Loops are separated to allow for reduced pipe sizing through the streets and allows for potential phasing of system installation. Note the black lines between the loops are interconnections that allow for back feeding of loops in the event of a service disruption on part of the system. This design allows for increased redundancy, as homes will be backed by the other sub-loops. The red circles indicate locations of manholes and small vaults that allow access to the utility for isolation purging and maintenance.

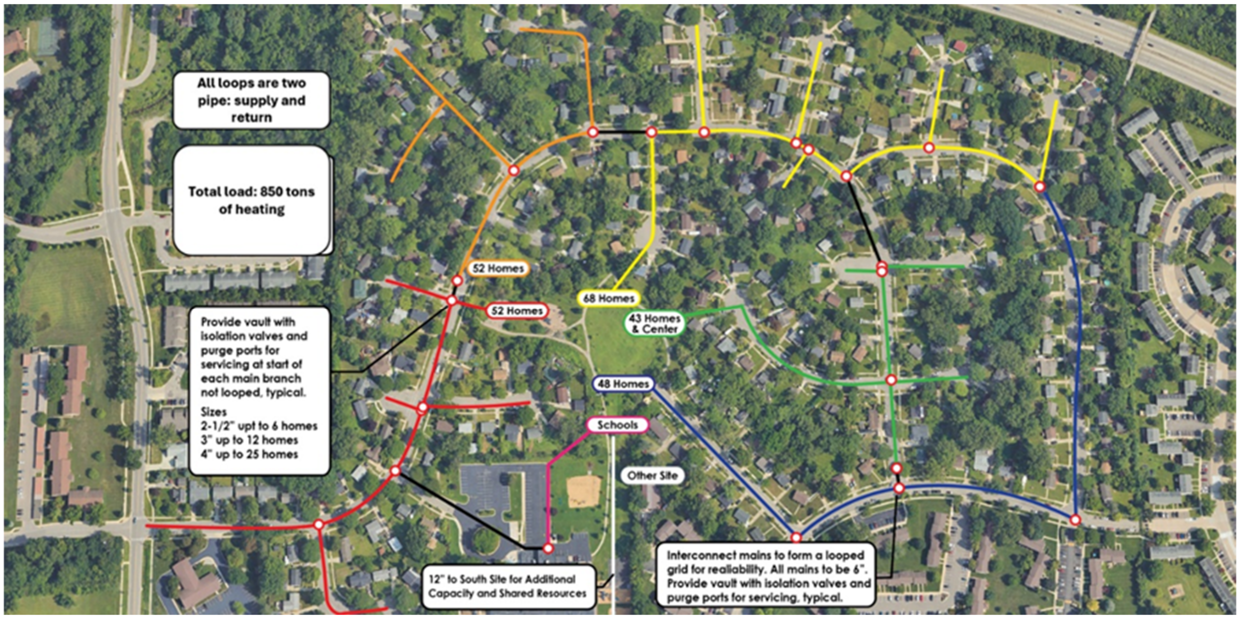



*Figure 19: Subloops of the neighborhood distribution*

General pipe sizing in a typical section of the loop is shown below (Figure 20). Pipe sizes are 6-to-8 inches throughout the neighborhood. The exception would be at the interconnection to the southern site, across E. Ellsworth Road. Here we would expect a 10-to-12-inch pipe to transfer geothermal water back and forth between the sites, which allows the sharing of load.

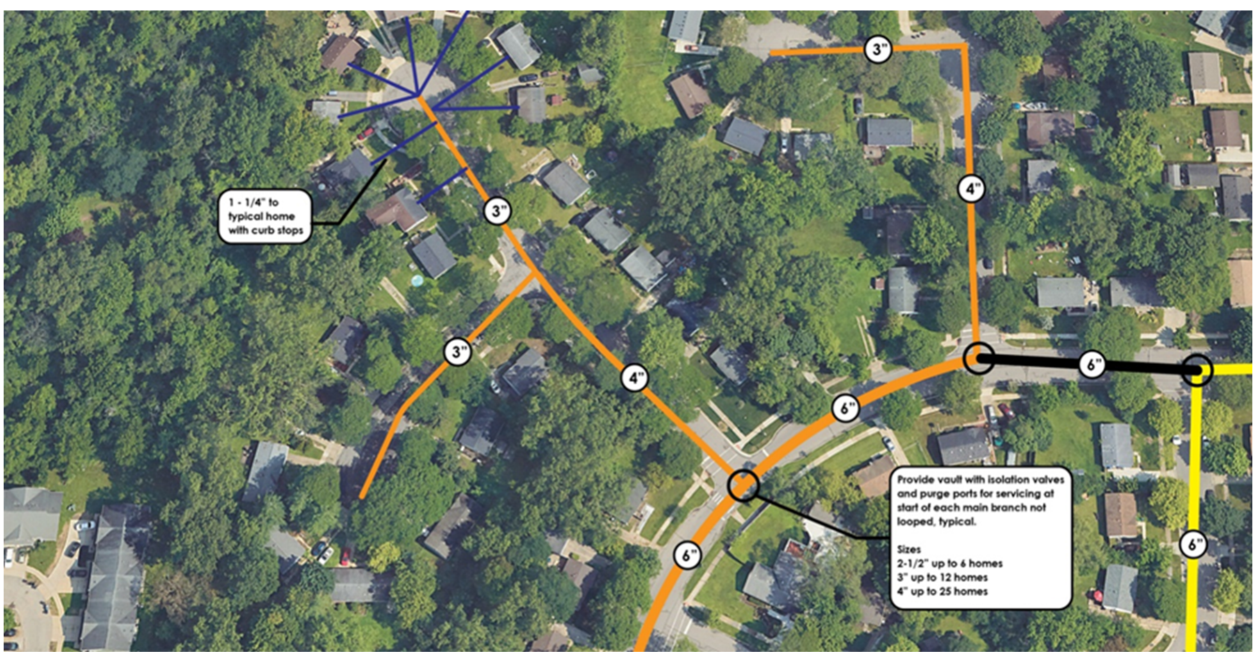



*Figure 20: Piping sizes in typical street*

This following graphic shows a plan view of a typical cul-de-sac, with the existing utilities in the thinner lines and the geothermal utility in the blue line (Figure 21). The dimensioned detail below it shows a section view of the right of way and the other utilities. The pair of geothermal pipes are being proposed to be routed at the location shown. This would be accomplished via directional boring under the streetscape and between the other utilities. Directional boring will allow for weaving between the other utilities, while not requiring many open saw cuts and lots of disruption to the right of ways.

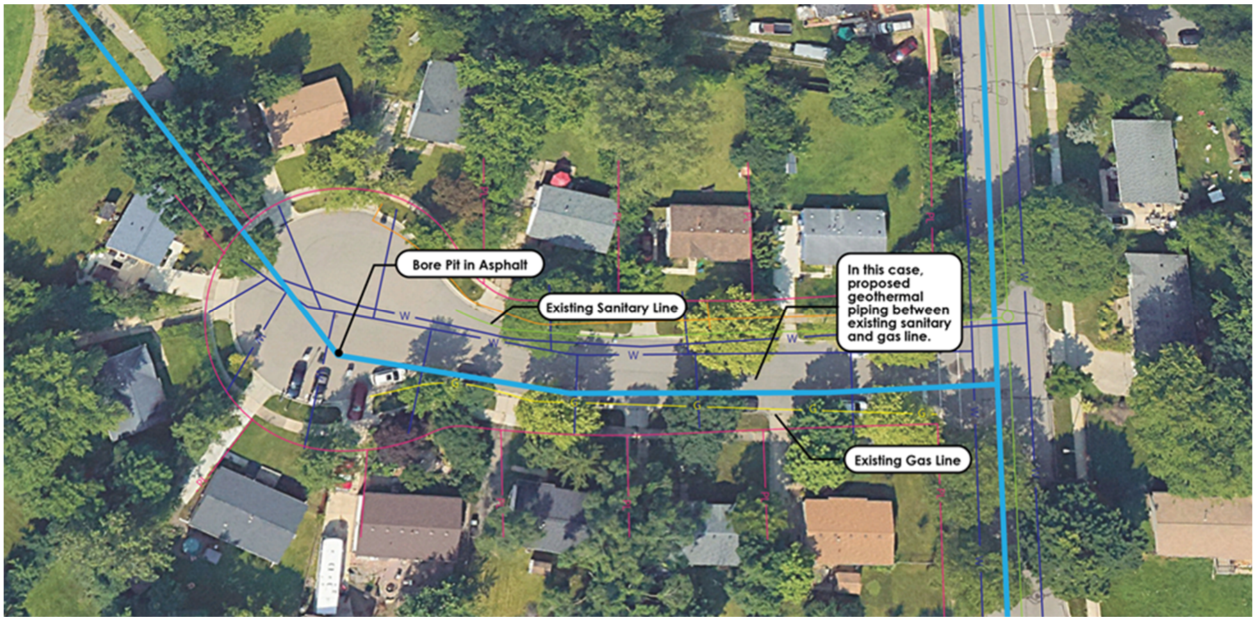



*Figure 21: Image of a cul-de-sac with existing utilities and geothermal system overlay.*

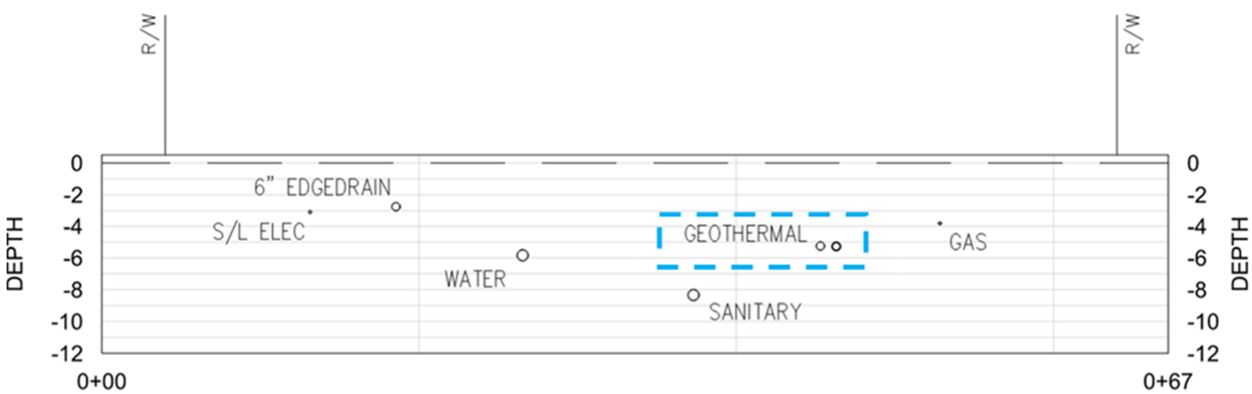



*Figure 22: Location of utilities within the street.*

<u>Connecting to Homes</u>

The typical connection to each home is shown below. Connected to the main pipe under the street, an initial stub would be installed right up to the utility easement. A curb stop shut off valve will be provided on both the supply and return at this location. The curb stop also provides isolation between the home and utility network in case of disruption. From here each home would be connected as it is brought online. The lines to the home would be directionally bored to avoid existing utilities and then pop up into the crawl space below each home. From there, the piping would be routed underfloor to the heat pump in the home's utility closet. A photo of the existing neighborhood roads also depicts the conditions and scale of these connections.

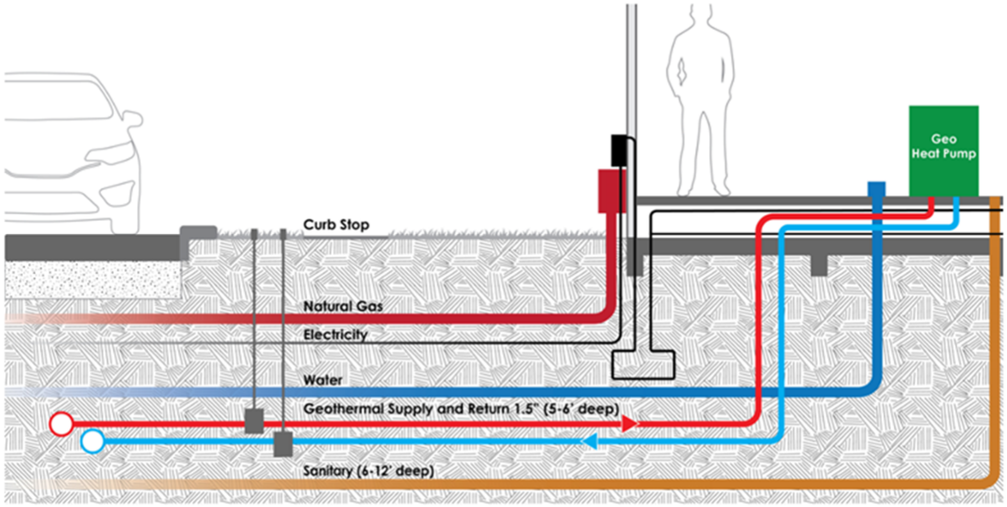



*Figure 23: Detail of geothermal connection to home heat pump*

*Figure 24: Photograph of typical Bryant Neighborhood street*

<u>In-Home Heat Pumps</u>

The team has confirmed that three different heat pumps options are available for the homes in Bryant. The team performed a site visit of some of the existing homes and determined that both the ranch-style family homes with existing furnace and water heater have adequate space for the heat pumps in the hallway closet. Split level homes include a mechanical basement room with space for many configurations.  All homes also have the option of an outdoor unit.

These three options vary both in configuration, overall size, and adaptability for different home situations. This allows each homeowner to have at least one or two solutions that can work for them, giving them choice in operational in-home design. Since the homes have existing air conditioning units and the new geothermal heat pumps have a lower electrical demand, the electrical service capacity to each home is expected to be adequate for the installation.

Description of the three units used as basis of design are included in Table 3.

| | Heat pump unit | Domestic Hot Water |
|---|---|---|
| Option 1 | Indoor/outdoor split | Remain gas or convert to heat pump |
| Option 2 | Indoor/indoor split | Electric on demand in closet or heat pump in laundry room |
| Option 3 | Packaged indoor heat pump | Electric on demand or heat pump in laundry room |

*Table 3: Options for in-home heat pump units*

Option 1 places an indoor air handling unit in the same footprint as the existing furnace. The outdoor heat pump and compressor would be located outside the home and connected via a refrigerant circuit. The domestic hot water heater could remain as is or be converted to a heat pump (assuming adequate makeup heat from the hallway). Alternatively, a domestic hot water heater could be placed in the laundry room, assuming that the washer and dryer are converted to a stacked unit. The benefits of this approach include:

- The outdoor unit allows for ease of ongoing maintenance if the system is owned by the utility. Not as much coordination with entering the home.
- Allows for more interior closet space, flexibility with domestic hot water heater

The drawbacks of this approach include:

- Less centralized equipment
- Outdoor equipment has reduced life compared to indoor equipment

After many discussions with several project stakeholders, it became apparent that the split system option may be the more viable option from a utility ownership perspective. This is because from the City and utility perspective, entering private homes is a barrier to utility operations.

Option 2 places an indoor air handling unit in the same footprint as the existing furnace. The split unit with compressor would be placed in the same closet as shown in the sketch below. The domestic hot water heater would need to be converted and or re-located. An on-demand electric water heater could be placed in the utility closet to condense appliances into one centralized location. Alternatively, an electric on-demand water heater or domestic hot water heat pump could be placed in the laundry room, assuming the washer and dryer are converted to a stacked unit. The benefits of this approach are that all equipment is in one centralized place and the lifespan of the indoor compressor unit is longer compared to an outdoor unit. The drawbacks are that access to the inside of a resident's home makes maintenance more difficult and the centralized system reduces interior square footage if the domestic hot water system is relocated.

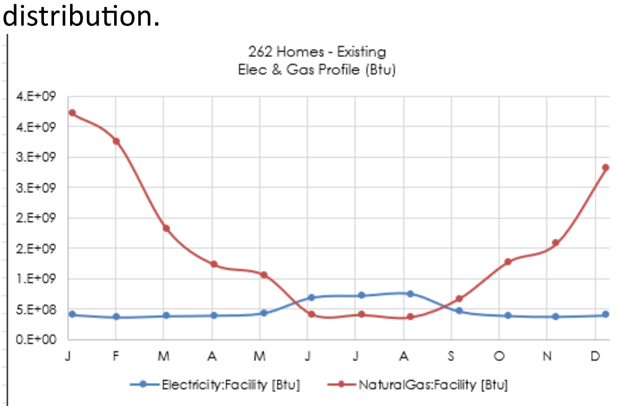
Option 3 places a fully packaged indoor air handling unit in the closet. Due to the configuration and unit size, this is the only equipment that could be in the existing furnace space. The domestic hot water heater would need to be converted and re-located. Alternatively, an electric on-demand water heater or domestic hot water heat pump could be placed in the laundry room, assuming the washer and dryer are converted to a stacked unit. The benefits of this approach are that all equipment is in one centralized place and the lifespan of the indoor compressor unit is longer compared to an outdoor unit. The drawback is that access to the inside of a resident's home makes maintenance more difficult and the centralized system reduces interior square footage if the domestic hot water system is relocated.

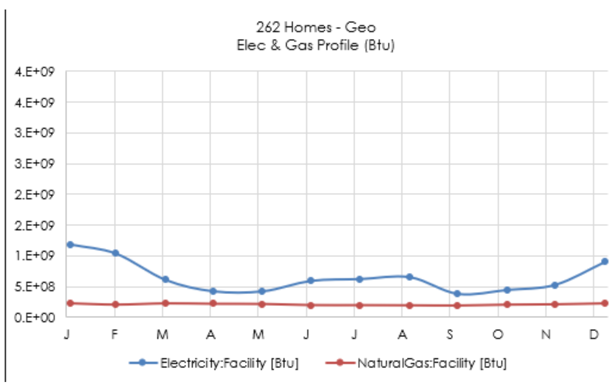
**Step Six: Analyzed the energy use, energy cost, and greenhouse gas impact for the geothermal solution**

Based on the above design considerations and decisions, the team developed a model of the potential energy, carbon and cost savings associated with deploying community geothermal. The existing systems were changed to geothermal heat pumps in the energy model, with an average cooling COP of 5.8 and average heating COP of 4.

<u>Energy Consumption</u>

The highly efficient geothermal system shows significant total energy reductions, nearly 46%, that are achieved across the neighborhood. This includes all end uses from heating and cooling to lighting and plug loads. Inputs and assumptions for the geothermal system energy model can be found in the GDR under Appendix H, File 29. The following graphs show how the electric and gas profiles change from the existing conditions to the geothermal system in the 262 homes. The raw energy usage reduction can be seen by the significant reduction in overall Btu. The electric profile now picks up both heating and cooling, peaking in the winter and summer, and the gas profile is constant, picking up only domestic hot water. The commercial buildings follow the same distribution.




*Figures 26 and 26: Bryant Neighborhood Energy, Cost, and Carbon (Existing vs Geothermal) (Data available in GDR under App. H, File 29)*

The following table (Table 4) shows the energy statistics for the entire neighborhood, broken up by building and energy end use with just the installation of a geothermal system. The percent savings are individually outlined for each building within the larger table. The cumulative reductions for all buildings are shown on the right.

| | 262 Homes - Existing | 262 Homes - Geo | Community Center - Existing | Community Center - Geo | Bryant Elementary - Existing | Bryant Elementary - Geo | County Health - Existing | County Health Geo | Wheeler Center - Existing | Wheeler Center - Geo | Wheeler Maintenance (S) - Existing | Wheeler Maintenance (S) - Geo | Wheeler Vehicle Storage (E) - Existing | Wheeler Vehicle Storage (E) - Geo | Central Geo Pumping (Homes Only) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lighting** | 2.9 | 2.9 | 8.3 | 8.3 | 8.6 | 8.6 | 7.5 | 7.5 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | |
| **Heating** | 73.4 | 15.7 | 70.8 | 14.4 | 30.2 | 10.6 | 30.8 | 10.9 | 34.3 | 12.1 | 29.3 | 10.4 | 35.7 | 12.6 | |
| **Cooling** | 7.4 | 5.1 | 9.9 | 8.6 | 5.1 | 4.2 | 4.2 | 3.5 | 6.3 | 5.2 | 2.4 | 2.0 | 0.0 | 0.0 | |
| **Pumps** | 0.0 | 0.4 | 0.0 | 4.1 | 0.0 | 3.1 | 0.0 | 3.1 | 0.0 | 3.1 | 0.0 | 3.1 | 0.0 | 3.1 | 3.3 |
| **Fans** | 8.1 | 3.4 | 8.4 | 4.4 | 3.3 | 2.2 | 2.9 | 1.9 | 8.5 | 5.6 | 18.2 | 12.1 | 17.1 | 11.3 | |
| **Receptacles** | 10.3 | 10.3 | 9.2 | 9.2 | 5.8 | 5.8 | 10.2 | 10.2 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 | |
| **DHW** | 8.8 | 8.8 | 2.9 | 2.9 | 3.8 | 3.8 | 5.2 | 5.2 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | |
| **EUI** | **110.8** | **46.5** | **109.5** | **51.9** | **56.8** | **38.5** | **60.7** | **42.3** | **71.4** | **48.4** | **72.3** | **49.9** | **75.1** | **49** | **3.3** |
| | **Savings:** | 64.3 | **Savings:** | 57.6 | **Savings:** | 18.3 | **Savings:** | 18.5 | **Savings:** | 23.0 | **Savings:** | 22.4 | **Savings:** | 25.8 | |
| | | 58.0% | | 52.6% | | 32.3% | | 30.4% | | 32.2% | | 31.0% | | 34.3% | |

| Whole Neighborhood - Existing | Whole Neighborhood - Geo |
|---|---|
| | |
| 24,138,552 | 6,231,869 |
| 2,448,037 | 1,804,210 |
| **26,586,590** | **8,036,079** |
| **Savings:** | **70%** |
| | |
| **kbtu** | |
| **40,967,134** | **22,087,933** |
| **Savings:** | 18,879,201 |
| | **46%** |

*Table 4: Bryant Neighborhood Energy (Existing vs Geothermal)*
*(See App. H, File 29)*

Isolating just the heating and cooling consumption for the entire neighborhood, the energy reduction between existing conditions and the proposed system reaches 70%.

Additional strategies like weatherization and solar PV, discussed in the next section, set the neighborhood up to continue to reduce heating and cooling consumption. With the integration of all the energy reduction strategies, total energy consumption for the entire neighborhood is projected to decrease by 62% compared to existing conditions.

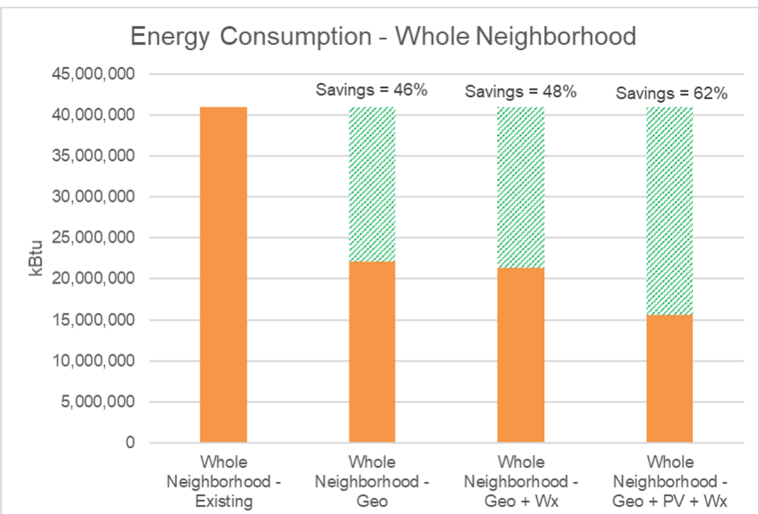


*Figure 27: Energy Consumption for the entire Bryant neighborhood based on four scenarios: a) as is; b) neighborhood geothermal; c) neighborhood geothermal with weatherization of homes; and d) neighborhood geothermal with weatherization and solar PV deployment.*

<u>Annual Energy Cost</u>

The cost analysis was performed with the current neighborhood rate structure. As seen below, the residential cost per unit of energy electricity is nearly 7 times that of gas.

| **Utility Rates** | Residential | | Commercial | |
|---|---|---|---|---|
| Electric | $0.058 | $/kBtu | $0.036 | $/kBtu |
| Gas | $0.008 | $/kBtu | $0.010 | $/kBtu |

*Table 5: Bryant Neighborhood Energy Cost Rates (Data available in GDR under App. H, File 29)*

Geothermal System Owner Cost

- The owner of the geothermal system will take on the cost for the central neighborhood pumping distribution, basically all the pumping energy up to private property lines.
- There is potential that the owner of the district system will develop a dedicated rate structure for buildings who implement the geothermal system.

Homeowners Cost

- The 262 homes achieve a 2.5% energy cost reduction from existing conditions, which is a start at alleviating the energy burden experienced by many residents in the neighborhood. Because of the switch to an all-electric geothermal system, and with the implementation of weatherization and future solar photovoltaics (see section below), the energy cost reduction for the homes could be nearly 77% from existing conditions.

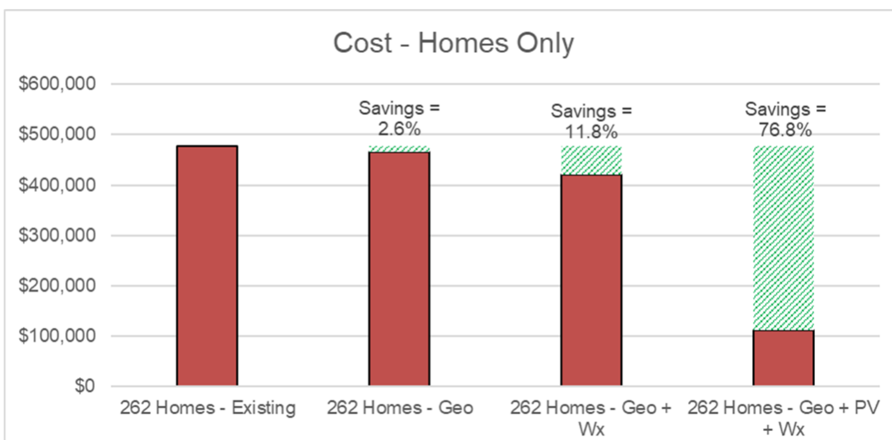



*Figure 28: Estimated Homes Energy Cost with Geo, Weatherization, and PV (Data available in GDR under App. H, File 29)*

Commercial Building Owner Cost

- The commercial buildings may see increases in energy cost at the current rate structure, depending on the efficiency of the internal building heat pump unit and the portion of pumping energy going to the commercial building. Energy efficiency and weatherization, however, will lead to significant energy savings for the commercial buildings.

If the geothermal system were deployed today without any supporting investments in weatherization or renewable energy generation, the annual energy cost for the entire neighborhood increases by 5% with the current rates of electricity and gas. Increases in energy usage between the existing conditions and the geothermal solution include the additional pumping energy required by the system. However, because the project team has secured funding to do deep energy efficiency work in neighborhood households, the neighborhood is projected to see an overall 37% cost savings, and residents specifically are expected to see between a 70%-77% reduction in energy bills when the geothermal system is installed along with energy efficiency improvements and solar PV installations.

Greenhouse Gas Projections

Greenhouse gas emissions for the neighborhood can be quantified in terms of the carbon emissions rate for both gas and electricity. The following rates tell a similar story to the energy cost, with electricity emitting 3.5 times that of gas.

| **Carbon Emissions** | tons of CO2/kBtu |
|---|---|
| Electric | 0.000191 |
| Gas | 0.000053 |

*Table 6: Bryant Neighborhood Carbon Rates (Data available in GDR under App. H, File 29)*

The following graph shows the steps to greenhouse gas emissions reductions with the stacking of neighborhood geothermal electrification, home weatherization, and home solar installation (Figure 29). These strategies and the analysis behind them are discussed in more depth in the next section. When analyzing greenhouse gas emissions, it is also vital to consider any utility planned decarbonization efforts. Considering a fully operational geothermal system in the Bryant neighborhood by 2028 and ongoing efforts to further decarbonize the electric grid, the greenhouse gas emissions achieved will be well over 40% by 2030.

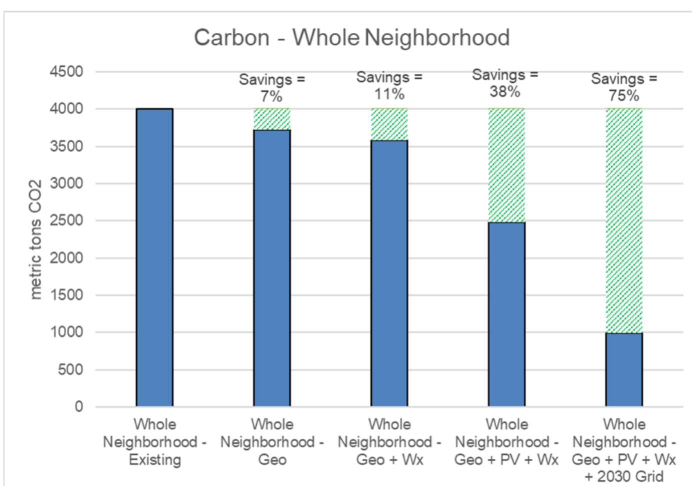



*Figure 29: Impact of future electric grid decarbonization goals on the Bryant project. (Data available in GDR under App. H, File 30)*

Future carbon projections for the electrical grid were gathered from recently filed integrated resource plans and State of Michigan policy developments. DTE, the local utility, has renewable energy goals to decarbonize the electric grid. It is targeting a 50% reduction by 2030 and 100% reduction by 2040. This grid decarbonization will lead to greater carbon savings over time for the all-electric geothermal system. The chart below shows the savings from geothermal integration, additional energy savings measures, and decarbonization of the local grid (Figure 30). The geothermal (red) vs gas heating (black) savings increases from 7% to 90% over time. The savings of the geothermal system with a fully renewable grid versus today is nearly 95% (160 tons vs 3700 tons).

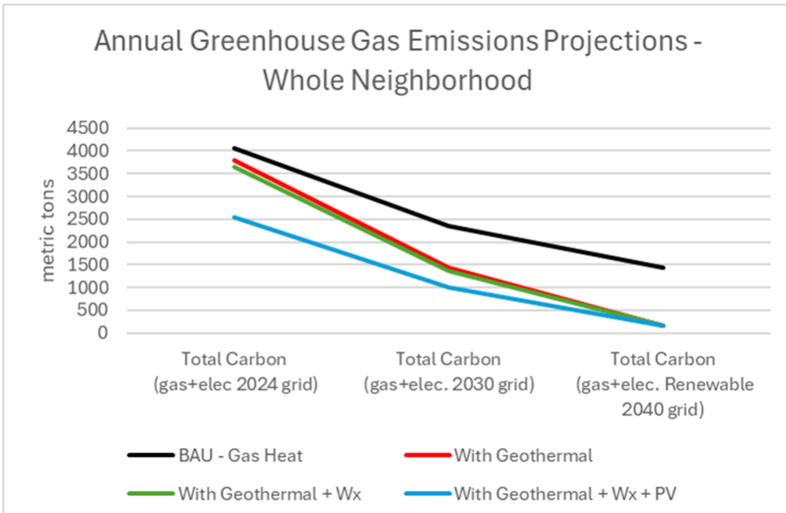



*Figure 30: Impact of future electric grid decarbonization goals on the Bryant project. (Data available in GDR under App. H, File 30)*

**Step Seven: Performed a risk assessment to understand project concerns.**
Next, the project team worked with residents, contractors, potential vendors, and city staff to identify and potential risks that could delay or derail the project. The team identified potential challenges in six areas: well constructability, well maintenance and redundancy, additional capacity, cost risk for homeowners, neighborhood disruption, and cost control.

***Well Constructability***
Experienced contractors are readily available in this region to construct the wells needed for the field. In fact, Ann Arbor is currently experiencing a high volume of geothermal field installations. The soils and geology in this area are well known by the drillers. The main challenges faced in the area of well construction relate to labor capacity and potential leakage of wells.

To mitigate the risk associated with labor, the City along with the University of Michigan and Ann Arbor Public Schools, have decided to collaborate on sequencing and issuing requests for proposals for geothermal installation. The idea is to aggregate our demand and provide multiple years' worth of work for contractors in the geothermal industry. By doing this, we believe we will be able to recruit more geothermal firms to set-up operations in the Ann Arbor area, helping to grow our local workforce. We've already discussed this strategy with three firms in the geothermal industry and/or interested in getting involved. All indicated that the aggregate demand between the University, City and public schools would be enough for them to grow their local Ann Arbor presence.

The second challenge relates to potential well leakage. Like all well designed geothermal systems, the system proposed in this application is a pressurized system and will be thoroughly pressure tested before backfilling of the system. Well piping is continuous throughout the length of the bore with only fused connections at the bottom and top of the well. Monitoring will help ensure the well is performing up to specifications. In the case of well failure, the well will be capped and the system load redistributed to ensure continual operations.

***Well Maintenance and Redundancy***

This project design includes geothermal wells on circuits of 10 wells total with a vault that allows for isolation of a circuit in the event of damage to a well. Damaged wells can be identified an isolated from the system on an individual basis with this set-up. Moreover, the geothermal field is in a park area where additional land is available to drill a few redundant wells. In addition, due to the nature of the wellfield being returned to a park, future construction in the area will be minimal reducing risk of future damage. Additionally, flow meters and water makeup meters will be provided to assist with leak detection.

Finally, overall system maintenance is part of system operation with funding for maintenance integrated into user rates. This will ensure that preventative maintenance is conducted along with maintenance needed to address any breaks or underperformances of the system.

***Additional Capacity***

The idea behind the project design is to grow the geothermal system over time to cover the full 262 homes in the neighborhood, the school, and the facilities located on Ellsworth. To do this, however, the project team had to identify means to scale up and scale out the system, including identifying additional capacity bore field locations and capacity needed to serve the entire system. This was done by working directly with local stakeholders and large land holders to explore expanding the wellfield. The public schools and the County Mental Health facility were both contenders for well expansion, and both agreed to serve as host locations for the wells. In this way, the project can easily scale up and build out future loops, connected to the centralized loop, as additional interest and demand emerges. This makes this project an easily scalable project.

***Cost Risk for Homeowners***

- At current cost rate structure, the cost savings of just switching to geothermal are minimal, but geothermal allows for the fully electrification that is needed to see the cost benefits that solar brings.
- The more residents that buy in, the better for scalability and shared costs.
- The addition of solar PV will work to hedge against future rate increases.

***Neighborhood Disruption***

Building out a neighborhood geothermal system as envisioned in this grant is going to be disruptive to the neighborhood. The amount of drilling, road work, inconvenience, and noise are significant and should not be underestimated. Instead of shying away from this reality, the project team has been open and transparent with residents about this disruption. We've talked with stakeholders about the types of inconveniences they are likely to experience and the amount of time they are likely to experience these disruptions. We've talked with them about techniques to mitigate those disruptions and the types of communication channels they'd like to use to ensure they are kept up to date on project developments.

Through this conversation, the project team identified the following strategies to help manage neighborhood disruption. First, through the design process, the team built a system whereby each loop is inter-connected with the adjacent loops to backfeed in lieu of damage or other maintenance need. For example, if the green loop main required repair it could be fed from the field on one side and the yellow loop on the other. This would help ensure that isolated future repairs can be conducted without completely taking the system offline.

In addition, curb stops are provided at the connection to each home. This allows an individual home to be isolated from the system in event of maintenance need or disruption to an individual home. And the distribution pumping system has redundant pumps and additional pressure capabilities to address changes to the system post-installation. System pumps will all be on variable speed drives.

Finally, the project team is proposing to hire a part-time (1/2 FTE) community engagement specialist to work directly with the community on all aspects of the project. This person will be hosting community meetings, going door to door to discuss project activities with residents, and generally available to work through any challenges faced by residents. We aim to hire this person from the community – so that a local resident benefits from the project but also can be the spokesperson for the project. In our phase one work, we identified multiple residents excited about the project and eager to get more involved. Hopefully one of those individuals will apply to serve as our community engagement specialist.

***Cost Control***

This project is being developed in a low-income, traditionally marginalized community. The allurement of centering a frontline community in our efforts to achieve a just transition carbon neutrality are the exact parameters that make this neighborhood especially cost sensitive. As such, all efforts must be taken to ensure that this project does not exacerbate energy poverty.

To do this, the project team is of course seeking as much funding support as possible, including this U.S. DOE grant. We are also planning to use federal tax incentives and municipal borrowing rates to lower project costs. In terms of system design, the entire north loop has been segmented for phased installation. This helps build the system overtime and add to the resiliency of the system via interconnected loops, all while allowing costs to be lower on the front end of project deployment.

Additionally, this phasing protects against cost overruns. If unforeseen issues (re-routing of existing utilities, repair of aging utilities un-earthed in construction, etc.) cause installation cost increases, loop size can be adjusted to help the project stay within budget and achieve project goals. And, by building this first geothermal system in Ann Arbor leveraging grant funding, the project team can build the expertise and real-world examples needed to secure additional funding for create more systems and build out the existing Bryant system.

To help additionally manage costs, the project team will competitively bid all elements of the project (other than design, workforce development, and engagement initiatives) as well as open up bids for alternate geothermal installation approaches to optimize field costs. As noted in other parts of our application, the entire distribution network and all drilling will be competitively bid, and contractors will be encouraged to propose innovative boring techniques to reduce cost of routing the utility mains and supply to the homes.

**Step Eight: Assessed efficiency and weatherization options to reduce system size and upfront costs**

The team took an in-depth look at weatherization in the homes and the installation of onsite solar to further demonstrate that paired with geothermal, financial savings, reduction in system size, and even deeper greenhouse gas reductions are achievable. It is important to note that the analysis of this section focuses specifically on the savings for the residents, while much of the previous section focuses on the entire neighborhood.

For the last three years, the City has been working with the residents of Bryant and Community Action Network (CAN) to identify what energy saving opportunities exist in each resident's home. Over the last year this information has allowed the team to secure $1 million to undertake deep energy efficiency and health and safety improvements in roughly 40 homes in the neighborhood. In addition, the City has been working with the County's Weatherization Office to get all income qualified households in Bryant into the weatherization program. In addition, the City of Ann Arbor recently received a state grant to support the installation of solar and energy storage systems in the Bryant neighborhood. This funding, roughly $5,000,000 for equipment and staffing, will support roughly 100 local households with significantly reducing their electrical bills and enhancing local resilience. In addition, the project team has also submitted multiple funding proposals to help support even more households in Bryant with undertaking deep and sustained energy efficiency improvements, including submitting grants to private foundations as well as state and federal agencies. These initiatives are still underway but are helping to improve the energy efficiency of Bryant households – and simultaneously making geothermal an even more financial, social, and economically viable solution.

<u>Energy Optimization – Weatherization (Wx)</u>

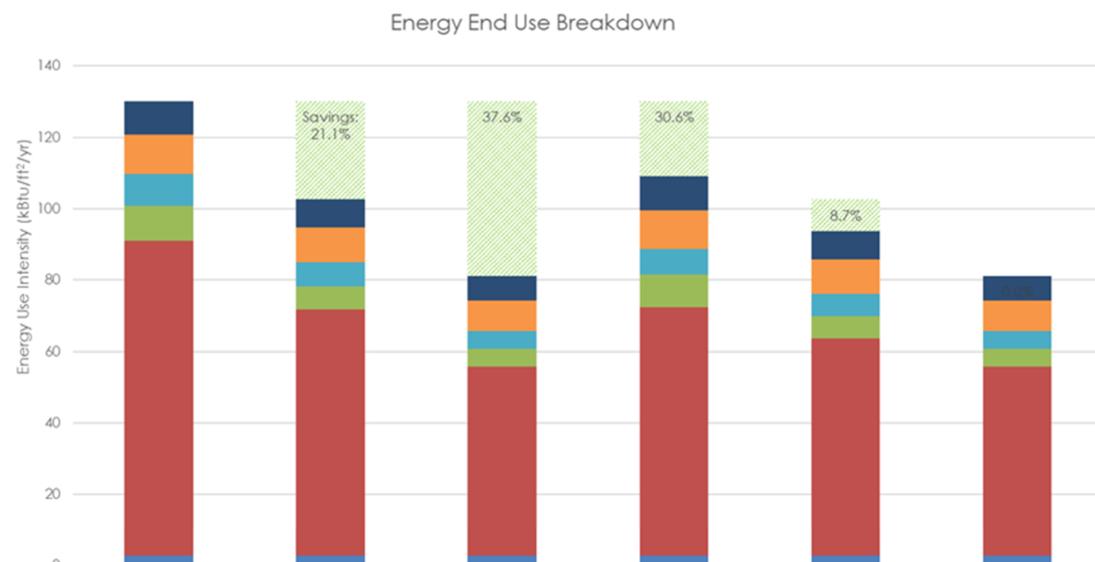
Effects of weatherization were analyzed to understand how it might lower the households' load on the neighborhood *(Data available in GDR under App. H, Files 13-15).* The energy audit data indicated that many households experience “drafty” spaces and weak envelopes, causing an increased use of the HVAC system to keep the home at comfortable conditions.

To model the effects of weatherization, the envelope values for the “Best” energy performance group was applied directly to the “Mid” and “Worst” homes. The table shows around a 10% reduction in both heating and cooling load with this switch.

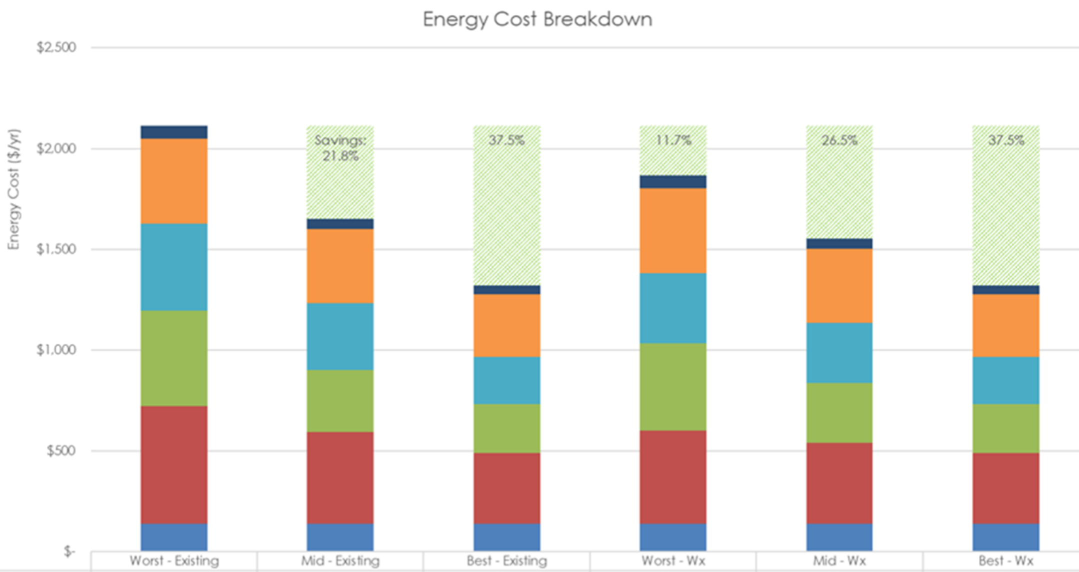
| | All 262 homes - Existing | All 262 homes - Wx |
|---|---|---|
| Heating Modeled Peak (tons) | 655 | 570 |
| Cooling Modeled Peak (tons) | 442 | 397 |

*Table 7: Home Weatherization for 262 homes*

Compared to existing conditions, weatherization alone has the potential to reduce the energy usage for a single home by 15-30%. This reduction mainly comes in the form of heating, cooling, and fan energy, aiding in achieving the project’s goal of 75% reduction of heating and cooling needs from fossil gas. The following graphs show the reduction for each of the energy performance buckets.




| | Worst - Existing | Mid - Existing | Best - Existing | Worst - Wx | Mid - Wx | Best - Wx |
|---|---|---|---|---|---|---|
| Savings: | 0 | 27.5 | 49.0 | 21.1 | 9.0 | 0.0 |
| DHW | 9.5 | 7.9 | 6.9 | 9.5 | 7.9 | 6.9 |
| Receptacles | 10.9 | 9.7 | 8.5 | 10.9 | 9.7 | 8.5 |
| Fans | 8.9 | 7.0 | 5.0 | 7.2 | 6.2 | 5.0 |
| Pumps | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cooling | 9.9 | 6.3 | 5.0 | 9.1 | 6.2 | 5.0 |
| Heating | 88.1 | 68.9 | 52.9 | 69.6 | 60.9 | 52.9 |
| Lighting | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |




| | Worst - Existing | Mid - Existing | Best - Existing | Worst - Wx | Mid - Wx | Best - Wx |
|---|---|---|---|---|---|---|
| Savings: | 0 | $462 | $792 | $246 | $560 | $792 |
| DHW | $63 | $52 | $46 | $63 | $52 | $46 |
| Receptacles | $424 | $365 | $307 | $424 | $365 | $307 |
| Fans | $429 | $336 | $239 | $347 | $299 | $239 |
| Pumps | $0 | $0 | $0 | $0 | $0 | $0 |
| Cooling | $477 | $305 | $242 | $436 | $296 | $242 |
| Heating | $583 | $456 | $350 | $461 | $403 | $350 |
| Lighting | $138 | $138 | $138 | $138 | $138 | $138 |

*Figures 31 and 32: Energy Use and Cost Breakdown (Existing v Weatherized Home)*
*(Data available in GDR under App. H, File 29)*

With the combination of geothermal, the accumulation of 262 weatherized homes aid in achieving the neighborhood's heating and cooling reduction goal. In addition, the homes experience a 12% projected energy cost reduction from existing conditions and greenhouse gas emissions reduction of 30%. These values do not include savings from solar PV.

| System/Plant | Energy Cost | | Energy Consumption | | CO2 | |
|---|---|---|---|---|---|---|
| | ($/yr) | % Savings | (kBtu/sf/ yr) | % Savings | (metric tons) | % Savings |
| **262 Homes - Existing** | $477,465 | - | 111 | - | 2,083 | - |
| **262 Homes - Geo** | $465,189 | 2.6% | 47 | 58.0% | 1,612 | 22.6% |
| **262 Homes - Geo + Wx** | $421,020 | 11.8% | 43 | 61.1% | 1,465 | 29.7% |

*Table 8: Energy Cost, Consumption, and Carbon with Geo + Weatherization projections.*
*(Data available in GDR under App. H, File 29)*

<u>Energy Optimization – Solar PV</u>

Based on neighborhood solar assessments, there is a 1680-MWh annual rooftop solar production potential across the 262 homes. The table below shows how geothermal provides savings, but with the inclusion of solar, homes would see significant energy cost savings of up to 70-72%, energy use savings of 82%, and carbon savings of 75%.

| System/Plant | Energy Cost | | Energy Consumption | | CO2 | |
|---|---|---|---|---|---|---|
| | ($/yr) | % Savings | (kBtu/sf /yr) | % Saving s | (metri c tons) | % Saving s |
| 262 Homes - Existing | $477,46 5 | - | 111 | - | 2,083 | - |
| 262 Homes - Geo | $465,18 9 | 2.6% | 47 | 58.0% | 1,612 | 22.6% |
| 262 Homes - Geo + Solar (Net Metered) | $134,27 1 | 71.9% | 20 | 81.7% | 511 | 75.4% |
| 262 Homes - Geo + Solar (Utility Buyback) | $155,07 0 | 67.5% | 20 | 81.7% | 511 | 75.4% |

*Table 9: Energy Cost, Consumption, and Carbon with Geo + Solar PV projections. (Data available in GDR under App. H, File 29)*

The solar production was distributed per month using a typical solar production curve for the year.

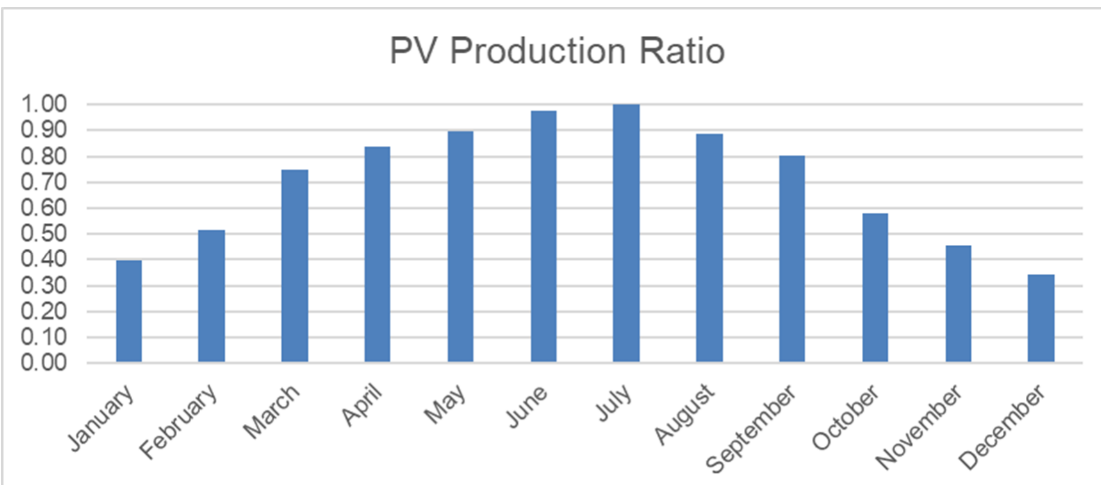



*Table 33: Solar Production Curve (Data available in GDR under App. H, File 29)*

The reduction in energy consumption was applied directly to the results of a geothermal system. As seen in the graph, the homes produce an excess of energy in the summer months and require pulling electricity from the grid in the winter.

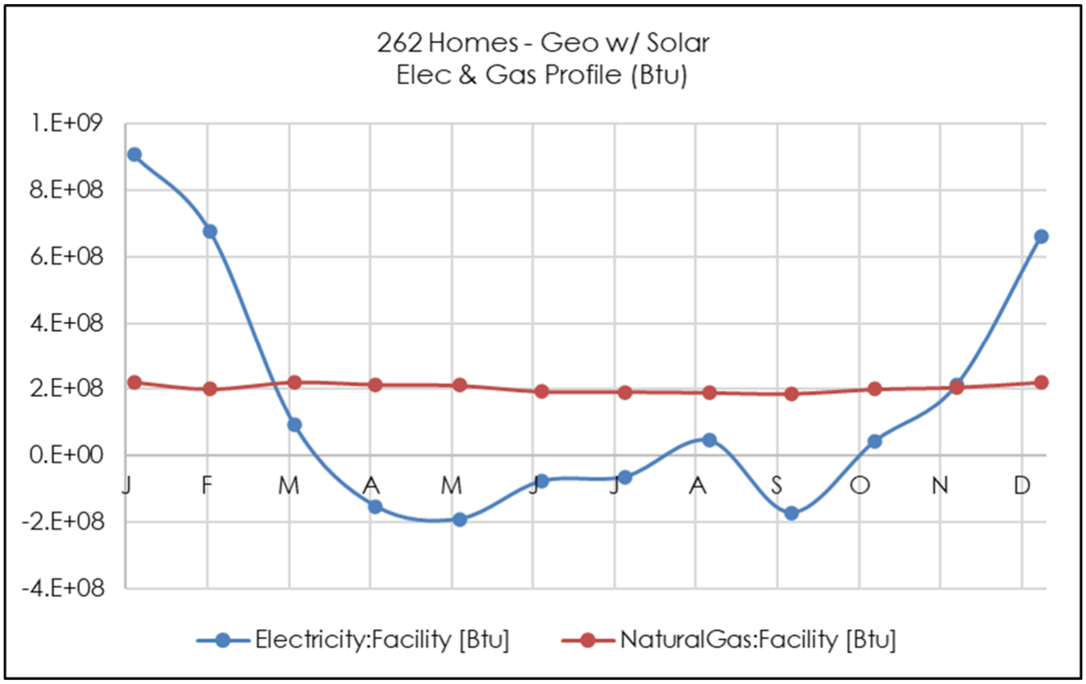



*Figure 34: Energy Consumption Curves with Geo + Solar (Data available in GDR under App. H, File 29)*

To understand the economic impact of overgeneration, the team analyzed two projected cost situations: Net Metered and Utility Buyback.

- For Net Metered, when the solar is producing more energy than needed onsite, the homeowner would receive reimbursement at the inflow rate of electricity, $0.196/kWh.
- For Utility Buyback, when the solar is producing more electricity than needed onsite, the homeowner would receive reimbursement at a reduced outflow rate of electricity, $0.09/kWh. This is the current cost that DTE, the utility, credits for solar production into the grid.

In either case, the households benefit largely from the combination of geothermal and solar installation, with a 72% cost reduction with Net Metered, 68% cost reduction with Utility Buyback, and carbon savings of 75%. These values do not include the savings from weatherization.

**Step Nine: Explore non-traditional geothermal installation approaches to optimize system size and cost**

The next to last step in our socio-techno-economic analysis was conducting a holistic assessment to ensure any non-traditional geothermal installation techniques were explored for viability in the project. This included analyzing the potential for angle drilling as well as open system drilling.

To increase available geothermal field capacity, minimize disruption to the surface area, and help accelerate the timeline for geothermal field installation the team explored incline drilling options to complement standard vertical board design. Standard vertical bore field design has the benefits of speed and a larger knowledge base in the industry, whereas angle drilling is relatively new to the US, but offers the benefit of less disruption of the surface ground area. Bores can be installed in a 10- by 20-foot footprint but reach ground area hundreds of feet horizontally. Angle drilling can allow installations in roadways and other tight areas possible. Lot lines should still be considered, as most ordinances do not allow a utility like this to pass under private property without easement waivers or other legal considerations.

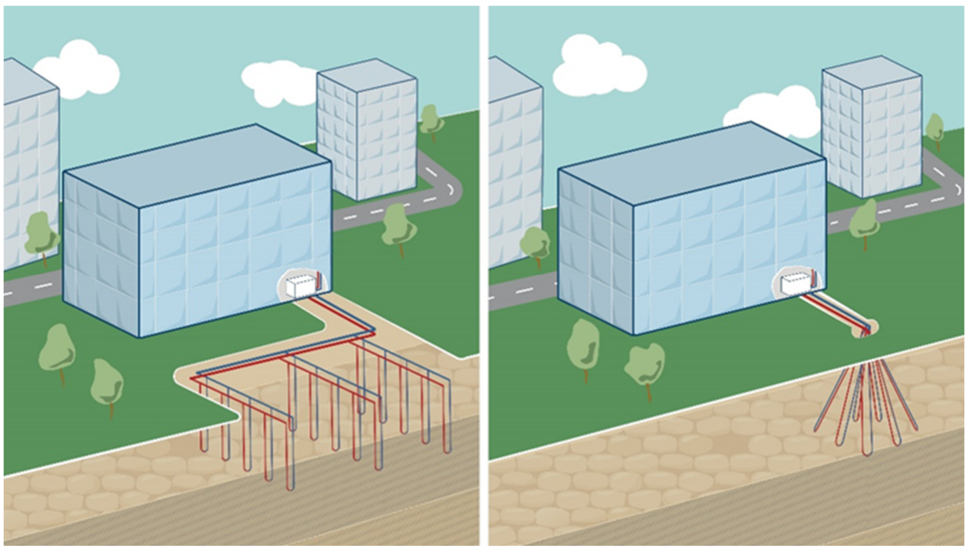


*Figure 35: Sample comparison of traditional drilling versus inclined or angled drilling.*

Potential angled drilling sites for this project included roadway cul-de-sacs, the community center greenspace, and a portion of the school's parking lot.


*Figure 36: North Loop Boring Sites*

Information collected from Celsius, a geothermal company specializing in angled drilling found that using an inclined pyramid design reduces the total number of bores needed from 232 bores to roughly 100 and no longer requires the entire field/park to be torn up. Instead, inclined drilling would enable the installation of the entire system from just five (5) points at the surface and then use inclined drilling in the subsurface. This will result in a less disruptive construction process (versus tearing up the entire park area), significantly less excavation and site remediation work (cost savings), less surface piping (cost savings), and a safer construction site (no more moving around a big rig after drilling each bore) all while capturing the same thermal capacity as the 232 vertical bore solution in the base design. Furthermore, Celsius found they could install an even larger GHX system from this site with a larger thermal capacity than the base vertical design, if that were of benefit to the overall project.

The project team is extremely interested in seeing if this design could be economically viable as part of the project. As such, when issuing competitive bids for drilling, the project team will encourage innovative approaches, including the use of inclined drilling.

**Open System**

One other alternative explored was the creation of an open-loop geothermal system versus a closed-loop system. Open-looped systems consist of a series of conventional water wells, drilled to the bottom of the aquifer with a submersible pump for water production. In addition, there would be a corresponding series of injection water wells drilled on the opposite side of the site to reintroduce the water back into the aquifer. A pair of heat exchangers would be used at the central pump house to transfer energy with the secondary distribution loop servicing all connected loads. These systems operate non-consumptively, and the heat exchangers would be double wall-vented NSF rated to protect the aquifer from contamination. These systems require additional in-depth testing and design to determine the proper quantity, size, and location for each of the wells. Operational and maintenance costs are higher due to the submersible pumps and heat exchangers and are not as cost effective for smaller systems but are very cost effective for larger scale systems. One additional benefit is these systems tend to operate at near constant temperature throughout the year, leading to very efficient heat pump operation and a potential to avoid costly and hazardous anti-freeze solutions.

At this time, the project team is prepared to move forward with a closed-loop system. However, if innovative open-looped systems are proposed during the competitive bidding process, the team is open to evaluating those systems.

**Step Ten: Provide socio-techno-economic model that includes current and future demand**

The community geothermal system is an essential piece of fully decarbonizing the Bryant Neighborhood. When paired with home weatherization and rooftop solar PV, the project goals of 75% reduction in heating and cooling energy load and 40% reduction in greenhouse gas emissions are exceeded. The energy burden experienced by the residents can be mitigated with these actions and the neighborhood can be well on its way towards becoming America's first carbon neutral existing neighborhood. Given the viability of this model, including the stacking of investments in weatherization and solar generation with geothermal deployment, the project team is confident in the transformational nature of this project and its ability to serve as a national model for equitable decarbonization.

**Closing Thoughts**

The current plan presented in this report is based on today's grid, today's electricity prices, and the typical approach to geothermal installation for the field. It also includes plans for stacking additional measures such as weatherization and solar PV. Note from our response that we also are going to bid out alternative geothermal field options to further optimize and reduce field costs of the installation. Both the open well geothermal system and the inclined drilling approaches will be bid out in addition to the conventional approach provided in this budget. This arrangement provides up to 75% reduction in carbon based on 2030 grid which is only two years after full installation of the system.

For the start of this phase one work, we are only covering 111 homes. In this case, many of the fixed cost of the fields are based on that smaller sample of homes, which can bring some challenge to the economics without grant funding from the U.S. Department of Energy. However, as we look to better the overall outcome with future scale and additional techniques, we can see that the financial outcome improves as the system scales in the future. That is why the project team has sought partners in the City of Ann Arbor, Salas O'Brien, and DTE that are willing on working with the project team to build out the full system (north and south loops). For this grant, however, we are only focusing on two loops (green and yellow) and the well field needed to grow the entire north system.

As we look to the future with additional scale, we plan to add more homes and commercial buildings to help improve the financial picture. Adding these buildings brings the following benefits:

1. It will dilute (on a per home basis) many of the fixed costs associated with the base infrastructure proposed in this project.
2. The more dense the load factor, the lower per ton connection cost of a commercial building.
3. Adding load diversity will reduce total geothermal capacity requirements by about 10% in the case of these commercial buildings.
4. And the entire system can serve as a living demonstration of how to equitably decarbonize heating and cooling systems in cold climates such as Michigan.

The chart below shows how as the system scales upwards, and these fixed costs of the base system get diluted, we can see the average annual cost of service per home decreases by 27%.

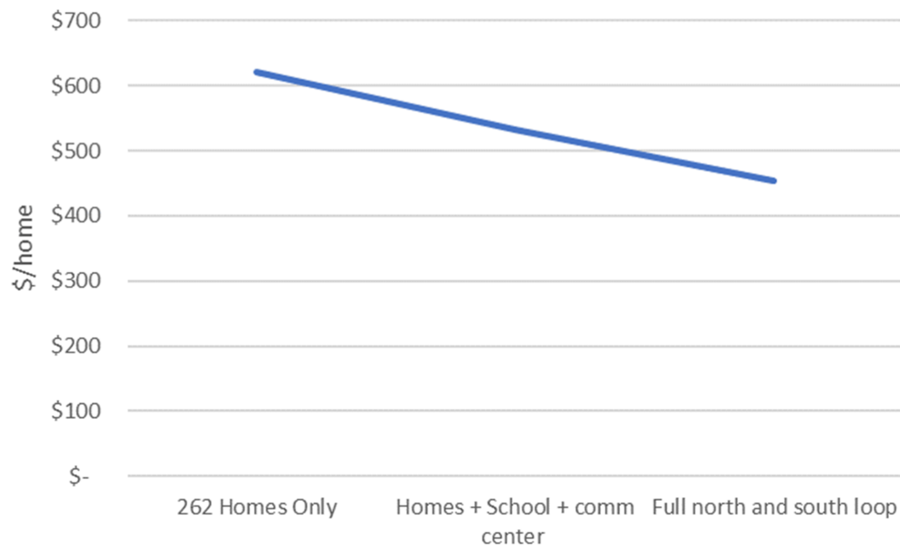



*Figure 37: Estimated costs per home under different geothermal build out scenarios.*

The commercial buildings have lower installed cost due to their low density and fewer number of connections. As we add more commercial buildings onto the system, this reduces the first cost per install ton by 32%.

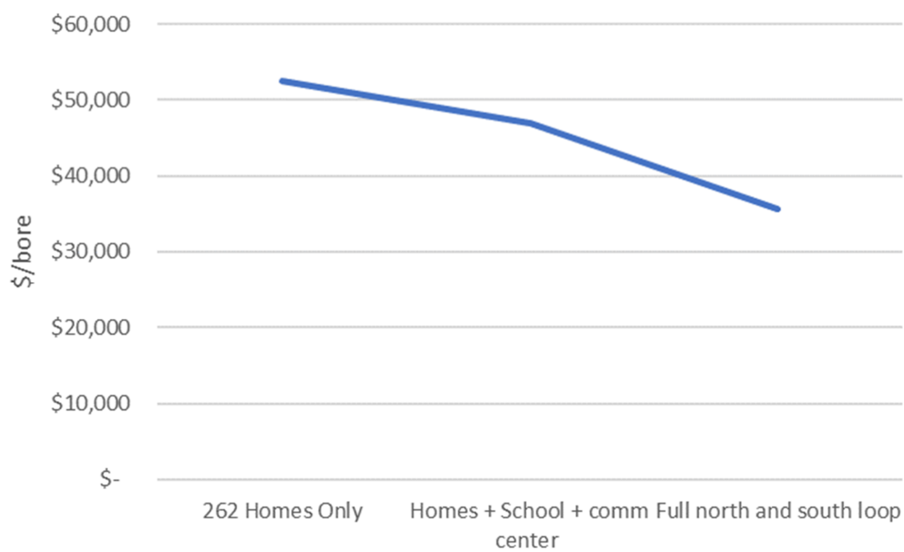



*Figure 38: Estimated upfront costs per ton under different geothermal build out scenarios.*

As we wrap this into the total carbon reduction story, we can also see that with scale, our cost per ton of $CO_2$ avoided is reduced by 18%. Figure 39 shows the cumulative reduction in $CO_2$ emissions over a 50-year period at various scales. Build out of the total system will increase carbon savings by 82% compared to only connecting homes to the system.

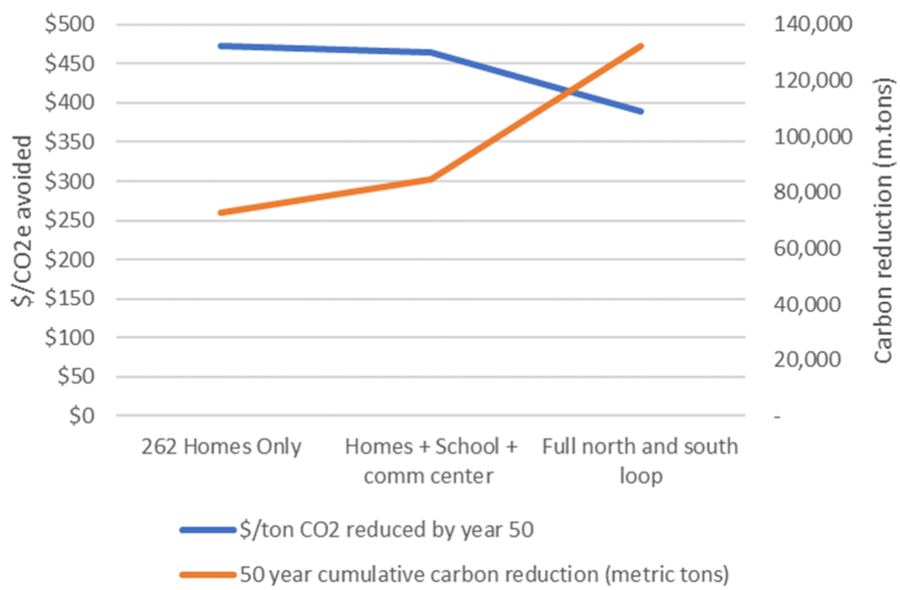



*Figure 39: CO2 reductions under different geothermal deployment scenarios.*

A summary of the system at various scales is provided in Table 10 for reference. Note that commercial savings and costs were analyzed for this study, but more detailed engineering is required to refine and finalize these values.

| | 262 Homes Only | Homes + School + comm center | Full north and south loop |
|---|---|---|---|
| Field size (heating tons) | 655 | 768 | 1136 |
| # bores (@500 ft) | 260 | 280 | 400 |
| Project cost (raw, before escalation, profit, etc) | $34,396,815 | $39,305,935 | $51,481,992 |
| Geothermal first cost $/installed ton of heating | $52,514 | $47,013 | $35,636 |
| Utilty O&M cost ($/year) | $162,950 | $174,300 | $238,349 |
| O&M annual cost ($/home) | $622 | $532 | $455 |
| Total reduction(current to 2030 grid projection) | 1455 | 1693 | 2642 |
| CO2 reduced in year 1 ($/m.ton) | $23,640 | $23,217 | $19,486 |
| CO2 reduced by year 50 ($/m.ton) | $473 | $464 | $390 |
| 50 year cumulative carbon reduction (metric tons) | 72,750 | 84,650 | 132,100 |

*Table 10: Summary of System Benefits across different deployment scenarios.*

Based on this data both Ann Arbor and other installations around the country should target around a 50/50 split between residential home load and commercial building load. If the commercial buildings are more energy intensive and or have greater offseason load (i.e. cooling load in the winter period) these benefits would be even greater. The final piece to improve the financial outcome of these systems is a close look at the utility rate structure. Note this particular area in Ann Arbor has an unusually high electricity cost per kWh for the Midwest. At $0.19 per kWh for the residential rate it does challenge the payback of these systems. Exploring low carbon, all-electric utility rates reduction of 25% (down to $0.14/kWh) greatly improves economics of these systems while supporting utility decarbonization goals. If a city or neighborhood is considering this approach our recommendation based on the results of this study is to consider the following:

- A 50/50 split of residential or commercial geothermal field load.
- Electricity rates around $0.15 per KWH and/or the creation of an all-electric rate structure.
- Centralized available land area to install geothermal system.
- Explore and bid out at least two or three different geothermal installation techniques to reduce the upfront costs of system construction.
- Focus on contractor pool for the neighborhood distribution system. This is the highest cost of our proposed system. Advance boring and horizontal installation techniques will be key to reducing installation costs in roadways crowded with many utilities.