BURO HAPPOLD

Somerville Networked Geothermal and Electrification Feasibility Study

Technical Report

P060580

9 September 2024

P01

Revision	Description	Issued by	Date	Checked
P01	Final Report	AN	9/9/24	JM

Report Disclaimer

This Report was prepared by Buro Happold Consulting Engineers P.C. ("BH") in accordance with, and remains subject to, the terms of BH's appointment for the benefit of City of Somerville, Office of Sustainability and Environment in relation to evaluating opportunities to provide electrified heating and cooling to its building stock. BH's responsibility shall be limited to the purpose for which this Report was prepared, with BH assuming no liability for any reliance placed on this Report by any third party.

Notwithstanding the foregoing, the content of this Report shall remain subject to the following

1. This Report is based upon the information and knowledge available to BH at the time of writing and, unless otherwise expressly stipulated herein, BH has not sought to verify or validate any data received by BH and/or which may underpin this Report.
2. BH assumes no ownership nor liability in respect of any third-party design, workmanship and/or deliverables, and shall not be held responsible for the consequences of any negligence, error or omission in respect of the same.
3. BH does not guarantee any particular outcome, nor does BH provide any warranty in respect of any third-party services, equipment requirements and/or software and is not responsible for the outcome or use of the same; regardless of whether the content of this Report is followed.
4. This Report shall not be construed as investment or financial advice.

author	**Alex Nutkiewicz**
date	**09 September 2024**
approved	**Jason Masters**

signature Jason Masters

date **09 September 2024**

Contents

Table of Tables

Table of Figures

Glossary

Term	Definition
A	Amp
AM	Amorphous Metal
ASHP	Air-source heat pump
BIL	Bilateral Infrastructure Law
CO2	Carbon dioxide
ComStock	Commercial building sector stock model
COP	Coefficient of performance
DOE	U.S. Department of Energy
DPU	Department of Public Utilities
EUI	Energy use intensity
FEMA	Federal Emergency Management Agency
GHG	Greenhouse gas
GIS	Geographical information system
GOES	Grain-oriented electrical steel
GSHP	Ground-source heat pump
HDPE	High density polyethylene
HEET	Home Energy Efficiency Team
HIFLD	Homeland Infrastructure Foundation Level Database
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
kV	Kilovolt
kW	Kilowatt
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transit Authority
NFHL	National Flood Hazard Layer

NREL	National Renewable Energy Laboratory
PACE	Property-Assessed Clean Energy program
ResStock	Residential building sector stock model
RGO	Rolled Grain Oriented
ROM	Rough order of magnitude
SFHA	Special Flood Hazard Area
TEN	Thermal energy network
USGS	United States Geological Service
VA	Volt-ampere
VAC	Volt alternating current
WSHP	Water-source heat pump

1 Executive Summary

The city of Somerville, Massachusetts has partnered with Buro Happold to develop a study to understand two key energy-related challenges:

- Task 1: Setting the city on a pathway towards full citywide electrification
- Task 2: Determine the feasibility of decarbonizing existing building thermal energy needs through a networked geothermal system in particular locations.

These initiatives align with the city's ambitious climate action plan – aiming for net-zero emissions by 2050 and a subsequent carbon-negative future. These types of projects have the potential to be examples for surrounding communities on how to overcome the challenges of urban electrification and transition away from natural gas.

To ensure the city of Somerville has a cost effective electrification pathway towards implementing more efficient electrical distribution infrastructure, Buro Happold concluded that the city has multiple pathways to increase electrical capacity to all residents. All are based on information retrieved from Eversource about the health and capacity of the conductors serving Somerville. While major thoroughfares already have their conductors underground, the real concern is for those streets where electricity is provided from conductors dropped from step-down transformers on utility poles. While transferring aboveground conductors to underground conductors along with their corresponding transformers is an option that Eversource presented to the city, the associated cost with this utility option would require an amount of funding that is not feasible throughout the city. Therefore, Buro Happold provided four alternatives for consideration.

The first option is to increase the number of step-down transformers on utility poles serving residents. The second option is to increase the size of the step-down transformers serving residents. Third is a combination of both. It should be noted that a survey of the affected utility poles might uncover the need to replace and/or upgrade the utility pole to accommodate extra weight and/or remove a pole in diminished capacity. A fourth option could be to replace the pole-mounted transformer with a ground-mounted transformer. All of these options need to be coordinated with Eversource and prioritized in Eversource's budgeting and upgrade plans. The city and Eversource have an opportunity to request federal funding to help with these conversion costs, but it will require a coordinated effort on both parties.

The second component of this work aimed at exploring the opportunity of deploying initial pilot project(s) for networked geothermal energy networks within the city of Somerville. These potential pilot project(s) will provide an opportunity to test how well this technology performs in Somerville and evaluate if these systems could scale to larger neighborhoods across the city. Networked geothermal systems are a type of district heating and cooling network that exchanges the natural thermal energy from the Earth to a group of buildings to provide space heating, cooling, and, in some cases, domestic hot water heating. Given the broad range of considerations required for implementing this type of system (e.g., space availability to drill boreholes, bedrock geology, diversity in heating and cooling requirements), Buro Happold conducted a geographical information system (GIS)-based assessment to develop a short-list of neighborhoods best suited for more detailed study as part of a HEET Kickstart project. To understand where a geothermal system could be installed, mapping key selection criteria was conducted – including key infrastructure network obstructions, areas of biodiverse significance, building typologies, open spaces for borehole and pump house siting, and demographic indicators.

Three key neighborhoods in Somerville were identified as most feasible locations to site a pilot networked geothermal study.

- **Ten Hills**, a largely residential neighborhood in northern Somerville, would create a network supplying a combination of residential buildings and several Somerville Housing Authority properties. This network could also integrate the use of the Mystic River for additional thermal storage capacity.
- **Central Hill**, the neighborhood in which Somerville City Hall, Somerville High School, and the city's public library are located, is another short-listed site for a pilot project. These key buildings, along with the surrounding residential community, could be used to create a dense thermal energy network.
- **Central Somerville Avenue**, near the former Ames Envelope Complex, contains key waste heat producing sites such as Veterans Memorial Rink and Aeronaut Brewing Company – could be leveraged to provide additional heating capacity to the nearby residential communities on the north side of Somerville Avenue or potential new developments south of Somerville Avenue.

A preliminary thermal analysis was performed for each of these sites to understand the amount of annual thermal and peak thermal load requirements needed to meet expected demands. A mapping study was conducted to understand the amount of horizontal infrastructure needed to deliver that thermal energy across the network. All three of these sites offer opportunities for a successful pilot project; however, this work also highlights the need for access to existing or newly installed three-phase transformers for geothermal pump houses, which could also influence site selection. While electrical capacity on the conductors is not a limiting factor in pilot site selection, the study emphasizes the importance of coordinating geothermal system implementation with specific power requirements necessary for the geothermal system.

For the networked geothermal portion of the electrification study, key findings indicate that power demand from pilot systems could be less than 0.5% of any 13.8kV distribution circuit capacity, suggesting minimal need for electrical upgrades. This resulted in a calculated net load reduction of 0.5 W/SF to 0.8 W/SF and would be anticipated in residential areas implementing geothermal systems compared to traditional air conditioning.

Overall, the study provides the city of Somerville with options for city-wide electrification and implementing cost-effective, sustainable heating and cooling solutions across neighborhoods that would greatly benefit from these improvements. The next phase of work related to networked geothermal, supported by HEET's Kickstart grant should aim to identify one or more sites for the pilot project(s), coordinate with Eversource on any necessary transformer upgrades needed to support the city's growing electrical demands, and develop a phased approach to further implementation based on the outcomes of the pilot project(s).

2 Introduction

2.1 Project Context and Motivation

Natural gas has long served as a significant part of Massachusetts' energy mix – accounting for 76.1% of generation capacity (2023) and used for 52% of the State's residential heating fuel.[1] While natural gas is a critical component of the State's fuel supply, it is also a key contributor of greenhouse gas (GHG) emissions. Along with the downstream emissions produced from combusting natural gas to produce heat and/or electricity, gas leaks along existing and often antiquated pipe infrastructure can release methane – a GHG with more than 80 times more global warming potential than CO_2.

Scientific findings, economic realities, and policy initiatives across spatial scales are rapidly driving forward the case for electrification and broader decarbonization. To prepare for the energy transition, cities must consider pathways for implementing cost-effective solutions that can provide their residents with electrified, renewables-led heating and cooling energy at-scale – while meeting their often-aggressive emissions targets. However, electrifying cities presents several challenges. The increased demand for electricity can strain existing grids, necessitating significant infrastructure upgrades.[2] Additionally, the integration of renewable energy sources requires substantial investment and careful planning to ensure reliability and stability.[3] Urban areas also face logistical challenges, such as the need for extensive retrofitting of buildings and the installation of new electric vehicle charging stations.[4] Furthermore, equitable access to these new technologies must be ensured to avoid exacerbating social inequalities.[5]

The city of Somerville – New England's densest populated municipality[6] – has chartered an ambitious climate action plan called *Climate Forward*, aiming to achieve net zero emissions by 2050 and has set aspirations for a carbon-negative future. *Climate Forward* outlines a plan to reduce contributions to climate change and to prepare the city for climate impacts. The actions include adding new building standards that emphasize resilience, improving energy efficiency in existing buildings, fuel switching heating systems, achieving 100%

[1] https://www.mass.gov/info-details/how-massachusetts-households-heat-their-homes
[2] https://www3.weforum.org/docs/WEF_Urban_electrification_and_energy_efficiency_2023.pdf
[3] https://news.climate.columbia.edu/2022/06/03/what-makes-electrifying-the-economy-so-challenging/
[4] https://www.weforum.org/agenda/2022/01/the-ev-revolution-obstacles-solutions/
[5] https://www.ifpenergiesnouvelles.com/article/smart-city-energy-challenges-facing-sustainable-cities
[6] City of Somerville, 2022

renewable energy and net zero emissions by 2050.[7,8] An emerging technology that can address these action areas is district-scale networked geothermal – bringing the city closer to a carbon net-negative future. Historically, thermal comfort was primarily provided by fossil fuels. In dense suburban and urban environments, networked geothermal coupled with district energy provides the most efficient and comprehensive solution to provide a non-fossil fuel derived, renewable thermal comfort.

To help the city of Somerville achieve their vision of a clean energy future, Buro Happold is collaborating with the Mayor's Office of Sustainability to investigate opportunities for city-wide electrification and pilot networked geothermal. Employing geospatial mapping, thermal energy and electrical system modelling, and observational assessments, this study identified key sites best suited to increase electrical capacity and utilize networked geothermal. The results of this study aim to inform the city's decision-makers what those solutions are and how to potentially move forward.

2.2 Report Structure

Overall, the objective of this report is to provide a summary of the results from the initial feasibility study for city-wide electrification and networked geothermal systems. The remainder of the report is structured as follows:

- Chapter 3 (Task 1 – Neighborhood Distribution Transformers): This section discusses the methodology and results from the city-wide electrification feasibility study in Somerville.
- Chapter 4 (Task 2 – Networked Geothermal): This section highlights what the technology is, key limitations for deploying the technology in Somerville, and recommended areas for further study in the HEET Kickstart project.
- Chapter 5 (Task Integration): This section discusses the impact of the transformer study on both aspects of the project – electrification and networked geothermal.
- Chapter 6 (Final Analysis): This section summarizes all additional results from the report, including economic, environmental, and social impacts of electrification and networked geothermal energy.

[7] City of Somerville, 2018
[8] City of Somerville, Climate Forward, 2024

Chapter 7 (Conclusions and Recommendations): This section summarizes all key findings from this study and provides recommendations on next steps towards implementation.

3 Neighborhood Distribution Transformers

The city's electrical distribution system will require significant upgrades to fully electrify buildings and vehicles in Somerville, particularly the number and/or capacity of the electrical distribution transformers that step-down voltage from mostly 13.8 kilovolts (kV) to 240/120 volts alternating current (VAC) for customer use.[9] City electrification is possible by reconductoring above-ground and below-ground distribution lines to increase line capacity to at least 13.8kV on all distribution lines and increasing the total capacity of all medium voltage step-down transformers to residents and businesses in the city. There are essentially three options that the city could initiate with Eversource to increase electrical capacity to city of Somerville residential and commercial customers:

1. Distribution lines could be transitioned from above-ground utility poles to underground conduits and transformers
2. The city could work with Eversource to utilize the existing utility pole infrastructure and either add more residential distribution transformers hung on utility poles or increase the capacity of the distribution transformers by swapping out under-capacity transformers for new, higher capacity step-down distribution transformers on the utility poles, or
3. A hybrid of options 1 and 2 could be applied to utilize 13.8kV distribution on current utility poles, drop the conductor into a ground-mounted transformer, and then distribute 240/120VAC via underground conduit and conductor pairs to ratepayer utility meters.

This section discusses how the Eversource Electric Sector Modernization Plan[10] (Figure 3-1) – coupled with the dataset provided by Eversource and the city of Somerville – was cross-referenced against on-the-ground verification of current electrical distribution conditions, City Planner interviews, and city-provided construction permit documentation to provide the conclusions stated above. It should also be noted that reconductoring should be implemented as much as possible with other infrastructural improvements to minimize the labor costs of construction and implementation. Reconductoring involves replacing the electric lines (i.e., conductors) with new conductors that have higher capacities that are

[9] We use "mostly" because there are 448 unique distribution conductors in the City of Somerville. 342 of them are 13.8kV. 105 of them are 4kV and 1 is 24kV.
[10] https://www.eversource.com/content/docs/default-source/default-document-library/eversource-esmp%20.pdf

needed throughout the city. Labor will always be the largest cost factor that the residents of Somerville will incur as they improve and/or repair their utility infrastructure.

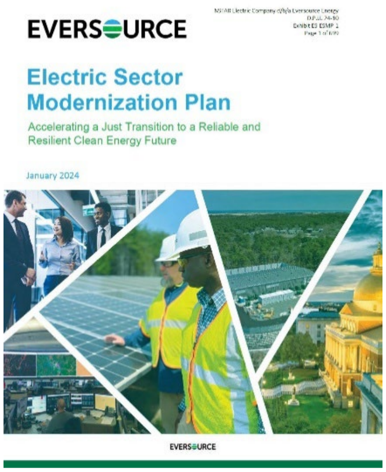


Figure 3-1. Eversource's Electric Sector Modernization Plan.

3.1 Existing Step-Down Transformers

Somerville is the most densely populated city in New England with more than 80,000 residents in approximately four square miles, meaning that there is a larger than typical supply of multi-family housing stock across the city. Because the streets existing rights-of-way are already crowded with utility networks, it is extremely rare that there is not some form of service either above or below ground on every street. Primary arterial streets like Highland, Medford, and Broadway have their electrical lines buried underground while more residential streets have their electrical power provided from overhead utility poles, as shown in the images in Figure 3-2. Here, the leftmost figure shows how the electrical conductors rise from underground on a Class 3 utility pole and strung on above-ground utility poles on more residential streets, and the right figure shows one of Somerville’s busier roadways without overhead utility poles.

Figure 3-2. Typical streets in Somerville. (Left) Somerville's quieter residential roadways with pole-strung transformers. (Right) Busier streets without overhead utility poles.

Additionally, Eversource recently completed a new 115kV underground transmission line that connects Eversource's Mystic Substation and Woburn Substation to improve reliability and the growing need for electricity in the service area that includes Somerville (Figure 3-3).[11] The line extends approximately eight miles between two existing substations, as indicated in Figure 3-4.

Somerville's electrical grid is primarily served by the Mystic Substation in the East (Figure 3-3) – in the location where a former, now retired power plant was once sited. Additional circuits are fed from the Alewife, Newton Street, and Woburn Substations in west, south, and north Somerville, respectively. Transformers at these substations reduce the high-voltage transmission (115kV) down to 13.8kV for distribution throughout Somerville. The grid comprises both underground and overhead distribution lines, with transformers stepping down voltage for various customer needs:

- **Three-Phase Distribution (13.8kV)**: Transformers on these lines step down voltage for customers requiring three-phase power and further reduce it to 4.16kV (i.e., 4160) or 240-120V for single-phase distribution

[11] https://www.eversource.com/content/residential/about/transmission-distribution/projects/massachusetts-projects/mystic-to-woburn-project

- **Single-Phase Distribution (4.16kV/13.8kV)**: Single-phase lines distribute power locally, with transformers further stepping down the voltage for residential and small commercial customers

While specific electrical load data from Eversource was unavailable for this work, qualitative assessments indicate that Somerville's substations were operating at 95% capacity as of 2023. The planned addition of a third transformer at the Somerville Substation #402, has occurred. Eversource mentions that the new 115V line, "is expected to reduce this load to approximately 58%", still needs to be confirmed by Eversource. It is unclear if there are plans to upgrade the downstream distribution systems.

It is recommended that the city work with Eversource to develop a plan to replace/upgrade the step-down transformers so that city and Utility funding sources can be combined to accelerate Somerville's city-wide electrification plans.

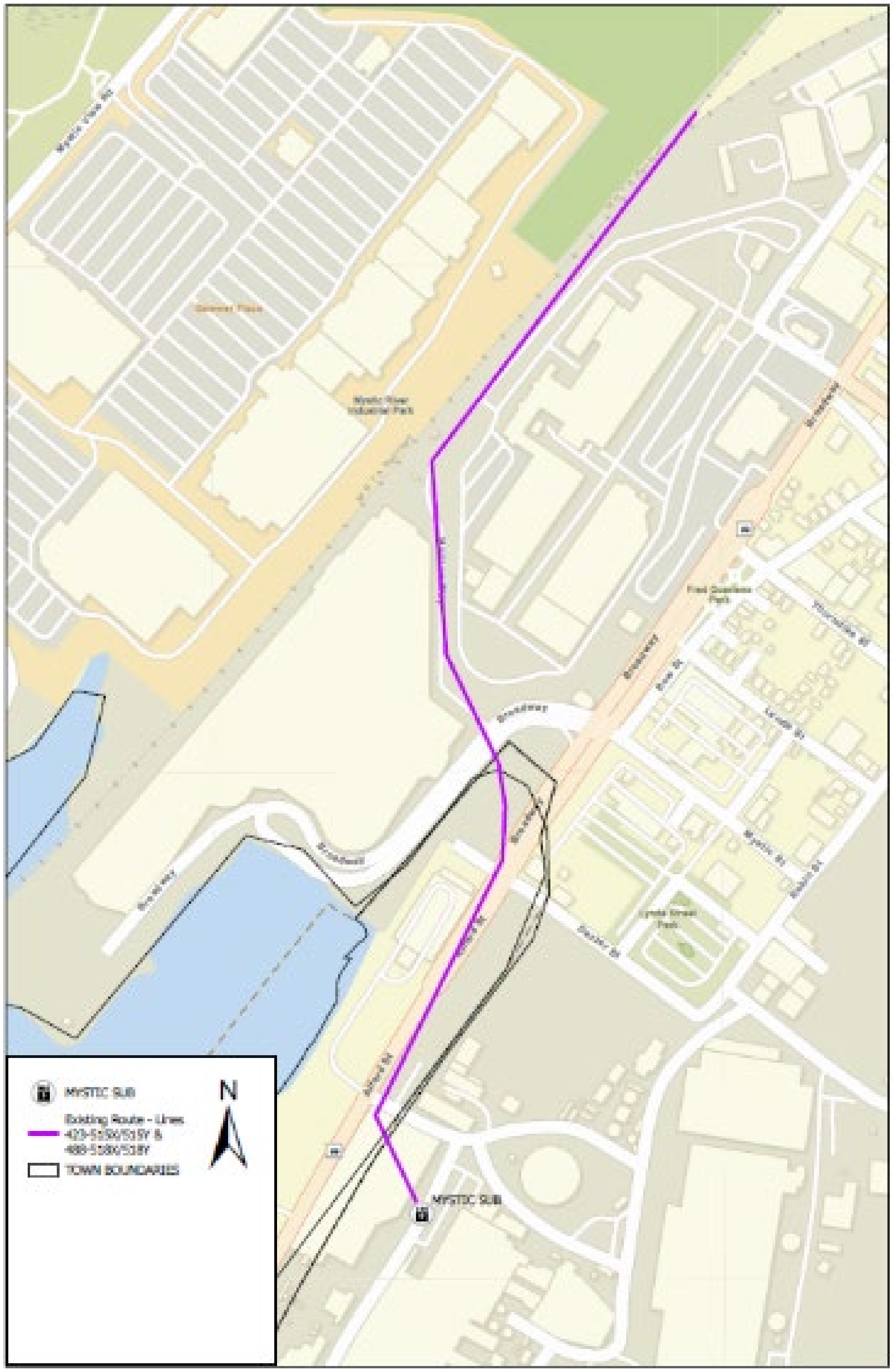


Figure 3-3. New Mystic Substation 115V distribution circuit.

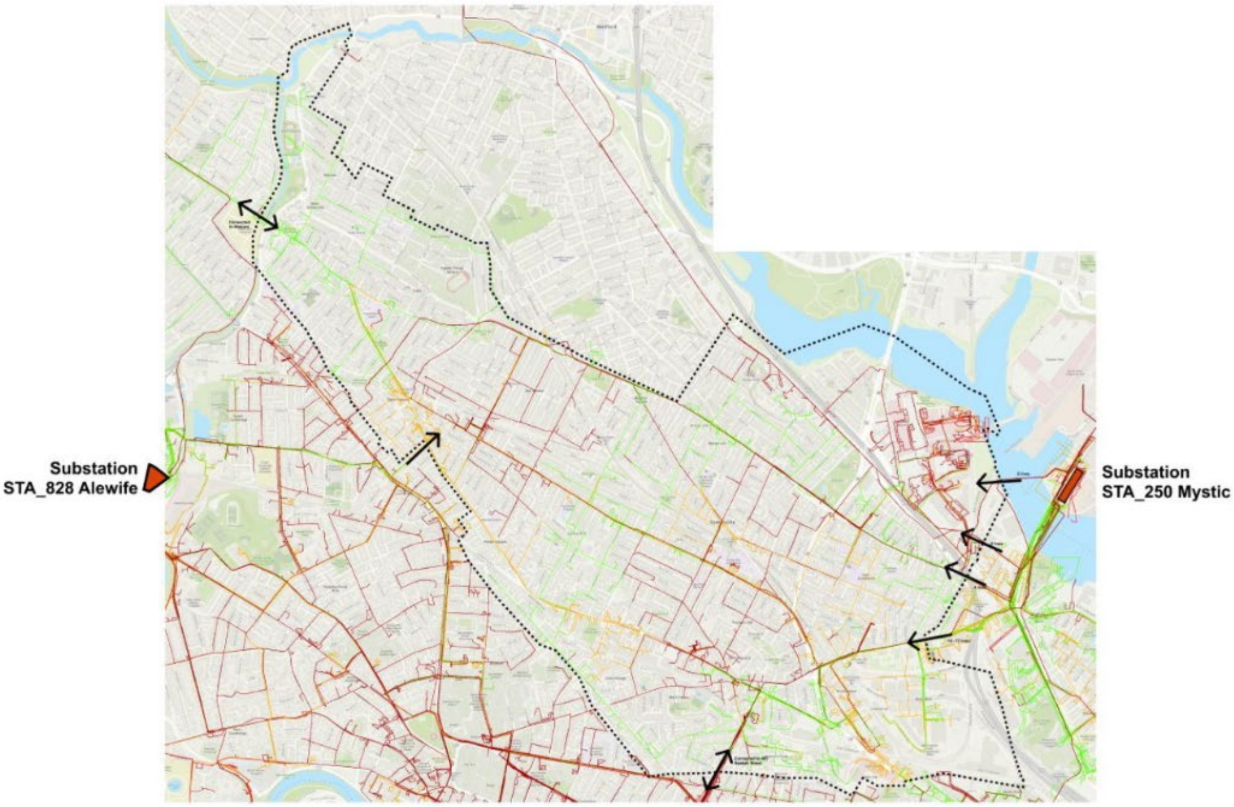


Figure 3-4. High voltage feeders in Somerville.

3.2 Sizing Replacement Step-Down Transformers

Addressing Somerville's issue of urban electrification requires a scalable solution to implement block-by-block electrification in Somerville's densely populated streets in a way that maximizes economic efficiency and economies of scale for residents and businesses. This approach is crucial given the challenges identified through recent assessments and feedback.

Sizing the replacement step-down transformers across the city will require a staged approach. It is economically unfeasible to assume that all of the transformers across the city can be replaced all at once. Municipal representatives have expressed that residents are voicing complaints that they have been receiving electrical service upgrade quotes that are nearly $50,000 per building.

Based on tabletop exercises from Eversource, an external developer and constituent feedback, Somerville has identified a need to expand the electric distribution significantly (doubling it in some cases) to fill gaps in the electric distribution system. This not only impacts a dwelling's ability to electrify systems within it, like heating, cooking, and hot water, but also the ability to host electric vehicle charging equipment. Buildings as small as three-unit multifamily dwellings electrifying all residential systems with one electric vehicle may need access to additional electric capacity. This capacity needs to be provided from the transformers on the utility poles to the dwellings. The transformers themselves are not the expensive issue. The largest percentage of the cost to upgrade comes from the labor involved to perform the upgrade. Additionally, the transformers, when ground-mounted utilize valuable, limited space in densely populated cities, above and below ground.

The city has expressed that without a clear process for different project types and an energy efficient, space-saving, and cost-efficient way to install these transformers, they are concerned that this may inhibit safer affordable housing projects and potentially slow development in the future.

It is important to note that the recently completed state-level Grid Modernization Plan reportedly only projects down to the substation level and does not consider how to transform power for use by individual buildings. This gap in planning highlights the need for a more comprehensive approach that considers the entire power distribution chain, from substations to individual meters.

Given these challenges, it is not a viable expectation for individual dwelling owners to bear the full cost of such extensive electrical upgrades. Therefore, we propose a staged approach that considers grouping adjacent or nearly adjacent dwellings to upgrade their step-down transformer service. By implementing upgrades in clusters, we can minimize electrical downtime, reduce inconvenience to residents, and optimize construction costs.

The cost of the equipment to upgrade service may input 20% to 40% of the overall cost, but labor and patchwork repair are the largest cost components to replace step-down transformers across the city. To find potential sources of capital to finance these electrical upgrades, the city is undertaking advocacy at the state level to address the possibility of adding this to the rate base through MassSave or other mechanisms and developing zoning incentives for developers and property owners to help facilitate electrification and fuel switching.

For Climate Forward 2024 (CF24), consultant KLA created a phased approach to residential building decarbonization consisting of three waves, informed by type of heating system listed in the Assessor's database. While this recommendation outlines decarbonizing an individual dwelling based on its individual ability to be decarbonized, pole-mounted transformers across Somerville are usually serving more than on dwelling. Therefore, the

KLA-phased approach may conflict with a transformer-centric approach. There is the possibility that the transformer-centric approach may align with KLA's individual dwelling approach, and that would yield the greatest cost efficiencies.

In January 2024, Eversource published its Modernization Plan for all of Massachusetts. Within this plan are sections that speak specifically about Somerville, the electrical service supporting the city, upgrades to that service, equipment health and viability, replacement planning, and other various details.[12] Through communication between Somerville and Eversource, Eversource has stated that they do not have a stated plan or schedule to replace transformers in Somerville. They do however have a stated plan to replace conductors across their service territory.

According to the accompanying database that Eversource provided to Somerville, there are 448 unique conductors (i.e., wires) supplying electricity to the city, as shown in Table 3-1. In Section 10.2 "Distribution Reliability Programs" of the Electric Sector Modernization Plan, Eversource states that they have a replacement program for their 4160 line (a.k.a. 4.16kV circuits). There are 105 x 4160 kV circuits. Only Station 59 coming from the Town of Arlington is scheduled to be upgraded to 13.8kV, and only seven of those conductors are relevant to Somerville. Three from that list have been retired over the past 5 years. That means there are 95 remaining 4.16kV circuits in the city that currently have no plan for upgrade by Eversource.

Table 3-1. Summary of conductors located across Somerville.

Conductor Voltage	Number of Conductors
4.16kV	105
13.8kV	342
24kV	1

We recommend that Somerville negotiate with Eversource to develop a plan to upgrade the remaining 4.16kV circuits to utilize some of the funding available to the utility and to the city through the Inflation Reduction Act (IRA) and/or the Bilateral Infrastructure Law (BIL). Additionally, we recommend that either the number of step-down transformers that currently provide electricity to ratepayers (most likely 100kVA) are increased to provide increase capacity to residents or the size of the

[12] Eversource Electric Sector Modernization Plan. https://www.eversource.com/content/docs/default-source/default-document-library/eversource-esmp%20.pdf

~100kVA step-downs are increased to a size appropriate to service the residents' increased capacity needs.

By upgrading those circuits, Eversource will have the opportunity to upgrade the transformers served by those circuits, thus achieving the city's electrification goals in a more cost-effective manner. We referenced the potential to use 288kVA or 333kVA pole mounted transformers, but a more discrete investigation is required to properly size transformers according to the needs of the cluster of residents the transformer is serving.

We also investigated the utility poles supporting the conductors in the city. According to the Eversource Electrical Modernization Plan, the average age of the utility poles is 36 years old. Eversource does not have a specific plan to replace poles but would do so based upon visual inspection or potentially a project that would include reconductoring and installing new/more transformers. If a larger transformer was the best solution, then Eversource might conclude that the utility pole needed to be replaced with a higher load classification as shown in Figure 3-5. While Eversource reported to the city that they do not install pole-mounted transformers greater than 100kVA on wooden utility poles, this does not follow the Utility Pole Horizontal Weight-Bearing Classifications established by the North American Wood Pole Council.[13] Eversource still has the option to upgrade to a higher weight-bearing pole if they choose to install a larger pole-hung transformer to provide the increased capacity to Somerville residents, and have done so repeatedly across the city as noted in every location observed by the consultant where electrical conductors emerge from underground to then transition to above-ground utility poles. If Eversource upgraded the

[13] North American Wood Pole Council. https://woodpoles.org/

necessary utility poles, this would perform two functions: 1) replace aging poles, and 2) increase overall electric distribution capacity.

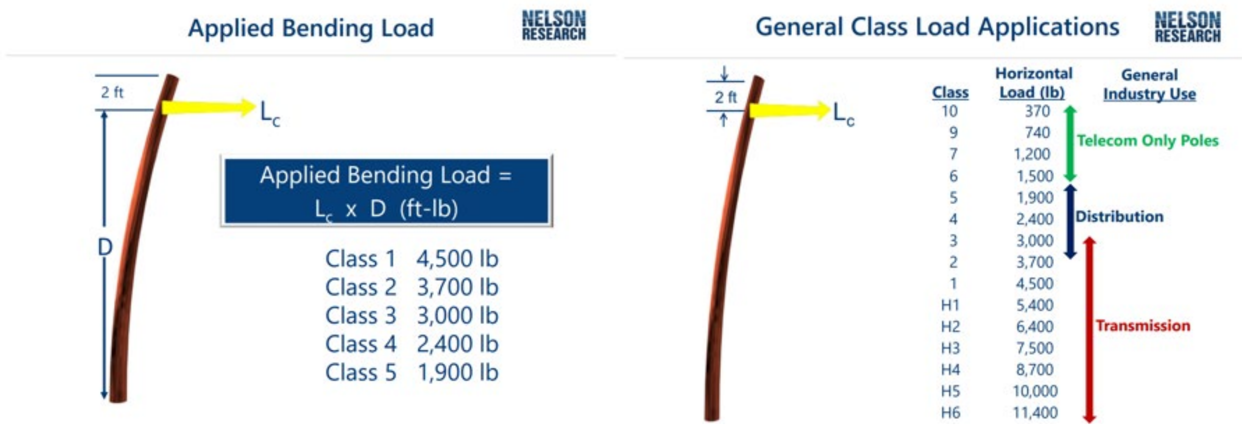


Figure 3-5. Utility pole classification.

The integration of networked geothermal systems into Somerville's grid will significantly impact utility transformers, specifically the main system pumps and customer connections will have the greatest impact.

- **Main System Pumps**: These pumps will be connected to transformers on the 13.8kV three-phase lines, which are more commonly located in commercial or industrial areas. Suitable sites for geothermal systems may therefore be identified at the interface between residential and commercial districts. Where suitable transformers are not nearby, new three-phase transformers and longer extensions of the 13.8kV distribution lines may be required.

Customers: At the residential level, dwellings are typically connected to pole-hung 75kVA or 100kVA transformers. When connected to a geothermal system, these dwellings may experience a net decrease in peak load due to the removal of electric radiant heat and window air conditioning units. However, if these loads are not removed and replaced with higher efficiency systems such as air or water source heat pumps, there could be an increase in peak load on the local transformer, necessitating upgrades.

3.3 Efficiency Gains Analysis

The electrical grid is undergoing a significant transformation to meet the growing demands of electrification and improve energy efficiency. At the heart of this evolution are distribution transformers, critical components that are experiencing unprecedented supply chain pressures and efficiency regulations. This section covers the technology of amorphous steel core transformers. It also addresses the recent Department of Energy (DOE) efficiency standards, the practical implications of implementing this technology, and its potential impact on grid modernization efforts.

3.4 Amorphous Steel Core Transformers

Electrical steel used in distribution transformer applications can be categorized as either amorphous alloy or grain-oriented electrical steel (GOES). The vast majority of current core manufacturing is established with GOES cores. Amorphous steel is a steel alloy that has a largely non-crystalline structure,[14] as shown in Figure 3-6.

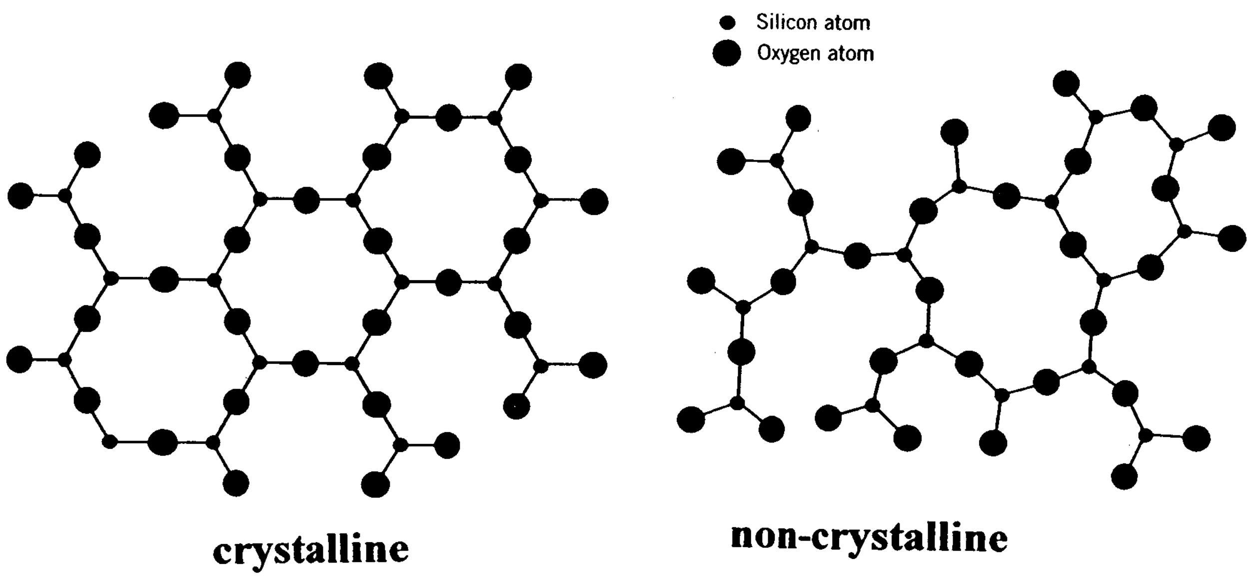


Figure 3-6. Material structure of grain-oriented electrical steel (GOES) vs. amorphous alloy.[15]

The Code of Federal Regulations defines distribution transformers as those that have an input of 34.5kV or less, and an output voltage of 600V or less, and a capacity of 10-2,500kVA.[16] These transformers are currently experiencing a large imbalance between supply and demand with lead times and costs increasing at unprecedented rates.[17] The U.S.

[14] P. M. Curran "Metglas Alloy for Distribution Transformer Cover", July 26, 1988, IEEE Power Engineering Society Meeting.
[15] Image source: University of California, Santa Barbara
[16] U.S. Department of Energy, "The Supply Chain Crisis Facing the Nation's Electric Grid," 2022. https://www.energy.gov/policy/articles/supply-chain-crisis-facing-nations-electric-grid
[17] National Renewable Energy Laboratory, "Major Drivers of Long-Term Distribution Transformer Demand", February 2024.

Department of Energy (DOE) Office of Electricity and Office of Policy, along with the National Renewable Energy Laboratory (NREL) have researched and reported on many factors (supply chain, increasing electrification, aging infrastructure, etc.) impacting the markets for these critical components. The supply of distribution transformers is critical for the reliability and growth of the power system. According to DOE and NREL, there are an estimated 60-80 million distribution transformers across the U.S. power system.

When used in the application of a transformer, at low and no-load levels, an amorphous steel core transformer has a lower power loss than a traditional transformer. At high load levels, the benefit in power loss is reduced – essentially, if transformers have a high capacity (use) factor, the benefit is diminished even further. This shift in loss reduction is illustrated in Table 3-2. While amorphous alloy core transformers are more efficient than traditional GOES core transformers, both have been designed to minimize losses and operate very efficiently. The individual benefit to the total power capacity of the single circuit the transformer is on is relatively small. By comparison, the efficiency percentage measured from a 500kV distribution transformer for an amorphous metal (AM), in this instance, steel core is 99.6%, while the efficiency for a cold Rolled Grain-Oriented (RGO) core transformer is 99.4%.

Table 3-2. Losses of transformers utilizing amorphous alloy.[18]

Rating	No-Load Losses		Loss Reduction
(kVA)	RGO	AM	
Single Phase			
15	55	20	64%
25	65	30	54%
50	105	35	67%
75	155	55	65%
100	200	75	63%
167	235	95	60%
Three Phase			
300	505	200	60%

[18] M. Hajiaghapour-Moghimi, A. Moradnouri and M. Vakilian, "Feasibility of Amorphous Symmetric Core Transformer Under Distribution Network Planning," 2018 Electrical Power Distribution Conference (EPDC), 2018

500	725	220	70%
750	1125	355	68%
1500	2170	725	67%
2500	2750	745	73%

When large numbers of transformers at the distribution level (down to 120V) are changed on a whole network, the power loss improvement, at low load levels, sums to a more significant total value, even if the percentage is small.

3.5 National Transformer Efficiency Policy

The DOE issued a proposed rule change to distribution transformer efficiency standards in 2023 that would have required that 95% of the steel used in distribution transformers to be Amorphous steel citing the improved efficiencies and decrease in losses across the power system. The proposed rule was set to take effect in 2027, but was met with headwinds from utilities, end-users, and transformer manufacturers alike. After considerations to supply chain, reliability, and impacts to American workers, the DOE issued their final ruling (EERE–2019–BT–STD–0018) in April 2024, which sets new transformer efficiency targets that can be met by utilizing 25% amorphous alloy while continuing to utilize grain-oriented electrical steel (GOES) for the remaining 75%. The DOE also increased the timeline for implementation of this ruling by two years to 2029, which will allow manufacturers to plan and implement changes to sourcing and manufacturing practices. This rule change is estimated to save Americans $800 million per year and up to $14 billion over the next 30 years when implemented across the high voltage transmission transformers and medium voltage distribution transformers. Since step-down transformers usually cover a relatively short distance as compared to medium and high voltage transformers, the city of Somerville would not realize any appreciable savings.

3.6 Benefits and Typical Use

The primary benefit of this amorphous alloy is the reduction in losses at low load conditions. When considering diversity on the grid, many of these transformers are at low load levels for many hours of the day. Adding up all the savings across the grid (60-80 million transformers), results in the need for less power generation for the many hours at the average grid load level. There are benefits at peak load levels to the grid generation needs, but the dominant savings comes from the small savings at low load multiplied by the many hours of operation at this level.

3.7 Relevance to Electrification Projects

Given the focus on electrification across the grid to support electric technologies (e.g., electric vehicles, heat pumps, electric cook stoves), NREL estimates an expected 160-260% increase in demand for distribution transformers within the US.[19] The replacement of traditional transformers with amorphous steel core transformers has generally been used to gain efficiency over time at low load conditions and not to improve or increase the peak capacity of the system. At the local level, if a single pole-hung 120V transformer is changed from a traditional transformer to an amorphous steel core transformer, there will be no increase in peak capacity and has no immediate benefit to a particular project.

When estimating the benefit to the city of Somerville, we assumed an estimated (600) 75kVA transformers and even replacing all pole-hung transformers to an amorphous alloy, would only reduce the demand on the system by up to 100kW. To contextualize the low impact of this change, for a reference neighborhood block of single-family homes, the benefit is equal to unplugging a laptop, or, for the whole city, the benefit is equal to saving the energy of one household from the more than 37,000 households in Somerville.

Based on the final ruling from DOE, there is no immediate action recommended on the part of Somerville or Eversource to immediately rush to replace distribution transformers with amorphous alloy cores since the manufacturing will not be in place until 2028-2029 when improved standards are put into effect.

3.8 Budget Estimation for Transformer Replacement

The cost of upgrading transformers varies depending on the required capacity and pole classification, as shown in Table 3-3. For example, increasing a dwelling’s service from 200 amps (A) to 400A could necessitate a 288kVA pole mounted transformer, which costs around $27,000. Additional costs for new poles and overhead lines will also need to be considered. The example below shows estimates of the total installed cost of a new 240V pole-mounted transformer at approximately $41,400. This estimate is similar to the cost estimate that the city reported from residents who received upgrade quotes from Eversource. This buoys support for the conclusion that the city may develop a program to group multiple dwellings that are served by a single transformer into individual upgrade

[19] Major Drivers of Long-Term Distribution Transformer Demand. https://www.nrel.gov/docs/fy24osti/87653.pdf

projects so that city-wide electrification happens on a more transformer-to-transformer plan.

Table 3-3. Line item costs for electrical grid upgrades.

Line Item	Purpose	Size	Unit	Unit Cost
Overhead Lines	Adding length to existing network	13.8kV	$/linear foot (LF)	$350/LF
Underground Lines	Adding length to existing network	13.8kV	$/LF	$450/LF
Pole-mounted transformer	Upgrading for end-of-life, portion of a street (8-10 dwellings)	100kVA (pole-hung transformer)	$/each	$16,000
Ground-mounted transformer	Upgrade whole street, 4 dwellings per pad mount	50kVA (pad-mount transformer)	$/Qty	$11,500
Riser to underground	Upgrading to support underground lines (implemented along with networked geothermal system)	Joint trenching (ambient loop + 13.8kV)	$/LF	$250/LF

3.9 Grid Impact Assessment

The grid impact assessment for the implementation of networked geothermal systems in Somerville reveals that the project is feasible with manageable increases in load on both 13.8kV circuits and the Mystic Substation. A modeled system designed to serve approximately 50 detached dwellings would require a total maximum power of 300kW. To cover the equivalent of 6,000 dwellings in Somerville, 120 such systems would be needed, distributed across 24 feeders, with each feeder supporting five systems. These scenarios are highlighted in Table 3-4, Table 3-5, and Table 3-6.

When assessing the impact on 13.8kV circuits, a single networked geothermal system increases the load by 0.7% on a 7MVA feeder, 0.03% on a 10MVA feeder, and decreases it by 0.05% on a 21MVA feeder. For multiple systems, the cumulative power requirement of 300kW results in a 4.3% increase on a 7MVA feeder, a 1.8% increase on a 10MVA feeder, and a 0.14% decrease on a 21MVA feeder. At the Mystic Substation, the total power requirement from multiple networked geothermal systems expected to be around 6MW – leading to a 3.2% increase in load on the substation with a capacity of 185MVA. The mid-range scenario shows a 2.0% increase, while the lower bound scenario indicates a 0.6% decrease.

The grid impact assessment indicates that the implementation of networked geothermal systems in Somerville is feasible. The upper bound scenarios show the highest impact, but even these are within acceptable limits for grid stability. With careful planning and phased implementation, the grid can accommodate the additional load without significant issues.

Table 3-4. Effect of a single building plugged in to a networked geothermal system attached to a single 13.8kV circuit.

	Power Requirement from Single Building on Networked Geothermal System	13.8kV Feeder Capacity	% Change
Upper Bound (*increase*)	+50kW	7MVA	+0.7%
Mid-Range	+30kW	10MVA	+0.03%
Lower Bound (*decrease*)	-10kW	21MVA	-0.05%

Table 3-5. Effect of many buildings plugged in to a networked geothermal system attached to a single 13.8kV circuit.

	Power Requirement from Multiple Buildings on Networked Geothermal System	13.8kV Feeder Capacity	% Change
Upper Bound (*increase*)	+300kW	7MVA	+4.3%
Mid-Range	+180kW	10MVA	+1.8%
Lower Bound (*decrease*)	-30kW	21MVA	-0.14%

Table 3-6. Effect of many buildings plugged in to a networked geothermal system attached to Mystic Substation.

	Power Requirement from Multiple Buildings on Networked Geothermal System	Mystic Substation Capacity	% Change
Upper Bound (*increase*)	+6MW	185MVA	+3.2%
Mid-Range	+3.6MW	185MVA	+2.0%
Lower Bound (*decrease*)	-1.2MW	185MVA	-0.6%

4 Networked Geothermal Systems

4.1 Feasible Technologies and Strategies

4.1.1 Thermal Energy Networks

Networked geothermal systems are a type of thermal energy network (TEN) that transfers the natural thermal energy from the Earth to a group of buildings to provide space heating, cooling, and, in some cases, domestic hot water heating. The Earth's subsurface temperature remains roughly constant year-round, where only the upper ~50 feet is subject to seasonal fluctuation from solar irradiation. At practical depths below the surface (up to ~500 feet below the Earth's surface), it can be assumed that the temperature is approximately 55 ºF year-round.

Networked geothermal systems can take the form of two kinds of configurations: open and closed-loop systems. In a closed loop geothermal network, boreholes are drilled, typically up to a maximum of 1,000 feet, into which a loop of pipework is dropped and grouted into place. Water mixed with a small percent of heat transfer fluid (i.e., glycol) is circulated through this pipe where it is either warmed or cooled depending on the temperature gradient to the ground, The geothermal vertical u-pipes are then manifolded into a horizontal, ambient distribution piping loops, where individual dwellings then connect to the horizontal loop, which then circulates through a water-to-water heat pump unit within the building or individual residence to provide heating and cooling in a much more efficient manner than conventional HVAC or air-source heat pumps. This entire system is self-contained in a closed-loop as shown in Figure 4-1.

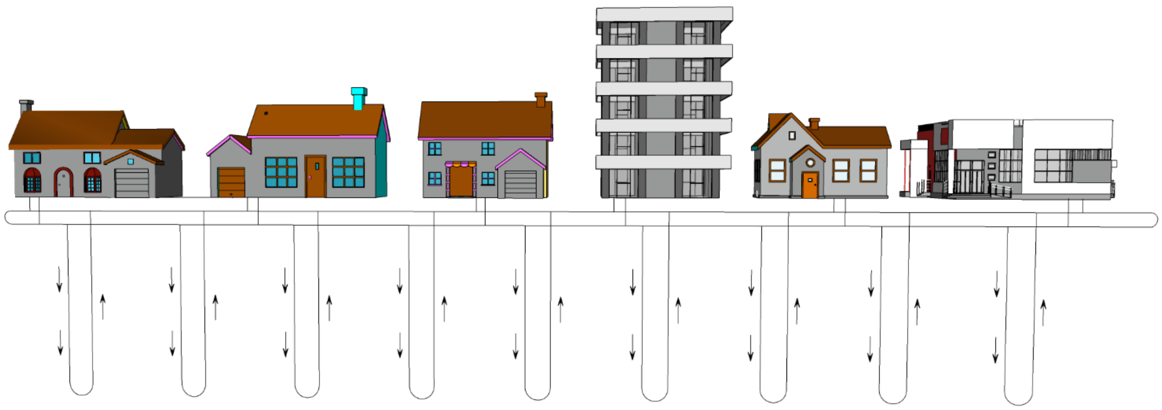


Figure 4-1. Schematic of a typical networked geothermal system.

Open loop geothermal systems (Figure 4-2) aim to access and abstract groundwater as a source of heat exchange, where a well is drilled – which functions similarly to a drinking water well – drawing water from an aquifer. At depth, this water is typically the same temperature as the ground, and, therefore, energy can be absorbed from it or rejected into it in much the same way as the closed loop system. The important distinction between closed and open loop systems is that in an open loop system, groundwater is brought out of the ground. The abstracted water is then either returned to a drilled discharge well, sent to waste, or sent back into the abstraction well (known as a standing column system). A well-performing open loop system can yield over 10 times the thermal energy as a single closed loop borehole (yield here depends on constant flow of water available from the well). However, the installation cost can be up to 10 times higher than a closed-loop system, and there can be additional risk tied to uncertainty in the bedrock at depth. These types of systems are best explored when:

- There is very high confidence in the aquifer, access to it, and flow rates of water possible from it.
- The possible water flow rates mean energy abstraction potential far exceeds the capacity possible from closed loop geothermal covering the same space.
- The extensive drilling required for closed loop geothermal is not feasible or possible.

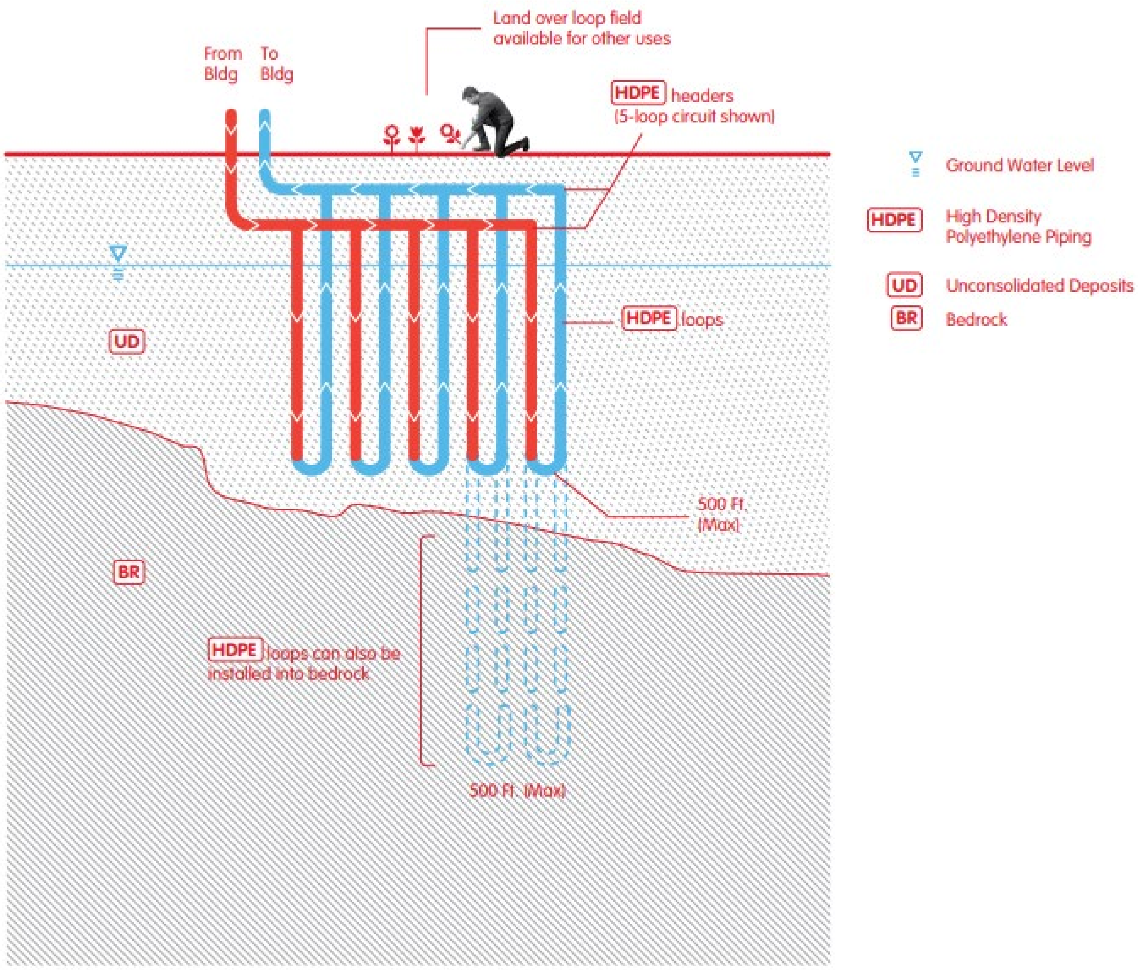


Figure 4-2. Concept diagram of a closed-loop geothermal system (NYC Heat Pump Manual).

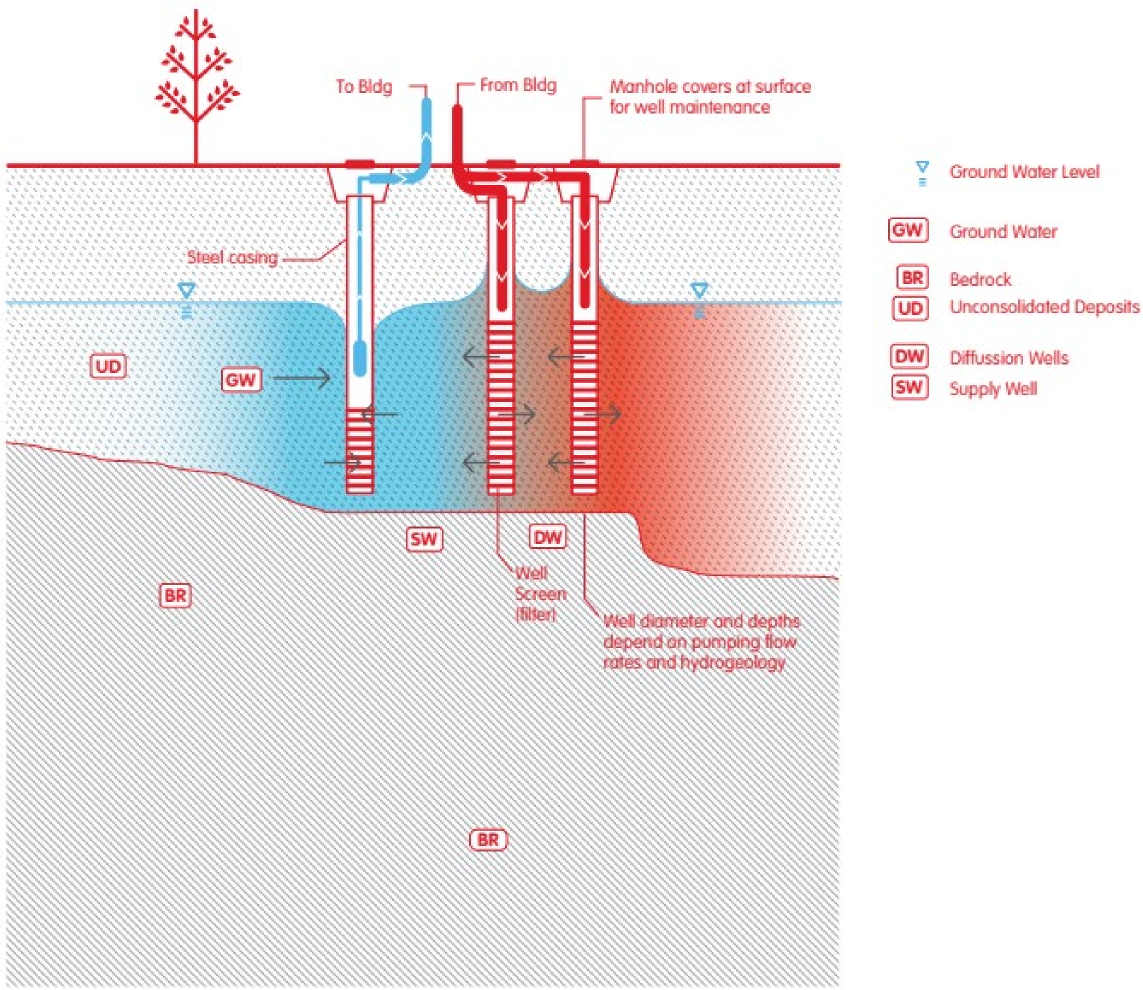


Figure 4-3. Concept diagram of an open-loop geothermal system (NYC Heat Pump Manual).

4.1.2 Energy Sources

In order to function in the delivery of heat or cooling to a building, a water-source heat pump (WSHP) must be connected to pipework in which there is water (or other heat transfer fluid), and the pipework must be connected to an energy source which can keeps the temperature in the pipe roughly constant. In addition to drawing thermal energy from a geo-exchange source, such as a borehole, thermal energy can also be captured from surface water bodies and heat capture processes.

Similar to a geo-exchange system, surface water exchange systems can be closed or open-loop systems. In a closed-loop system, pipework or a heat exchanger is placed in a body of water (e.g., river, lake, pond) at sufficient depth to avoid the freezing layers of the water, and heat transfer fluid is pumped through the pipework which abstracts energy from or rejects energy to the body of water. In an open-loop system, an abstraction pump is placed in a body of water at sufficient depth to avoid the freezing layers of the water. The body of water itself is then pumped to a heat transfer station where energy is abstracted or rejected before the same water is returned to the original water body. This type of system has the potential for installation within the Mystic River on the north side of Somerville.

Waste heat sources can also be utilized to maintain consistent temperatures in the thermal energy network. Water in the sewers and within wastewater treatment plants have been shown to be areas where waste heat can be recovered. This phenomenon is the result of the prevalence of hot water entering the sewer network from residential or commercial premises, and, therefore, it can provide a warm heat source in winter. Industrial processes and heat generators can also be captured and integrated into these networks, including sources such as:

- Power generation stations
- Mystic River
- Data Centers
- Electrical transformers
- Metalwork shops
- Paint shops and curing plants
- Breweries and distilleries
- Ice rinks
- Major laundry facilities
- Sterilization facilities
- Food processing plants
- Crematoriums

Heat is recoverable from many points of these processes but typically would fall into the following three categories:

- Heat recovery from flue gases – heat exchangers placed inside flues can easily warm ambient temperature water.
- Waste process streams containing warm water – similar to wastewater heat recovery, these processes work with a cleaner waste stream.
- Heat recovery from process cooling – industrial processes which require chilling can be targeted for heat recovery in the same way as data centers/refrigeration.

4.1.3 Grid and Additional Non-Energy Benefits

There are multiple benefits to operating a networked geothermal system over traditional district energy infrastructure or distributed electrification (e.g., individual air source heat pumps), including energy sharing, diversity, and the potential to reduce electrical loads. By interconnecting opposing loads, energy can be recycled or shared instantaneously. In other words, when one building is heating, it is rejecting cooling, and this cooling can then be used at another building. Diversity – referring to the heterogeneity of how customers consume thermal energy – can allow for heat sources in thermal energy networks to be sized to meet the collective demand of all customers rather than their individual peaks – allowing for the size of a borehole network or auxiliary thermal injection systems to be designed at a smaller, and more cost effective, size.

In 2023, the United States consumed ~4.48 trillion cubic feet of natural gas to produce heat in residential buildings.[20] If this was converted into electrical resistive heat, the grid would need to output an extra 31% beyond the 4,178 GWh it produced in 2023. While some conductors may be able to handle the increased load, most utilities do not know the full effect that could have across their distribution systems. This is why increasing electrification alone can run the risk of overloading certain areas of the electrical grid. There are three approaches to remedy this this problem:

- Improve the building envelope performance through insulation, sealing gaps, energy efficient windows, and doors. This will reduce the per square foot energy required to heat and cool a space.
- Add load management measures – by utilizing technologies such as smart appliances, batteries, or demand response technologies, electrical peak demands can drop at the most constrained times.
- Use more renewable energy and energy efficient electrification technologies – by utilizing renewable sources coupled with energy efficient heat pumps, electrical loads decrease whilst still providing the same thermal output to satisfy the building demand.

Figure 4-4 shows the impact of sourcing thermal energy for heating and cooling from the ground instead of the air. Here, the dark pink line, representing annual ground temperatures, shows much lower fluctuations in temperature than the light blue line representing the typical outdoor air temperature in Somerville. Because the ground

[20] https://www.eia.gov/tools/faqs/faq.php?id=50&t=8

temperatures are much more stable, less energy at the building level is required to "step up" or "step down" the resulting temperature needed to achieve a typical comfortable indoor set point temperature, represented by the green bar.

From an emissions perspective, drastic reductions in peak summer months reduce grid strain during the hottest days, when transmission lines are unduly burdened by higher ambient temperatures and resistive line losses. Loads are also relatively flatter and calmer - all without exploiting additional opportunities for load shaping and network level control around time of use, the ability to turn the ground source system on and off as needed to shed load or shape loads to meet grid needs or during times of lower carbon intensity. Grid emissions peak in the Winter and Summer when customers are increasing their demands, through home heating and cooling. As spring begins and temperatures float in a relative ambient, comfort band - there is a surplus of lower emissions power and reduction in HVAC demand.

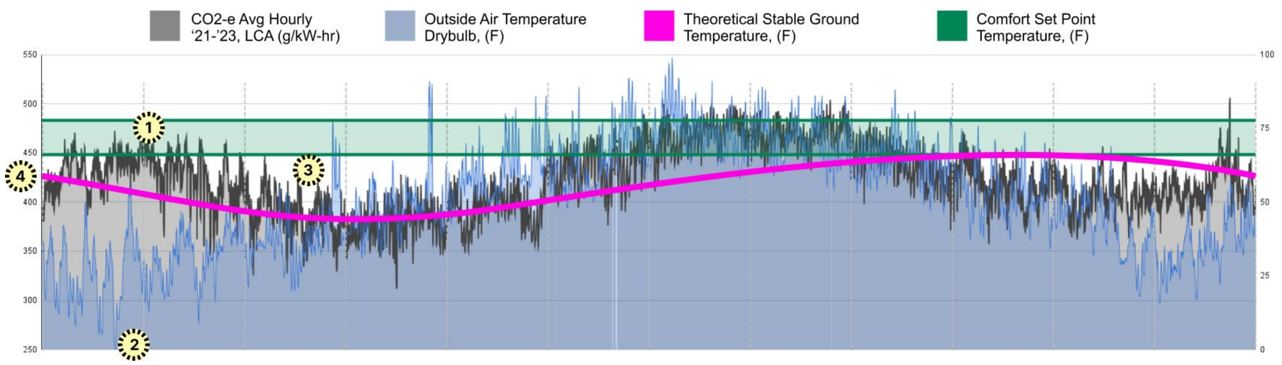


Figure 4-4. Typical annual air and ground temperatures in Somerville, plotted against typical indoor comfort setpoints. Points 1 and 2 refer to the typical emissions and temperature profiles in the city, respectively. At Point 3, in the shoulder seasons, grid carbon emissions factors drop, if a solution were to require charging the field with electrically generated warm water, this would be the time of year to do it. Point 4, indicates a theoretical borefield temperature, illustrating how consistent it is – staying closer to the indoor air temperature.

In addition to the key energy implications of utilizing networked geothermal systems to deliver thermal energy to a network of buildings, because they emit virtually no nitrogen oxides or fine particulate matter during operations, they can help mitigate poor air quality and subsequent public health issues.

These systems also have the potential to promote energy equity. Networked geothermal systems offer an equitable path to decarbonization because it can allow any utility customer to plug into a lower carbon-producing energy network with potentially minimal building upgrades to do so. Due to their increased levels of efficiency, they can lower utility costs for otherwise burdened customers. Finally, the workforce to build and maintain geothermal systems aligns closely with that required for gas infrastructure. This allows workers with expertise in natural gas infrastructure, such as pipefitters, to transition more easily to working renewable energy infrastructure than would be feasible for other energy industries such as wind and solar.

4.2 Above- and Below-Ground GIS Obstruction and Utility Mapping

Given the density of Somerville's built environment, in order to understand the full feasibility of deploying a networked geothermal system, mapping above- and below-ground obstructions is key to learning where pipes, boreholes, and other central infrastructure could be sited to deliver thermal energy to the network's "plugged-in" buildings. GIS mapping was used to determine if obstructions, described in the following subsections, would eliminate a site from consideration or add a magnitude of complexity and potential increased costs that would need more investigation in later stages of design. Figure 4-5 shows an overview of the key obstructions used to highlight and/or eliminate sites from feasibility contention.

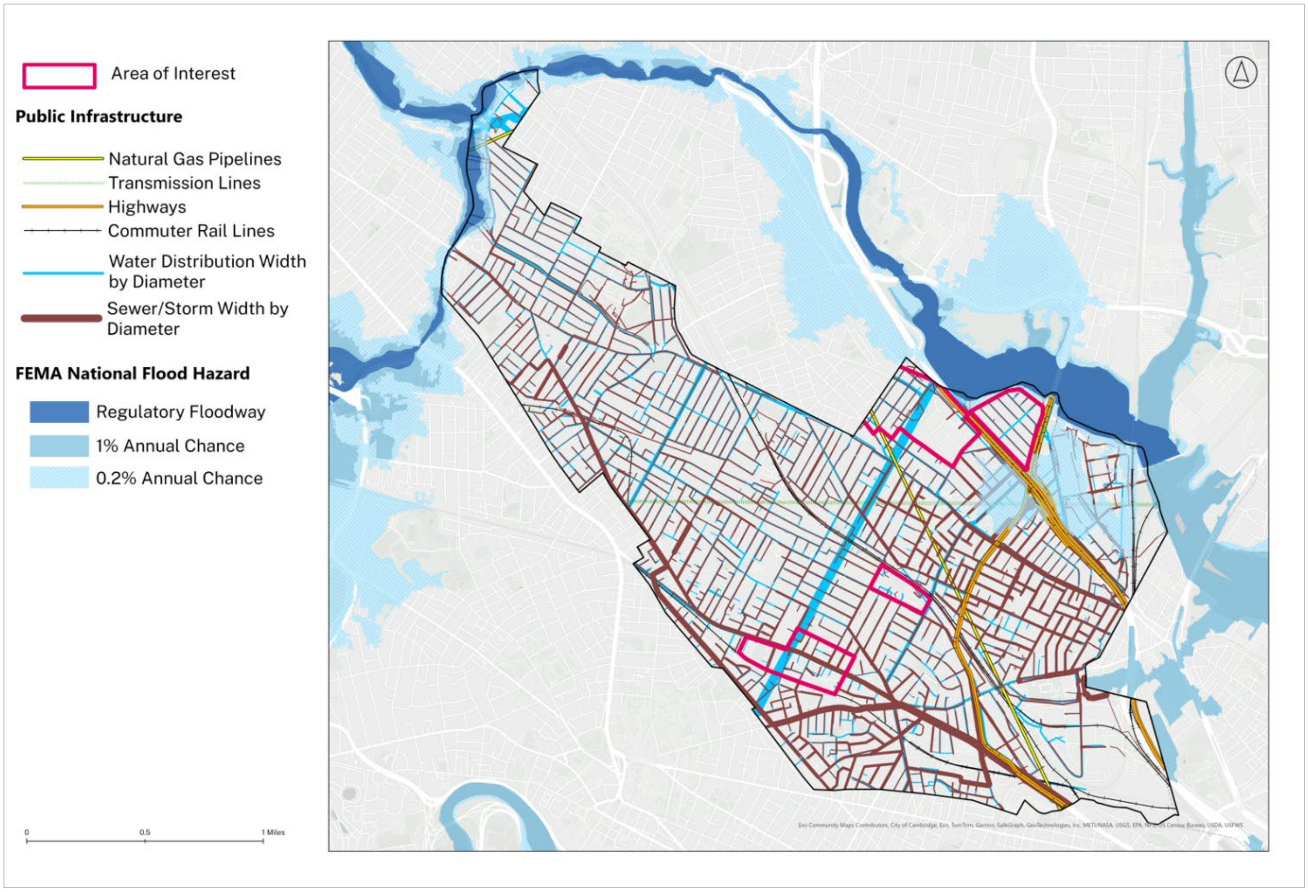


Figure 4-5. Public infrastructure interference and flood zone mapping in Somerville.

4.2.1 Natural Gas Pipelines

This polyline dataset represents the major natural gas transmission pipelines in the U.S., including interstate, intrastate, and gathering pipelines as visualized in Figure 4-5 with the yellow lines.[21] This data was created for the purpose of identifying major natural gas transmission pipelines in the United States. These data were compiled by the U.S. Energy Information Administration from various sources including federal and state agencies, and other external sources such as company web pages and industry press. The data was last updated in January 2020.

When selecting sites for networked geothermal systems, it is essential to avoid areas with significant infrastructure like gas pipelines to prevent potential hazards and interference.

[21] https://hifld-geoplatform.hub.arcgis.com/datasets/geoplatform::natural-gas-interstate-and-intrastate-pipelines/about

This ensures the safety of both the geothermal system and the existing gas infrastructure, reducing the risk of accidents and service disruptions.

4.2.2 Transmission Lines

A shapefile of transmission lines, sourced from the Homeland Infrastructure Foundation Level Database (HIFLD), visualizes the location and physical characteristics of existing electric power transmission lines, depicted in Figure 4-5 as the dashed green line.[22] In addition to citing the location of these lines, the dataset also provides information on the structures, wires, insulators, and associated hardware of the system. The data was filtered to include only underground transmission lines given the scope of this study.

The transmission lines dataset is important to avoid disruptions to the electrical distribution network. High-voltage transmission lines are critical for delivering electricity over long distances, and any interference could lead to power outages or other electrical issues. Mapping these lines ensures that geothermal installations do not compromise the integrity of the electrical grid.

4.2.3 Sewer Gravity Mains

This feature class represents the network of underground pipes that use gravity to transport raw wastewater to regional treatment plants. The data was filtered to include pipes with diameters greater than 24 inches as this is likely to be representative of areas in the existing rights-of-way that may exclude possible locations for where to site a networked geothermal system. Figure 4-5 depicts the sewer mains using brown lines with the thickness of the line representing pipe diameter. The data was provided by the city.

The sewer gravity mains dataset highlights the network of underground pipes that transport wastewater. Avoiding these mains is vital to prevent major infrastructure interventions that could disrupt sewage services. Interference with sewer mains could lead to costly repairs and public health issues, making it essential to map and avoid these areas during site selection.

4.2.4 Water Distribution Lines

This dataset includes water distribution main line pipes that carry treated municipal water, maintained by the city's Water Department. Similar to the filtering of data for sewer gravity mains, this data was filtered to include pipes with diameters greater than 36 inches. Figure

[22] https://hifld-geoplatform.hub.arcgis.com/datasets/geoplatform::transmission-lines/about

4-5 depicts the water distribution using blue lines with the thickness of the line representing pipe diameter. The data was provided by the city of Somerville.

The water distribution lines dataset includes main pipes that carry treated municipal water. Similar to sewer mains, it is important to avoid these lines to prevent disruptions in water supply. Interfering with water distribution infrastructure could lead to significant service interruptions and costly repairs, so mapping these lines helps ensure that geothermal installations do not negatively impact the water supply network.

4.2.5 Highways

This layer represents the official MassDOT-maintained street transportation dataset, including both public and many private roadways in Massachusetts. The data was filtered to only include Interstate Highway, Ramps, and Principal Arterial roads, as these are roads that will is unlikely to be able to be trenched for implementation of any utility upgrading project. These roads are shown in Figure 4-5 as orange lines. The data was provided by the city of Somerville.

When planning geothermal networks, it is beneficial to avoid areas with major roads to facilitate future expansion without the need to cross highways. Crossing highways can increase costs and reduce energy delivery efficiency due to the increased distance. Therefore, avoiding these areas allows for easier and more cost-effective expansion of the geothermal network.

4.2.6 Commuter Rail Lines

This layer includes active passenger, freight, and MBTA Commuter Rail and Rapid Transit railways, along with abandoned rail lines and railroad beds now used as rail trails. The data was filtered to include only active rail lines, represented in Figure 4-5 as the black line with dashes. The data was provided by the city of Somerville.

The commuter rail lines dataset includes active railways used for passenger and freight transport. Similar to highways, avoiding these areas is important for the same reasons: it allows for easier expansion of the geothermal network without the complications and costs associated with crossing active rail lines. Ensuring that geothermal installations do not interfere with rail infrastructure helps maintain efficient transportation services and reduces potential project costs.

4.3 Thermal Balancing

In addition to the geospatial data discussed in Section 4.2, a key component of the siting analysis was to understand the impact of thermal load profiles on the ability to balance a thermal energy network. While more accurate modelling of building heating and cooling loads would require the use of customer-specific electricity and natural gas data, given this data was unavailable for use in this study, Buro Happold utilized typological energy use data from NREL's ComStock and ResStock databases. These datasets employ traditional bottom-up physics-based energy modelling tools, utility data, and building survey data on typical physical characteristics to generate time series datasets of energy end use information for ~500,000 buildings across the United States. The preliminary results from this thermal load modelling are further discussed in Section 4.5.

To capture estimated heating and cooling load profiles for buildings across the city, the ComStock and ResStock datasets were scraped of building energy use information and cleaned to produce a dataset describing typical energy use intensities (EUI) and thermal load profiles for 16 commercial and 4 residential building typologies across the city. Figure 4-6 shows a typical heating (Red Line, peaking at Point 6) and cooling profile (Blue Line) for a single-family residential building in Somerville. Based on this initial modelling, it can be seen that the heating peaks are higher than the cooling ones during the summer months and will dictate the sizing for a future networked geothermal system.

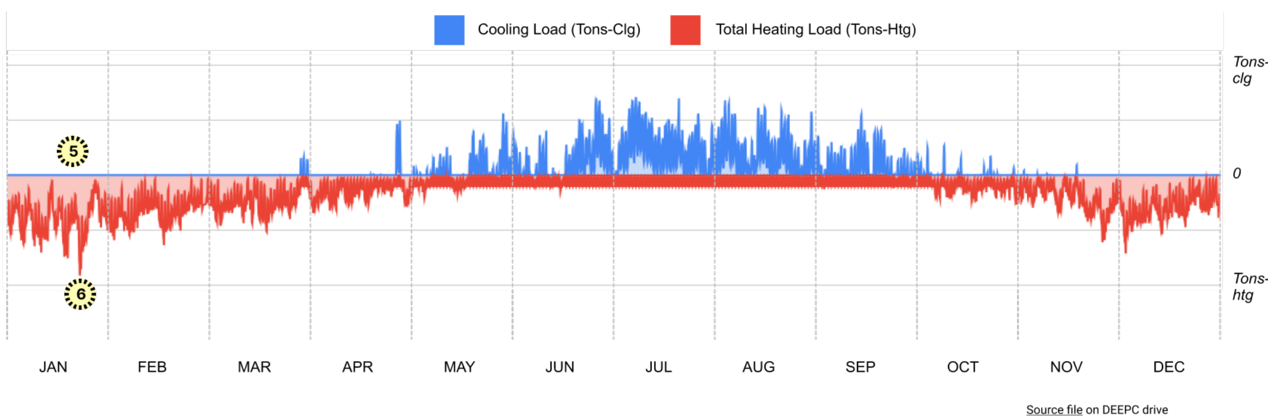


Figure 4-6. Typical heating and cooling profile for a single family residential building in Somerville.

While this data provides a first-order understanding of expected heating and cooling loads for all buildings studied for each site evaluated in this siting assessment, concept and continued levels of detailed design should employ the use of metered energy data and building-level audits in the design of a networked geothermal system.

4.4 Environmental Impacts Analysis

In addition to mapping the key physical infrastructure obstructions that could limit the opportunity for installing a networked geothermal system, this section highlights three of the key environmental or geological considerations that should be included when deciding the most suitable sites for a pilot project.

4.4.1 Bedrock Lithology

The polygon data layer for bedrock lithology, visualized in Figure 4-7, in Massachusetts provides critical insights into the dominant lithology and lithogeochemical character of near-surface bedrock, produced by the US Geological Survey (USGS).[23] The dataset's attribute "ROCK_GPA" categorizes lithogeochemical units, grouping them based on similarities in geochemistry and lithology. Understanding the type of bedrock is essential for assessing the heat abstraction potential and feasibility of geothermal networks. Different rock types have varying thermal conductivity of these rock types has a corresponding heat capacity, which determines how productive a borehole can be in conducting heat.

[23] https://www.mass.gov/info-details/massgis-data-bedrock-lithology

Figure 4-7. Bedrock lithology in Somerville, MA.

Table 4-1, adapted from the USGS shows each rock type and its corresponding heat capacity. Generally, the rock typology indicates that potential yields are promising for geo-exchange activities and capacities, which influence the efficiency of heat transfer.

Table 4-1. Specific heat extraction (Watts/foot) value by bedrock type, based on 1800 full load extraction hours per year.

Rock Type	Specific Heat Extraction (Watt/foot)	Specific Heat Extraction (Watts/meter)
Extrusive Igneous Rocks (e.g. basalt)	13-20	40-65
Intrusive Igneous Rocks (e.g. granite)	20-26	65-85

Metamorphic Rocks (e.g. gneiss)	21-26	70-85
Carbonate Rocks (e.g. limestone)	14-18	45-60
Basic Sedimentary (e.g. sandstone)	20-24	65-80
Gravel, Sand, Saturated Water	20-24	65-80
Clay, Loam, Damp	45580	35-50

4.4.2 Depth to Bedrock

The depth to bedrock data dataset, visualized in Figure 4-8, for Somerville in was produced by the Massachusetts Geological Survey, Department of Earth, Geographic and Climate Science, UMass Amherst, and sponsored by the MassDOT Office of Transportation Planning.[24]

[24] https://www.mass.gov/info-details/massgis-data-bedrock-altitude-and-overburden-thickness-layers

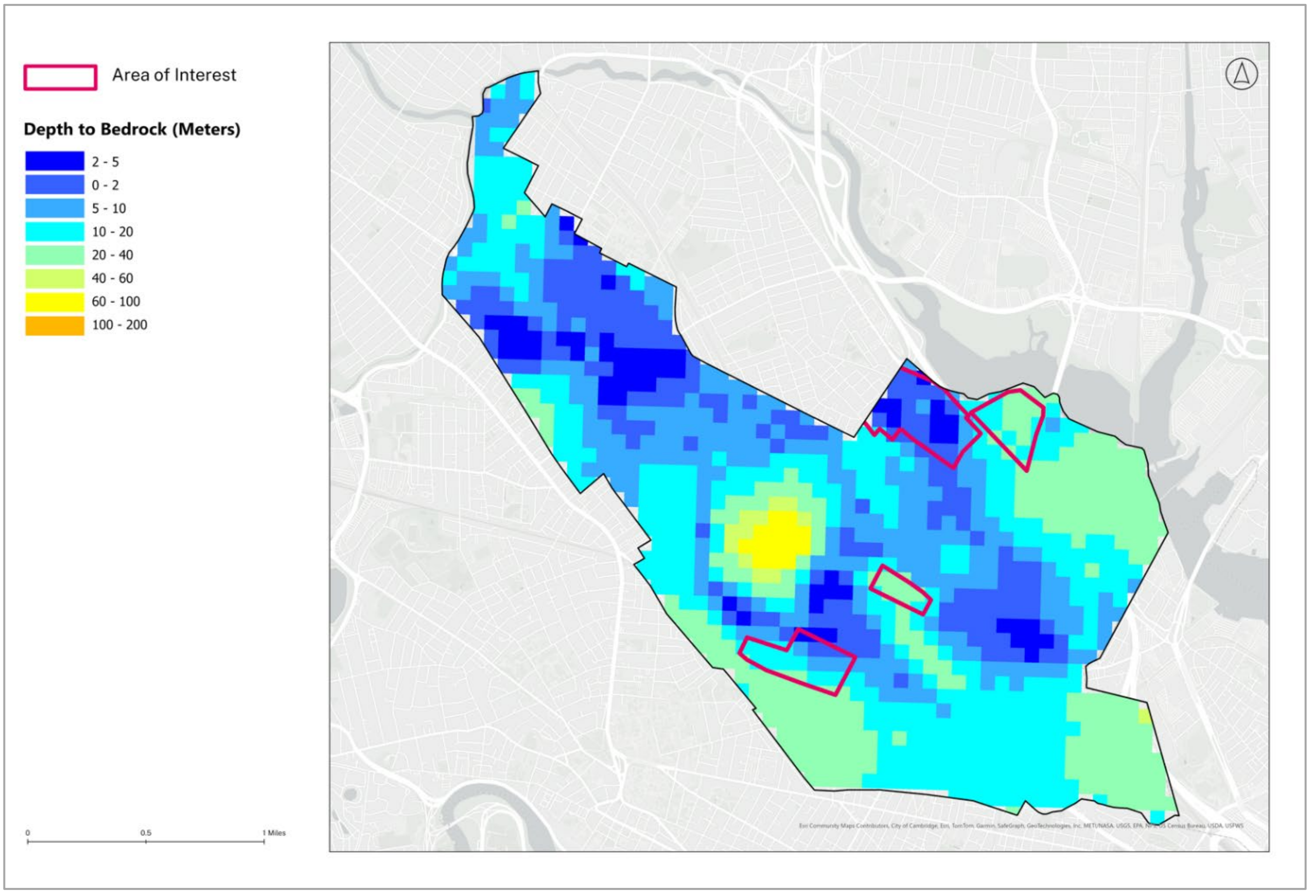


Figure 4-8. Depth to bedrock in Somerville, MA.

The depth to bedrock raster, with a 100-meter resolution, illustrates the thickness of the overburden across Massachusetts. Shallow bedrock depths can reduce drilling costs and simplify the installation of geothermal systems, making projects more economically viable. Conversely, deeper bedrock requires more extensive drilling, increasing both the cost and complexity of the project. The depth to bedrock can influence the thermal gradient and the overall efficiency of the geothermal system, as deeper systems may encounter higher temperatures, enhancing heat extraction potential.

4.4.3 FEMA Flood Hazards

The National Flood Hazard Layer (NFHL) dataset, provided by FEMA, maps the current effective flood risk areas, including Regulatory Floodway, 1% Annual Chance Floodway, and 0.2% Annual Chance Floodway zones as visualized in Figure 4-4. The Regulatory Floodway is where the channel of a river or other watercourse and the adjacent land areas that must be reserved to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. The 1% Annual Chance Floodway (100-year flood zone) has a 1% chance of flooding in any given year. It is also known as the Special Flood Hazard Area (SFHA) and is subject to mandatory flood insurance purchase requirements. The 0.2% Annual Chance Floodway (500-year flood zone) has a 0.2% chance of flooding in any given year. It is considered a moderate flood hazard area and is not subject to mandatory flood insurance purchase requirements. Areas prone to flooding pose significant risks to the infrastructure of geothermal networks, including potential damage to underground pipes and equipment. Flood zones can also complicate construction and maintenance efforts, leading to higher costs and increased project risk. Careful consideration of flood hazard data is necessary to ensure the resilience and reliability of geothermal systems in flood-prone areas.

4.5 Recommended Pilot Areas

This section discusses some of the key quantitative outputs from this feasibility study. To evaluate each of the sites, conceptual line diagrams were drawn to understand what the length of an expected network would look like. The buildings located along the network were then modelled to understand their annual heating and cooling demands, based on the methodology discussed in Section 4.3. The peak heating and cooling demands, annual loads, and estimated opportunity for heat capture potential from industrial, manufacturing, or heat-producing commercial sites, were reported for direct comparison. Additionally, a final metric – heat line density – was used to evaluate the relative “cost-effectiveness” of each network on a conceptual level. This equation as shown below can be used to compare how much thermal energy is delivered on an annual basis per foot of trenching and horizontal pipe required for the network’s installation:

$$Heat\ Line\ Density\ \left(\frac{MWh}{ft}\right) = \frac{Annual\ Heating\ and\ Cooling\ Use\ (MWh\ )}{Length\ of\ Horizontal\ Network\ (ft)}$$

The following subsections show what a potential network layout could look like to serve the cluster’s buildings, an estimate heating and cooling load profile, based on the modelling approach discussed in Section 4.3, and highlights key metrics as part of this modelling, namely:

- Population served
- Network length (linear feet)
- Annual heating and cooling energy delivered ($MWh_{thermal}$)
- Peak heating and cooling loads met ($MW_{thermal}$)
- Heat line density ($MWh_{thermal}$/foot)

4.5.1 Central Hill

The Central Hill site serves a population that includes 77 residential buildings, as well as key public facilities such as City Hall, Somerville High School, and the Public Library. A preliminary network layout, shown in XXX, spans 3,910 linear feet, but has the potential to expand to other nearby residential buildings and the local YMCA given availability of space in the existing rights-of-way. As shown on the map in XXX, there is a limited amount of greenspace and open parking lots surrounding the municipal buildings. Currently, the proposed network is bordered to the north by the MBTA Green Line, which could introduce potential challenges related to network routing, borehole drilling, and/or siting of a central pump house. Directional or deviated drilling, similar to the approach used in Framingham, could be employed to minimize surface-level interference. If the geothermal borefield were extended to the north on the other side of the MBTA line to increase the thermal capacity of this system, then additional permitting would be required to connect the north borefield to the south. The north site would also be ideal for a pump house.

The preliminary estimates for annual heating and cooling energy requirements are substantial, with 10,417 MWh needed for heating and 2,324 MWh for cooling. The peak heating load is 9.69 MW, while the peak cooling load is 1.45 MW. The heat line density for the site is calculated at 3.26 MWh per foot.

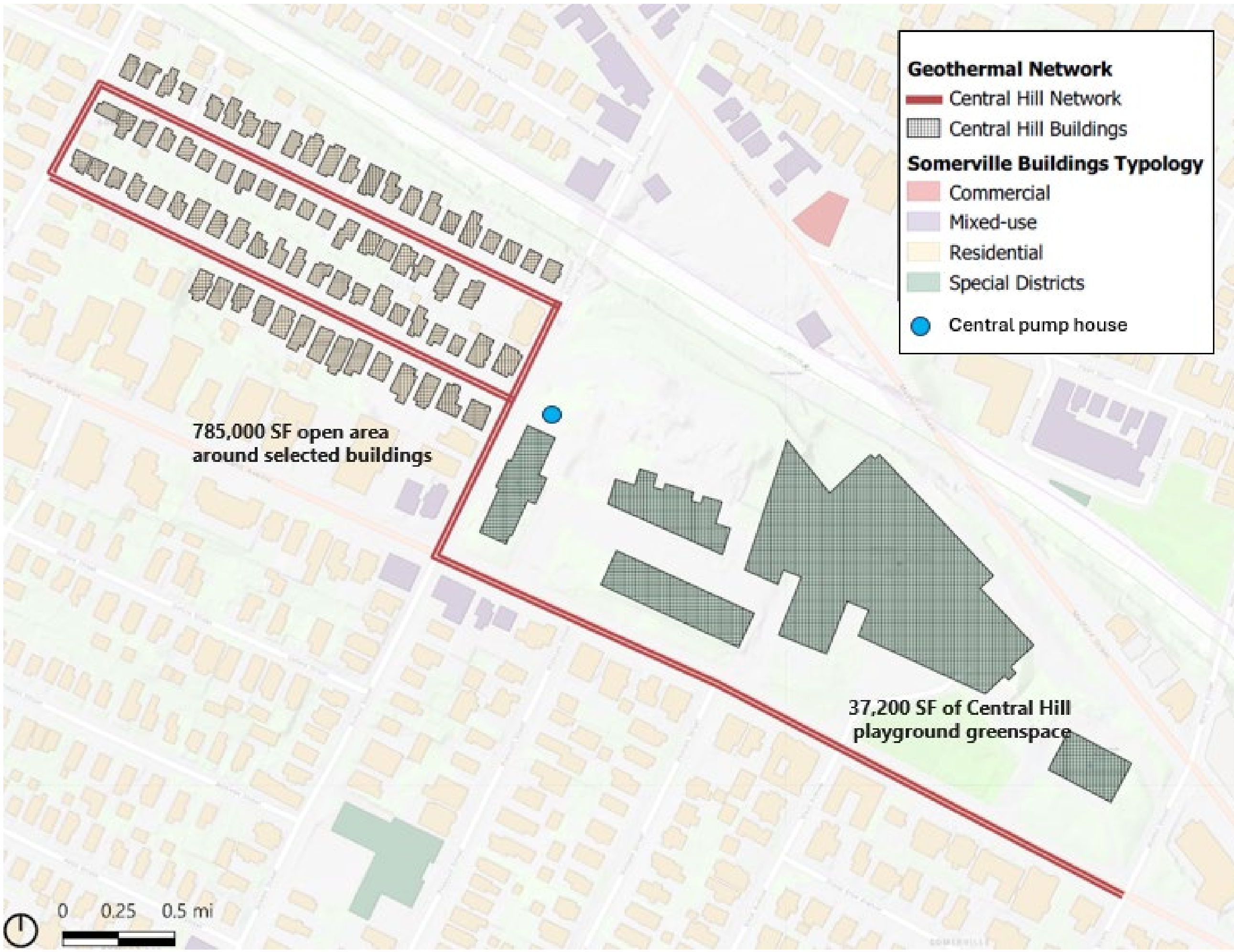


Figure 4-9. Preliminary network layout for proposed site in Central Hill.

Table 4-2. Key outputs from concept-level modelling in Central Hill.

Metric	Output
Population Served	77 residential buildings City Hall, Somerville High School, Public Library, 1895 Building
Network Length (linear feet)	3,910
Heating and Cooling Energy Delivered ($MWh_{thermal}$)	10,417 MWh (Heating) 2,324 MWh (Cooling)

Peak Heating and Cooling Load Met ($MW_{thermal}$)	9.69 MW (Heating) 1.45 MW (Cooling)
Heat Line Density ($MWh_{thermal}$/linear foot)	3.26

4.5.2 Ten Hills

The Ten Hills site (Figure 4-10) serves a population comprising 54 residential buildings and 11 Somerville Housing Authority buildings. The network spans 5,020 linear feet, and its major crossing passes underneath the Interstate 93 freeway. A primary central pump house, where all key infrastructure support systems (e.g., control systems, pumps, auxiliary thermal capacity and storage) has preliminarily been sited near the Somerville Housing Authority – where the vast majority of boreholes would likely be drilled. A secondary location, near the Mystic River, has also been sited for additional capacity and/or to support the inclusion of a heat exchange system with the river itself. To confirm the viability of this site, next steps in a feasibility assessment will require further engagement with key stakeholders (e.g., MassDOT) to understand the impacts this network design may have.

The heating and cooling energy requirements, as shown in Table 4-3, are lower than Central Hill, with 3,482 MWh needed for heating and 858 MWh for cooling annually. The peak heating load is 2.50 MW, while the peak cooling load is 0.56 MW. The heat line density for the site is calculated at 0.86 MWh per foot, which is lower than the results seen in Central Hill given the need to pass the Northern Expressway to reach the Somerville Housing Authority development.

Since there is a future project to underpin I-93, this could be an opportunity to combine construction objectives with Mass DOT. This could significantly reduce construction costs if transportation and the city were able to work together. While past effort for mutualistic collaboration between city and state objectives have observed friction, the state's and city's objectives for the 2050 energy transition goals are aligned. This is the opportunity that should be exploited to develop the Ten Hills option.

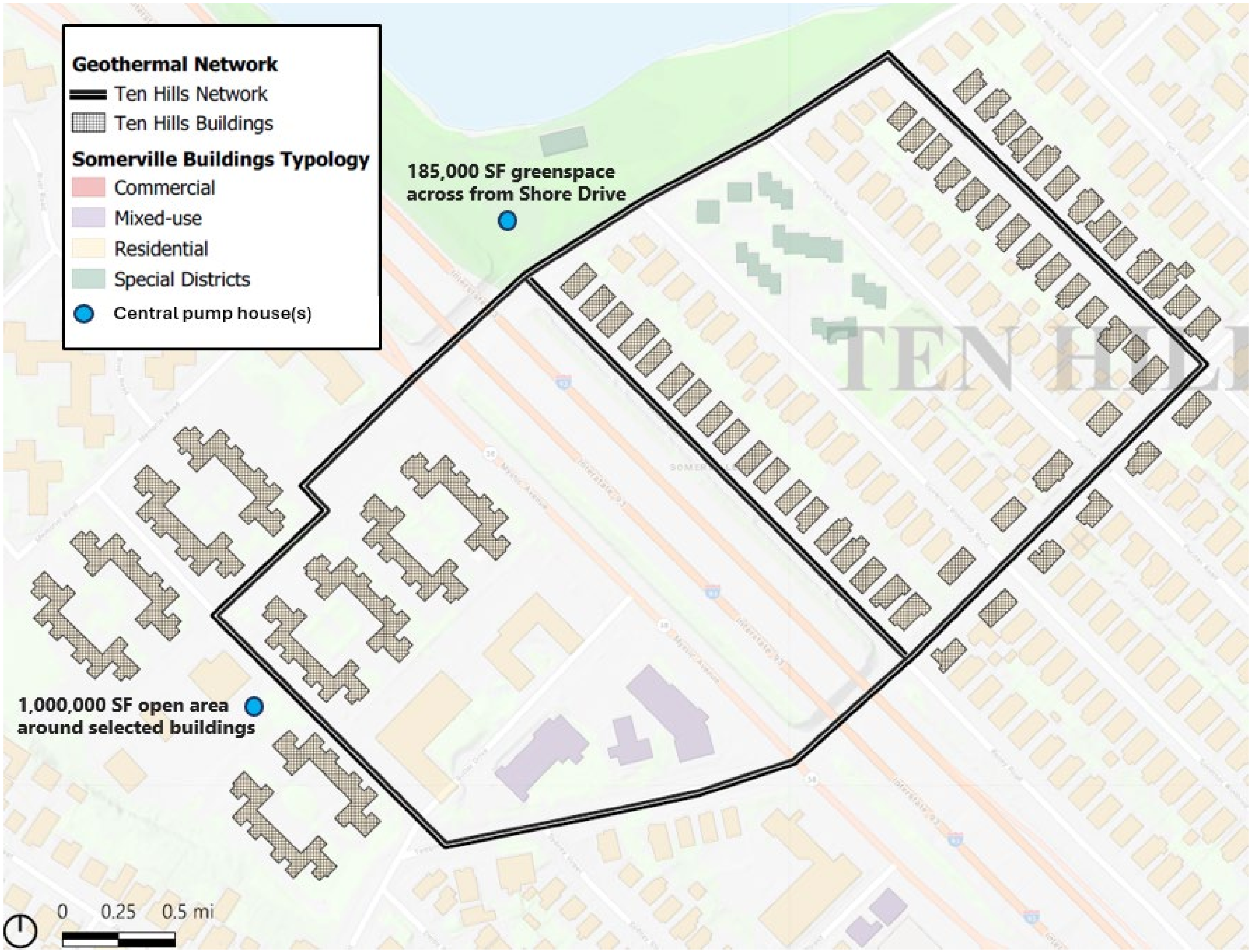


Figure 4-10. Preliminary network layout for proposed site in Ten Hills.

Table 4-3. Key outputs from concept-level modelling in Ten Hills.

Metric	Output
Population Served	54 residential buildings 11 Somerville Housing Authority buildings
Network Length (linear feet)	5,020 feet
Heating and Cooling Energy Delivered ($MWh_{thermal}$)	3,482 MWh (Heating) 858 MWh (Cooling)
Peak Heating and Cooling Load Met ($MW_{thermal}$)	2.50 MW (Heating) 0.56 MW (Cooling)

Heat Line Density ($MWh_{thermal}$/linear foot)	0.86

4.5.3 Central Somerville Avenue

The proposed network, located along Central Somerville Avenue (Figure 4-11), is a potential site that could serve a diverse population, including 85 residential buildings and 6 mixed-use facilities such as Greentown Labs, Form Energy, Veterans Memorial Rink, Aeronaut Brewing, and other retail establishments. The network extends over 5,730 linear feet in order to serve several residential streets of single and multi-family dwellings. The main artery of the network extends through Somerville Avenue, and therefore, additional surveying of the existing utilities in the right-of-way will need to be done to confirm the viability of this particular network routing. One of the benefits of this particular site in Somerville is the opportunity to engage with industrial heat-producing customers. These sites, which include Aeronaut Brewing Company and the Veterans Memorial Ice Rink, produce waste heat that can be captured and integrated into the heat network for distribution to nearby commercial and residential buildings. This site also contains several large open spaces well-suited for borehole drilling: the parking lot near Market Basket and the sports fields at Conway Park.

The annual heating and cooling energy requirements are 4,749 MWh for heating and 949 MWh for cooling (Table 4-4). The peak heating load is 2.19 MW, while the peak cooling load is 0.46 MW. The heat line density for the site is 0.99 MWh per foot. Opportunities exist at the Ames Envelope Complex site to capture waste heat from Form Energy, Aeronaut Brewing and Veterans Memorial Ice Rink. While structured interviews with the operators of these sites will be essential to quantifying the amount of heat capture potential, a literature review of other operational breweries and ice rinks and the United States show potential for integration into the heat network. For a typical ice rink, it is expected that about 2,000 kWh of heat is generated daily in the production and maintenance of ice – primarily through the refrigeration condenser unit.[25] Breweries are much more variable in their heat production based on the time and amount of time during the year when actual brewing is conducted, the volume of production, and the processes that are employed to capture heat.[26] Therefore, additional interviewing is planned to be conducted during the next phase of

[25] Xcel Energy. "Managing energy costs in ice rinks." https://www.xcelenergy.com/staticfiles/xe/PDF/Marketing/MN-Bus-Custom-Efficiency-Ice-Rink-Savings-Suggestions.pdf

[26] "The green brewery concept: Energy efficiency and the use of renewable energy sources in breweries." https://www.sciencedirect.com/science/article/pii/S1359431111001657#tbl1

work as part of the HEET Kickstart project to confirm feasibility of including a brewery in the heat network.

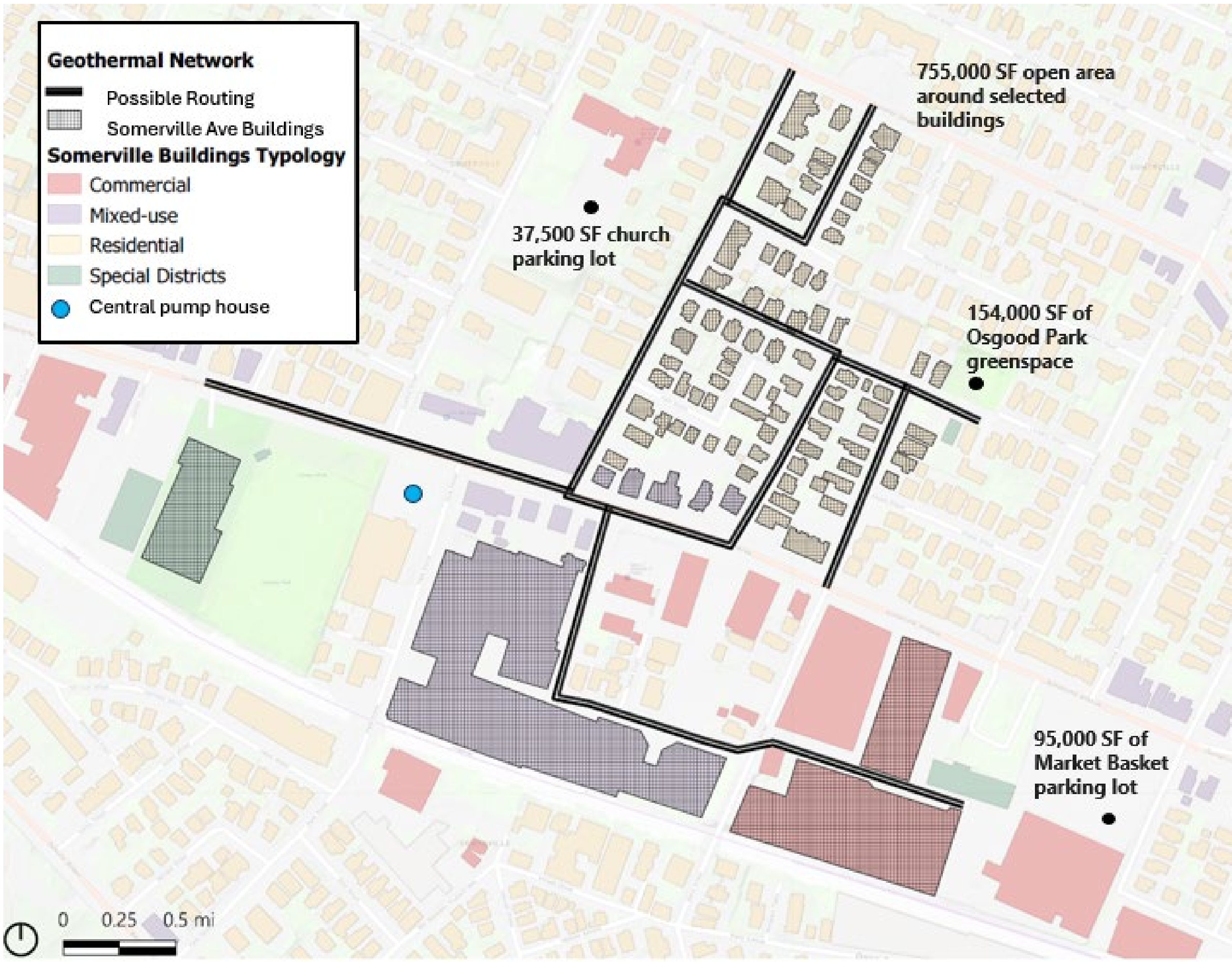


Figure 4-11. Preliminary network layout for proposed site along Central Somerville Avenue.

Table 4-4. Key outputs from concept-level modelling in Central Somerville Avenue.

Metric	Output
Population Served	85 residential buildings 6 commercial buildings (Greentown Labs, Veterans Memorial Rink, Aeronaut Brewing, other Retail)

Network Length (linear feet)	5,730 feet
Heating and Cooling Energy Delivered ($MWh_{thermal}$)	4,749 MWh (Heating) 949 MWh (Cooling)
Peak Heating and Cooling Load Met ($MW_{thermal}$)	2.19 MW (Heating) 0.46 MW (Cooling)
Heat Line Density ($MWh_{thermal}$/linear foot)	0.99

It should be noted that Table 4-4 does not include the additional 2,000 kWh/day expected to be collected from Veterans Memorial Ice Rink. Table 4-5 shows the key outputs from this initial modelling. Overall, out of the three sites studied in depth, Central Hill has the highest heat line density, based on the higher quantity of thermal energy delivered per unit length of horizontal pipe work/infrastructure that would be required for the network.

Table 4-5. Model output comparison.

Metric	Ames Complex	Ten Hills	Central Hill
Residential Buildings in Network	85	54	77
Commercial Buildings in Network	6	11	4
Network Length (feet)	5,730	5,020	3,910
Total Heat Delivered ($MWh_{thermal}$)	4,749	3,482	10,417
Total Cooling Delivered ($MWh_{thermal}$)	949	858	2,324
Peak Heating (MW)	2.19	2.5	9.69
Peak Cooling (MW)	0.46	0.56	1.45
Heat Line Density (MWh/ft)	0.99	0.86	3.26

5 Task Integration: Networked Geothermal and Electrification

The team reviewed all available information in the public domain and we have estimated the change to electrical demand caused by the installation of one or many networked geothermal systems. We have studied the electrical infrastructure, determining the built capacity and arrangement of the system. We do not currently have access to actual electrical load information from Eversource. Therefore, we have compared the potential change in electrical load due to geothermal to the total capacity of the system, to determine a percentage change to the electrical demand, and possible effects on the existing utility transformers. We also studied amorphous steel core transformers, in the context of any benefit related to electrical demand changes due to addition of networked geothermal systems.

5.1 Electrical Infrastructure Summary

The power demand associated with networked geothermal pilot system is approximately less than 0.5% of the capacity of any of the 13.8kV distribution circuits that it will be connected to. This is unlikely to require any electrical upgrades to the distribution, transmission or upstream infrastructure. Depending on the amount of electric resistance heat and window air conditioning units installed in buildings that would be replaced by the geothermal system, the electrical demand is likely to reduce in the pilot area.

Overall, an anticipated net load reduction in a residential networked geothermal community can be anticipated in the range of 0.5 W/SF to 0.8 W/SF. This would be typically half or less than what would be required if air-source heat pumps were used instead of water-to-water heat pumps as used in networked geothermal systems.

If we compared air-sourced heat pumps' electrical consumption versus ground-sourced heat pumps normally used in networked geothermal systems, then we see the ground-sources, also known as water-based heat pump systems are inherently more efficient, as they use water to cool or heat the condenser. During most hours of the year, the ambient water source will be at a temperature closer to the desired indoor ambient temperature for occupant comfort, meaning the compressor will not need to work as hard or cycle as frequently. In addition, water-based heat pumps have the benefit of having a higher Specific Heat Capacity - meaning that more units of energy (thermal heat) can be moved per unit of energy (electric power) put into the system.

Figure 5-1 shows the general amount of useful heating and cooling that can be extracted on a unitless basis, this is known as the coefficient of performance (COP), for every 1 unit of electricity input to the system, several units of heating or cooling can be delivered to the load (room or space). For an air-based system, the COP can typically be between 2 and 3, and up to 4 under ideal conditions. For ground-source heat pumps, they will operate for more hours each year under more ideal conditions, with lower compressor lift (less work) due to more consistent ground temperatures, achieving COPs between 5 and 8 as measured at Colorado Mesa University. While ground-source heat pumps attached to a single geothermal system may achieve COPs near 6, those same ground-source heat pumps networked together allow the excess energy from one residence to be share across the network without adding any more pumping demand, thus increasing overall efficiency and reducing overall grid power demand. These performance and energy efficiency gains, make ground source heat pumps incorporated in a networked geothermal system a better candidate for district and community level heating and cooling systems, where the upfront investment can be paid back through rates over a longer period of time.

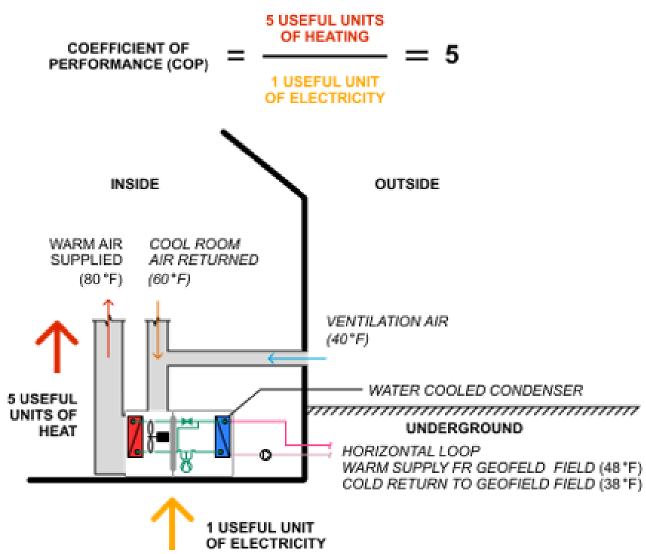


Figure 5-1. Diagram of ground-source and air-source heat pumps.

There is no available electrical capacity data available that can be used as a legitimate differentiator between one local area or another. The electrical distribution network within Somerville can likely accommodate a pilot project anywhere that space is available and public sentiment is favorable, considering the potential demand changes and redistribution, within practical limits. Based on the data available, electrical capacity concerns should not be a key differentiator in the selection of pilot sites.

5.2 Required Electrical Infrastructure

The geothermal pump house will require access to existing 3-phase transformers, or a new set installed on a 3-phase distribution line, which will one of several determinants for siting a networked geothermal pilot project. A qualitative heat map of the density of the 3-phase distribution lines, can be seen in Figure 5-2 where suitable transformers are more likely to be located. However, it should be noted that the geological considerations, such as the availability of practical borehole construction sites and thermal load-balancing customers are more important than local electrical capacity.

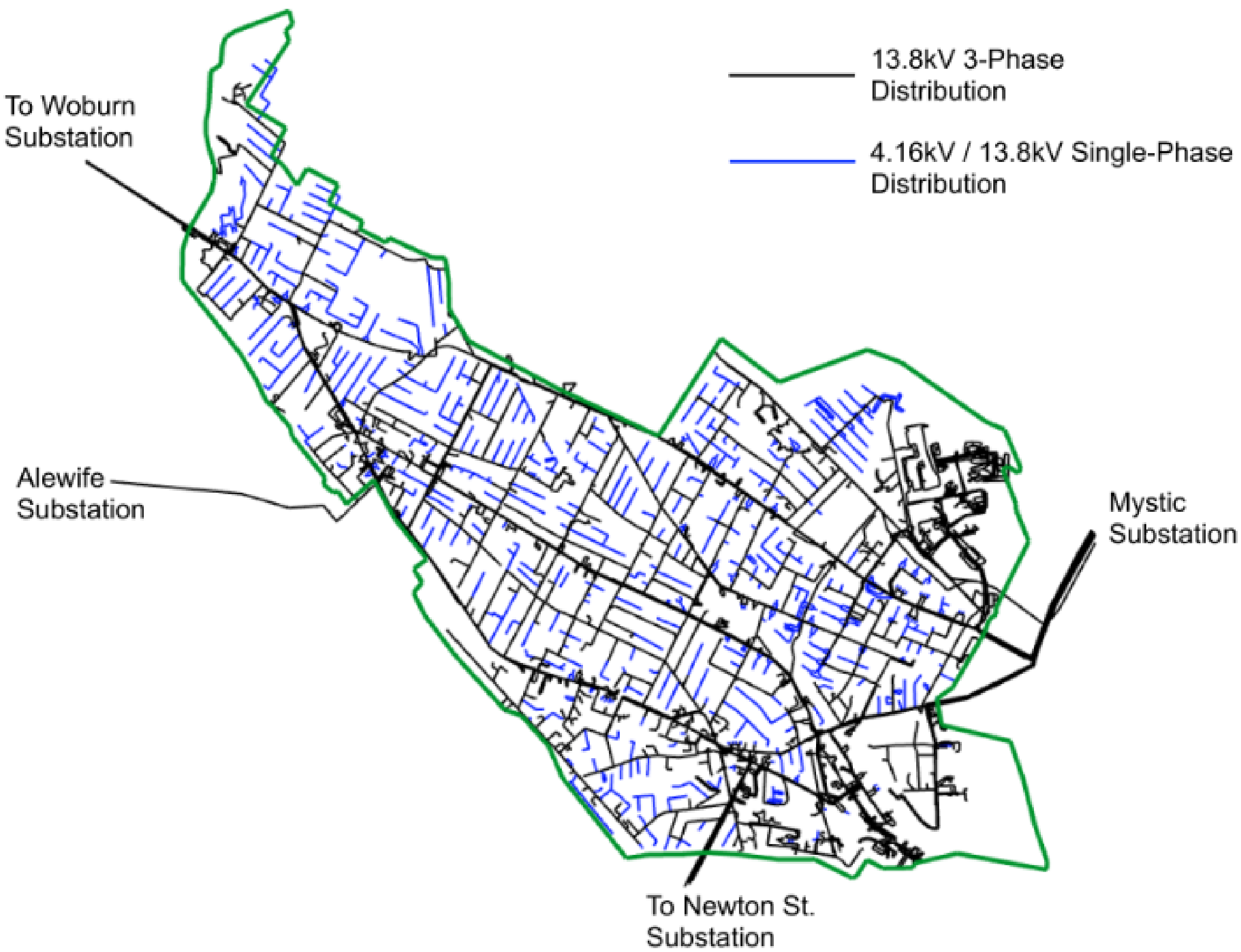


Figure 5-2. Somerville electrical distribution network.

In most cases, the style of transformers used to serve the pump house will be 100-150kVA 13.8kV-480V 3-phase pad-mounted transformers. At the micro-local level, the dwellings that will have heat-pumps installed are served by 240V/120V pole-hung transformers. Depending on the local demand on these transformers, they may be candidates to be replaced during the connection of the household to the networked geothermal system. This must be studied in more detail at the three sites chosen, but it is not a feasible differentiator in site selection.

Changing transformers from conventional steel core to amorphous steel core transformers can potentially increase the capacity of a typical circuit supplying a networked geothermal system by roughly +0.2%. In the context of a 0.5% increase in demand, switching the transformer type has a similar order of magnitude effect on the demand/capacity ratio. However, we do not recommend changing transformers, as outlined in Section 3.3.

5.3 Somerville Electrical Grid Layout

To aid understanding of the electrical capacity available for electrification and the role of transformers, the key components of the electrical distribution grid are discussed – highlighting how the grid is laid out and where various transformers are located.

Substations: The Somerville electrical grid is served primarily from Mystic Substation in the eastern part of the city; however, some circuits are served from Alewife, Newton Street, and Woburn Substations, in the west, south and north respectively. Transformers at the substations step voltage from the high voltage transmission down to 13.8kV for distribution into Somerville.

13.8kV Three-phase Distribution: From the substations just outside of Somerville, distribution lines traverse the city by distances of up to 5 miles. Some are underground, some are overhead on poles. Transformers on these lines step voltage down for customers of three-phase power. For single-phase distribution (13.8kV - 4.16kV), transformers on these lines step down to 4.16kV or 240-120V.

4.16kV/13.8kV Single Phase Distribution: Single phase lines that further distribute power locally, up to 2,000 feet long. Transformers on these lines step voltage down for customers from 4160V or 13.8kV down to 240/120V.

5.4 Spare Grid Capacity for Increased Load

While Buro Happold was unable access actual electrical load data from Eversource, we can make qualitative statements regarding the grid layout and the known capacity of the grid, shown in Figure 5-2 and Figure 5-3. We can report the potential percent usage of built grid capacity one, or many, networked geothermal systems could draw. We have identified 24 main 13.8kV 3-Phase feeder lines entering Somerville. Eight of these are served from the Mystic substation. Each line is rated for between 6MVA to over 20MVA. In total this represents about 260MVA of peak power capacity.

Extrapolating this on a larger scale, we have estimated the amount of power required to roll out this technology across the city of Somerville. Given that the modelled system was developed to serve ~50 single-family detached, and that there are about 6,000 of these types of dwellings across the city, about 120 networked geothermal systems would be required to serve the full building stock. With about five systems able to be served off a single feeder, about 300 kW (6 systems x 50 kW) of power would be required.

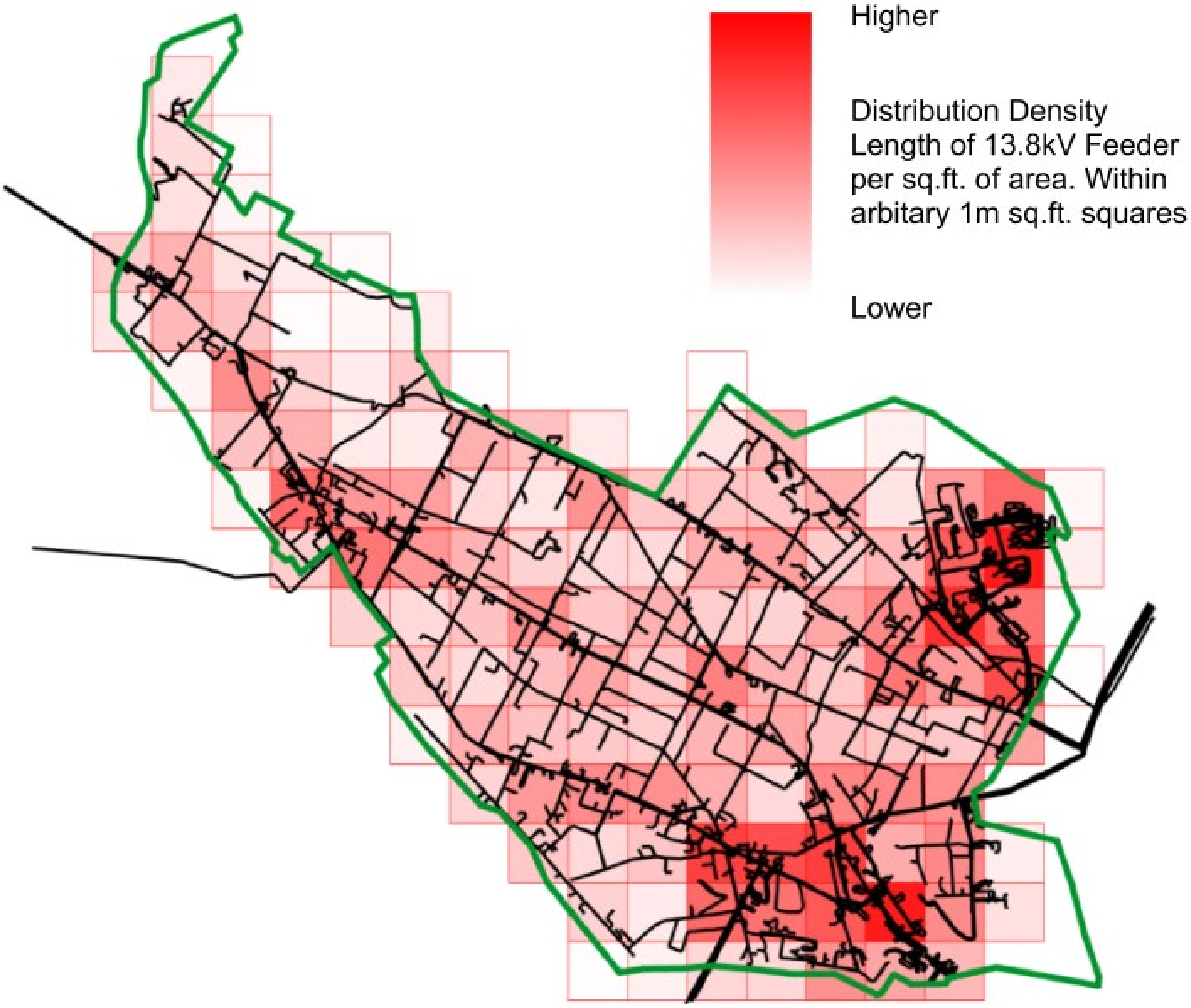


Figure 5-3. Electrical distribution density by area.

5.5 Networked Geothermal Effects on Electrical Transformers

5.5.1 Main System Pumps

The main pumps for circulating water through the boreholes and distributing it to all the customers will be connected to transformers on the 3-phase 13.8kV lines. In typical residential areas these transformers are not common or frequently located, they are typically located in more commercial or industrial areas. This could be a practical location differentiator in the selection of suitable sites for geothermal systems (i.e. locating the first pilot projects at the interface between residential and commercial districts). The heat map, shown in Figure 5-3, is a qualitative estimate of where such transformers are more likely to be located. If there are not suitable utility transformers nearby, it is likely that a networked geothermal system will require an additional 3-phase transformer, and longer extensions of 13.8kV distribution to said transformers, as shown in Figure 5-4 at position “B”. As such, the main system pump power requirement will likely not pass through any of the existing grid distribution transformers, they will directly connect to the 13.8kV lines.

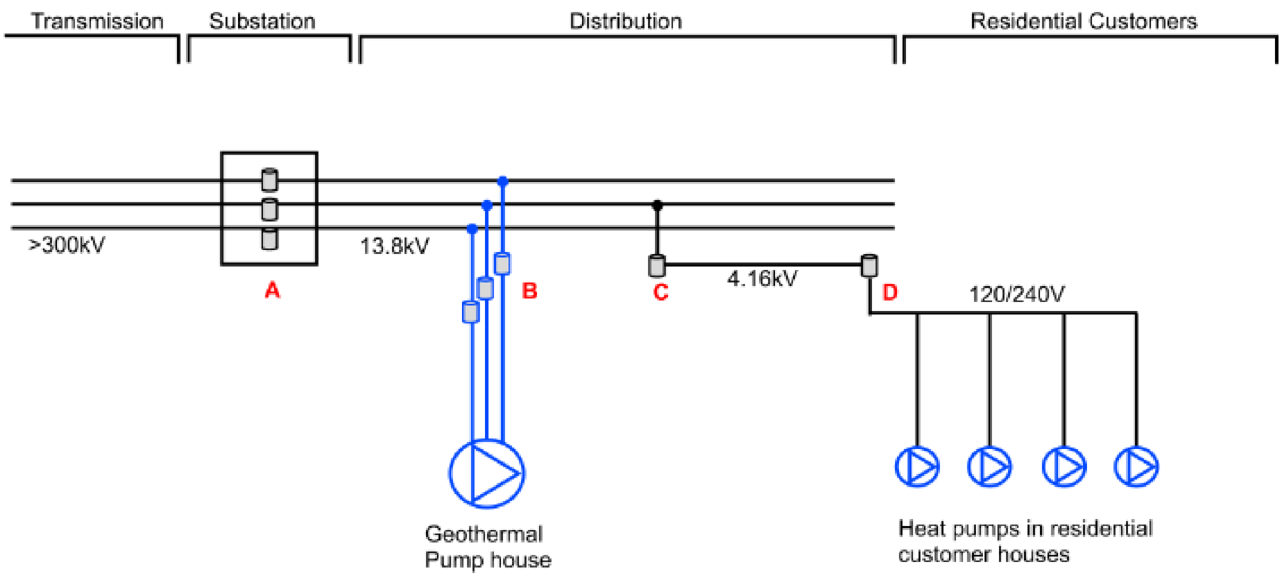


Figure 5-4. Electrical grid connection layout for a networked geothermal system.

5.5.2 Customers

At a local level, detached residential dwellings are connected to pole-hung 75kVA / 100kVA transformers attached to the 4.16kV or 13.8kV distribution lines as shown by position “D” in Figure 5-4. Each transformer supports perhaps 6 to 10 dwellings, depending on its size. When attached to a networked geothermal system, these dwellings will have any electric radiant heat and window AC units removed. This is likely to result in a net decrease in peak load.

These transformers in position “D” in Figure 5-4 are numerous and are unlikely to have data collected. To avoid potentially overloading a residential step-down transformer, it might be necessary to place a current meter on the outgoing distributed power to residential dwellings for at least 30-days to properly assess a transformer’s spare capacity. But, when coupled with the city’s plan to increase electrical capacity to all residents, the opportunity to upgrade residents’ step-down transformers when installing a networked geothermal system is the perfect time to reduce individual labor costs through the economies of scale combining multiple utility upgrades into one job.

6 Final Analysis

6.1 Economic Analysis

Several scenarios have been priced to evaluate different alternatives and methods for delivering electrical services to a networked geothermal system, as well as additional transformer upgrades where required. This rough order of magnitude (ROM) cost figure is at the pre-conceptual, feasibility stage of the project. These estimates should not be used to develop a project specific budget but should be used for refinement during the concept stage. Estimates have been developed using industry standard tools, processes, and benchmarks based on the intended use, and level of design development available for potential project sites. These costs are up to date for this level of detail as of September 2024.

Table 6-1 shows the breakdown of costs for electrical distribution and networked geothermal projects using the Ten Hills neighborhood of Somerville as a cost proxy. This cost could be assumed equal to Central Hill and Ames Envelope Complex if we assume that the underground infrastructure is the same. These prices cannot be refined further without specific investigation on each site. The unit cost items for electrical distribution were developed using 1,000 feet of typical residential street.

Table 6-1. Somerville networked geothermal ROM costs.

Line Item	Cost
Total Indirect Costs	**$2,388,150**
Total Direct Costs	**$15,921,000**
Site Conditions	$268,000
Networked geothermal	$10,381,000
In-Dwelling Improvements	$4,000,000
Electrical Upgrades	$822,000
Communications	$200,000
Exterior Improvements	$250,000
Risk Allowance	**$4,577,288**
Total Networked Geothermal Cost Estimate	**$22,886,438**

The capital expenditure (CapEx) estimates for a networked geothermal system include:

- Indirect costs (e.g., traffic management, permitting, design fees, insurance)
- Site conditions (e.g., demolition, clearing, and preparation of primary borefield area, 2 pump houses, allowance for river water exchange system)
- Networked geothermal systems (e.g., 60’ x 350’ area with boreholes drilled at 500’ deep, spaced 25 feet on center, 8" insulated HDPE pipe in 2-foot deep trench, controls, meters)
- In-dwelling improvements (i.e., building retrofits for network compatibility)
- Electrical upgrades (e.g., underground electrical feed 13.8kV, overhead electrical feed 13.8kV, pad-mounted transformers 50kVA 13.8kV/480-277V, New riser poles at corner of Mystic Avenue/Shore Drive and Bailey Road/Temple Road, electrical connections and commissioning allowance, low-voltage allowance conduit and low-voltage fiber)
- Exterior improvements (e.g., roadworks allowance)

As previously mentioned, any specific references to the work in the Ten Hills area can also be transferred to specific work in Central Somerville Avenue or Central Hill sites at this level of analysis. While there will be certain site-specific work that will be different in each of the three sites, at this point, the total costs will be relatively equal.

Indirect costs are estimated at approximately 15%, above the total direct installed costs, without escalation – assuming work commences in 2024. Based on actual project timing, backward- and forward-looking escalation factors can be applied later. It can be assumed that the ROM cost estimates are within +/- 50% of the expected actual cost of implementation. These costs are meant to inform relative and go-forward decisions. Each progressive project stage should aim to increase the level of costing accuracy through additional project development and level of detail to inform decisions and reduce uncertainty.

Costs inside the dwelling are based on an assumed $25,000 upgrade cost per dwelling (including heating system upgrade and associated work, not including transformer upgrades) with a total of 160 dwelling units which is a function of a hypothetical 6000-ton system. This assumption is highly variable based on specific existing conditions in each residence including the age, type of dwelling, HVAC, and electrical condition. Furthermore, the Framingham pilots are funding the in-home upgrades through Eversource. The difference is that the Somerville system would be a commercially operated system that would need to consider detailed cost-recovery mechanisms for the in-home upgrades since that equipment wear will depend more on the dwelling occupant than on the ability of the system owner to maintain the networked geothermal infrastructure. Whether that occurs via on-bill financing, PACE financing or some combination of debt and equity contributions, if the in-home conversion costs can be financed off the main implementation cost, then the total cost drops from $22.8 million to $17 million, improving the cost comparison to 53% of the cost of Framingham. However, it must be stated that these are hypothetical rough-order-magnitude cost estimates, which would need to be refined as design specificity increases.

6.2 Framingham Networked Geothermal Comparison

Since the technology of networked geothermal is so new at this time, there are very few relative comparisons to judge efficiency. The Framingham networked geothermal pilot system, diagrammed in Figure 6-1, funded through Eversource is a 375-ton system serving 24 residential dwellings, 5 commercial buildings and 10 low to moderate income apartment buildings that costs approximately $20 million. If the system in Somerville is designed for approximately 600-ton with an estimated cost of $23 million, then the hypothetical costs could be capturing an economy of size. The Somerville system would be 37.5% larger, but only cost 13% more than Framingham. This means that the Somerville system could be a cost reduction of 29% over the Framingham system.

Figure 6-1. Framingham networked geothermal layout.

7 Conclusions and Recommendations

7.1 Key Findings

The study has reviewed publicly available information and estimated the change in electrical demand due to the installation of networked geothermal systems. Without access to actual electrical load data from the Utility Company, the study compared the potential change in electrical load to the total system capacity to determine the percentage change and possible effects on existing utility transformers. The study included an analysis of amorphous steel core transformers for their potential benefits.

The power demand from the networked geothermal pilot system is less than 0.5% of the capacity of any 13.8kV distribution circuit it connects to, making electrical upgrades due to the networked geothermal system unlikely. The replacement of electric resistance heat and window air conditioning units with geothermal systems is expected to reduce electrical demand in the pilot area. The anticipated net load reduction in a residential networked geothermal community ranges from 0.5 W/SF to 0.8 W/SF compared to traditional air conditioning systems. Electrical capacity data is not a significant differentiator for pilot site selection, as the distribution network can likely accommodate a pilot project anywhere within practical limits.

The geothermal pump house will need access to existing 3-phase transformers or new ones installed on a 3-phase distribution line, which could be a differentiating factor for site selection. The typical transformers used will be 100-150kVA 13.8kV-480V three-phase pad-mounted transformers. Local electrical capacity is less critical than factors like borehole construction sites and thermal load-balancing customers. At the micro-local level, dwellings with heat pumps may require transformer replacements if the existing transformers are near the end of their useful life. The use of ground source heat pump systems will shift peak electrical load from the warmest afternoon to the coldest morning, benefiting the bulk transmission grid. These systems offer significant potential for load leveling and shaping compared to other residential systems.

7.2 Limitations

Significant challenges arose during the site selection process due to the lack of access to critical local data. On the transformer side, detailed electrical consumption and transformer capacity data were unavailable for analysis, necessitating the use of general NREL ComStock and ResStock data to estimate energy consumption in a specific set of buildings. In the geothermal analysis, information on local gas pipelines and local electrical transmission lines, essential for understanding existing infrastructure and ensuring the feasibility of integrating geothermal systems, was also unavailable. This limitation may have impacted the precision of site selection, as national datasets do not provide the granular detail necessary for optimal planning at the local level. Despite these constraints, the best possible recommendations were made based on the available information.

7.3 Next Steps and HEET Kickstart Project

In order to realize a networked geothermal pilot project, there are several later stage tasks that need to be accomplished. Some of this work will be done as part of the HEET-funded Kickstart project, which aims to do more detailed design and siting for a single pilot site. Buro Happold, in conjunction with Brightcore Energy, will be working on this funded project, part of which will aim to:

- Identify all potential agencies that may be impacted by the work
- Further produce a more detailed conceptual layout of each networked geothermal site
- Conduct a reliability assessment of key systems and components for likely failure modes for these systems
- Determine the range of electrical loads based on a "high probability" of customers included on that system
- Refine a cost estimate that will reflect the next stage of design and equipment specifications
- Develop partnerships with local utility companies to develop customer communication plans and opt-in programs for demand management that align with other regional ISO programs

Before issuing the Design RFP, Somerville should explore varying contract and ownership structures that would influence the project's procurement and execution strategy. The city should assess whether there is a need for Owner's Representation to oversee the project and ensure that it meets the desired standards and objectives. Typically, this type of work for this level of capital value can range between $210,000 to $350,000, or somewhere in the range of 1% to 1.5% of the total contract value. In addition to the technical aspects of the project, the city should conduct a more detailed customer engagement to identify specific buildings and customers to include in a networked geothermal pilot project. Using the feedback and engagement letters received by customers, more detailed modeling of these systems can be conducted to determine the network's thermal balance and potential need for auxiliary heat and/or cooling injection to ensure the longevity of the system. And, finally, Somerville should identify and apply for additional grant funding being disseminated by federal agencies (e.g., Department of Energy) to help finance these initial projects. Overall, by demonstrating the viability of a technology like networked geothermal, the city of Somerville can pave the way for how it, and other similarly dense cities in New England can begin to electrify their building stock to better prepare for a sustainable energy future.

Appendix A

A.1 Electrical Conductors Serving Somerville

	1	2	3	4	5
Substation Name	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic
Location Hosting Capacity(MW)	1	2.8	1	0.2	2.7
Operating Voltage	13.8	13.8	13.8	13.8	13.8
Circuit Name	250-H4XY	585-114H	250-H4XY	227-52H	227-51H
Bulk Circuit Name	250-H4XY	585-114H	250-H4XY	227-52H	227-51H
Distribution Substation Name	N/A	N/A	N/A	N/A	N/A
Distribution Substation Voltage(kV)	N/A	N/A	N/A	N/A	N/A
Bulk Substation Voltage(kV)	115/13.8	115/13.8	115/13.8	115/13.8	115/13.8
Bulk Substation Rating (MVA)	185	185	185	185	185
Bulk Sub Hosting Capacity(MW)	165.4	165.4	165.4	165.4	165.4
Circuit DER Online(kW)	1815	1935	1815	84	0
Circuit DER In Queue(kW)	1415	15	1415	0	0
Circuit Rating (Amp)	440	485	440	0	290
Circuit Rating (MVA)	10.52	11.59	10.52	0.00	6.93

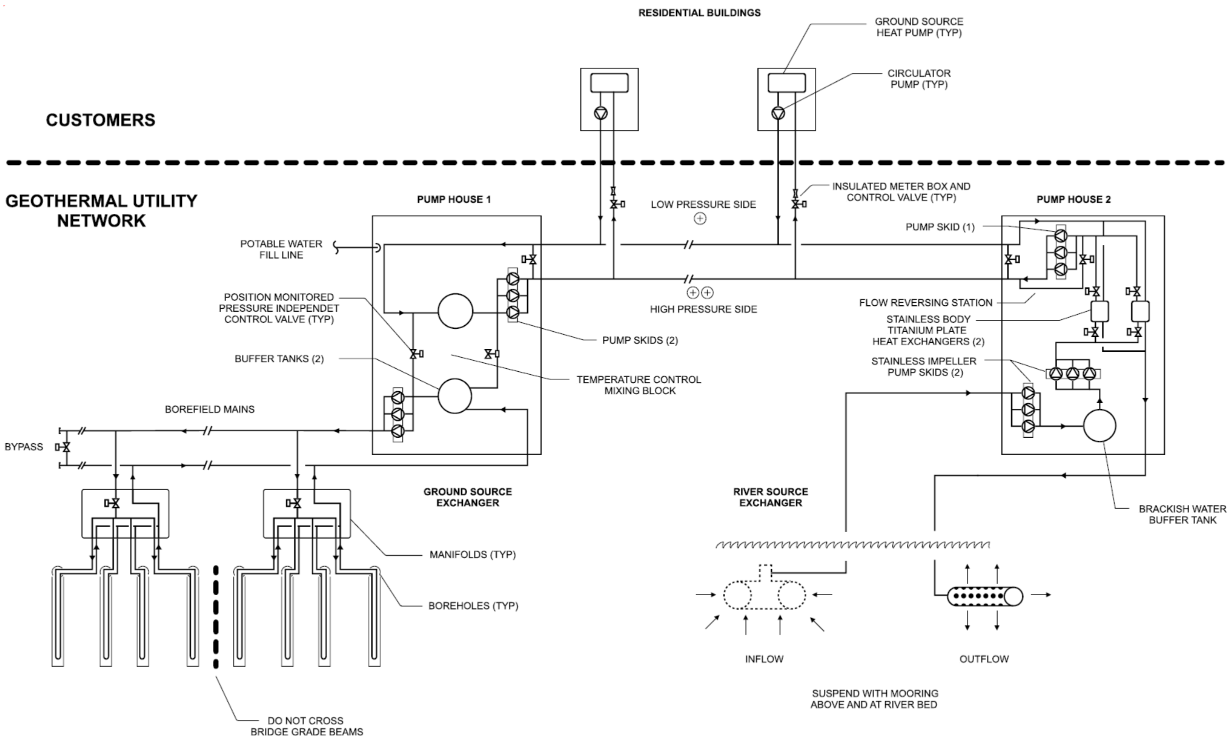
	6	7	8	9	10
Substation Name	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic
Location Hosting Capacity(MW)	2.8	3.2	4	2.7	2.7
Operating Voltage	13.8	13.8	13.8	13.8	13.8
Circuit Name	585-114H	250-1N81H	250-1N38H2	10-H2	10-H2
Bulk Circuit Name	585-114H	250-1N81H	250-1N38H	10-178XY	10-178XY
Distribution Substation Name	N/A	N/A	N/A	STA_010 West Street	STA_010 West Street
Distribution Substation Voltage(kV)	N/A	N/A	N/A	/	/
Bulk Substation Voltage(kV)	115/13.8	115/13.8	115/13.8	115/13.8	115/13.8
Bulk Substation Rating (MVA)	185	185	185	185	185
Bulk Sub Hosting Capacity(MW)	165.4	165.4	165.4	165.4	165.4
Circuit DER Online(kW)	1935	1677	37	52	52
Circuit DER In Queue(kW)	15	311	22	0	0
Circuit Rating (Amp)	485	485	485	295	295
Circuit Rating (MVA)	11.59	11.59	11.59	7.05	7.05

	11	12	13	14	15
Substation Name	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic	STA_250 Mystic
Location Hosting Capacity(MW)	4	3.8	3.2	4	3.7
Operating Voltage	13.8	13.8	13.8	13.8	13.8
Circuit Name	250-1N38H	387-148H	30-179XYH	250-1N90H	250-1N90H2
Bulk Circuit Name	250-1N38H	387-148H	30-179XYH	250-1N90H	250-1N90H
Distribution Substation Name	N/A	N/A	N/A	N/A	N/A
Distribution Substation Voltage(kV)	N/A	N/A	N/A	N/A	N/A
Bulk Substation Voltage(kV)	115/13.8	115/13.8	115/13.8	115/13.8	115/13.8
Bulk Substation Rating (MVA)	185	185	185	185	185
Bulk Sub Hosting Capacity(MW)	165.4	165.4	165.4	165.4	165.4
Circuit DER Online(kW)	129	772	2405	577	480
Circuit DER In Queue(kW)	22	28	0	27	10
Circuit Rating (Amp)	485	485	600	485	405
Circuit Rating (MVA)	11.59	11.59	14.34	11.59	9.68

	16	17	18	19	20
Substation Name	STA_402 Newton Street	STA_402 Newton Street	STA_402 Newton Street	STA_402 Newton Street	STA_828 Alewife
Location Hosting Capacity(MW)	4	0.2	0.2	0.2	2.8
Operating Voltage	13.8	13.8	13.8	13.8	13.8
Circuit Name	76-1462	819-1458XY	819-1374XY	819-1460XYZ	16-1461H
Bulk Circuit Name	76-1462	819-1458XY	819-1460XYZ	819-1460XYZ	16-1461H
Distribution Substation Name	N/A	N/A	STA_819 Prospect Stree	N/A	N/A
Distribution Substation Voltage(kV)	N/A	N/A	/	N/A	N/A
Bulk Substation Voltage(kV)	115/13.8	115/13.8	115/13.8	115/13.8	115/13.8
Bulk Substation Rating (MVA)	75	75	75	75	124
Bulk Sub Hosting Capacity(MW)	66.6	66.6	66.6	66.6	116.6
Circuit DER Online(kW)	0	8576	0	8576	812
Circuit DER In Queue(kW)	0	281	0	281	44
Circuit Rating (Amp)	485	910	455	910	360
Circuit Rating (MVA)	11.59	21.75	10.88	21.75	8.61

	21	22	23	24
Substation Name	STA_828 Alewife	STA_828 Alewife	STA_211 Woburn	STA_211 Woburn
Location Hosting Capacity(MW)	3.2	4	3.5	3.5
Operating Voltage	13.8	13.8	13.8	13.8
Circuit Name	16-1462	59-1471	59-1393H1	59-1393H1
Bulk Circuit Name	16-1462	59-1471	59-1393H	59-1393H
Distribution Substation Name	N/A	N/A	N/A	N/A
Distribution Substation Voltage(kV)	N/A	N/A	N/A	N/A
Bulk Substation Voltage(kV)	115/13.8	115/13.8	115/13.8	115/13.8
Bulk Substation Rating (MVA)	124	124	120	120
Bulk Sub Hosting Capacity(MW)	116.6	116.6	92.8	92.8
Circuit DER Online(kW)	440	258	1407	1407
Circuit DER In Queue(kW)	17	0	123	123
Circuit Rating (Amp)	360	485	485	485
Circuit Rating (MVA)	8.61	11.59	11.59	11.59

A.2 General Flow Diagram of Ten Hills Networked Geothermal System


RESIDENTIAL BUILDINGS
GROUND SOURCE HEAT PUMP (TYP)
CIRCULATOR PUMP (TYP)
CUSTOMERS
GEOTHERMAL UTILITY NETWORK
PUMP HOUSE 1
LOW PRESSURE SIDE
INSULATED METER BOX AND CONTROL VALVE (TYP)
PUMP HOUSE 2
POTABLE WATER FILL LINE
PUMP SKID (1)
POSITION MONITORED PRESSURE INDEPENDET CONTROL VALVE (TYP)
HIGH PRESSURE SIDE
FLOW REVERSING STATION
STAINLESS BODY TITANIUM PLATE HEAT EXCHANGERS (2)
PUMP SKIDS (2)
BUFFER TANKS (2)
TEMPERATURE CONTROL MIXING BLOCK
STAINLESS IMPELLER PUMP SKIDS (2)
BOREFIELD MAINS
BYPASS
GROUND SOURCE EXCHANGER
RIVER SOURCE EXCHANGER
BRACKISH WATER BUFFER TANK
MANIFOLDS (TYP)
BOREHOLES (TYP)
INFLOW
OUTFLOW
SUSPEND WITH MOORING ABOVE AND AT RIVER BED
DO NOT CROSS BRIDGE GRADE BEAMS

Alex Nutkiewicz
Buro Happold Consulting Engineers P.C.
100 Broadway, Floor 17
New York, NY 10005
USA

T: +1 212 334 2025
Email: alex.nutkiewicz@burohappold.com