A Grounded Energy Solution?
An Analysis of Geothermal Network Suitability in North Philadelphia

A thesis submitted by

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Abstract

The City of Philadelphia has committed to carbon neutrality by 2050 but has no comprehensive plan to get there. Gas consumption accounts for a quarter of the city's emissions. Philadelphia Gas Works, the municipal utility, plans to install thousands of miles of replacement gas mains through 2058. Many Philadelphians face particularly high energy costs. To achieve climate goals and enable low-income Philadelphians to access renewable energy, PGW could pursue gas-to-geothermal transitions rather than a gas-to-gas strategy. In this thesis, I analyze a North Philadelphia neighborhood to determine the technical suitability of a project site for geothermal network design. I completed a site assessment and energy load analysis. The results suggest that the site is suitable for the design stage of geothermal planning. I recommend that PGW pursue a managed energy transition strategy and start by completing geothermal feasibility assessments in low-income neighborhoods slated for gas main replacement.

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Chapter 1: Introduction

To avert the worst impacts of climate change, the world must reduce greenhouse gas (GHG) emissions by one-quarter by 2030 and be carbon neutral by 2050 (Intergovernmental Panel on Climate Change 2022). This requires the elimination of emissions from burning coal, oil, and gas across all sectors of the global economy, including buildings, industry, transportation, agriculture and waste. Globally, cities account for between 60 percent to 75 percent of GHG emissions and play an indispensable role in decarbonization (United Nations 2023). In most U.S. cities, gas accounts for a large portion of GHG emissions. Transitioning urban gas networks to clean energy and electric alternatives presents an opportunity to significantly reduce GHG emissions. Across the U.S., many cities are exploring approaches to begin this transition, and several are considering the role of geothermal in advancing it. This thesis focuses on decarbonizing the gas network in Philadelphia, Pennsylvania, using geothermal energy resources to displace gas.

The City of Philadelphia has committed to achieve carbon neutrality by 2050 but has no comprehensive plan to get there (Philadelphia Office of Sustainability, 2021). Philadelphia Gas Works (PGW), the municipal gas utility, plans to replace hundreds of miles of old gas mains with new gas mains, through to 2058 (Dorie Seavey 2023). This will undermine the city's 2050 carbon neutral goal and cost billions of dollars to ratepayers (ibid) in a city where gas combustion already accounts for a quarter of GHG emissions (Energy & Environmental Economics, Econsult Solutions, and Portfolio Solutions 2021). To advance towards Philadelphia's climate goals while satisfying heating and cooling needs, PGW could explore gas-free, "nonpipe" alternatives, such as geothermal. In this thesis, I complete a technical suitability analysis for PGW to construct a networked geothermal system instead of new gas infrastructure in one North Philadelphia neighborhood.

Geothermal energy systems capture thermal energy from the Earth's crust and employ it for use in buildings (IRENA and IGA, 2023). The form of geothermal on which this thesis is focused is *networked* geothermal. Buildings on networked geothermal systems can both receive energy from a main thermal source (e.g. the earth, "geo") and can also exchange thermal energy between buildings. For instance, a building with surplus heat, like an ice rink, can share that excess thermal energy with another building with high heating needs, like an apartment building in the winter. Networked geothermal systems can provide space and water cooling in addition to heating (Grossman, McFadyen, Nelson 2025). This is enabled with a geothermal, or "ground source," heat pump (GHP): devices which are connected to each building on the network and transform the thermal energy input to meet heating or cooling end use (ibid). The common name for these networked geothermal systems is a *thermal energy network* (TEN), and when owned and operated by an energy utility, a *utility thermal energy network* (UTEN) (ibid). Throughout this thesis I will use the terms TEN or UTEN, in line with these definitions, or "geothermal network" to generally refer to these systems.

The neighborhood I focus on underwent a PGW gas replacement project in 2022—old gas mains were replaced with new ones. Two essential steps in determining the feasibility of installing a thermal energy network include determining the technical suitability for geothermal and the projected capital costs. At present, upfront capital costs are often a main obstacle to TEN development. The determination of the technical suitability of a site is an indispensable first step towards estimating upfront capital costs. In this research, I chose to tackle this first step—determining technical suitability—from which a project site could be advanced to a *design* phase in UTEN planning, at which point a complete design assessment, including cost projections, is done. I chose to analyze a project site on which gas-to-gas replacement has already been completed for two reasons. Information from PGW on completed and in-progress gas-to-gas replacement projects was more accessible than information on projected projects. Secondly, the eventual gas-to-geothermal cost projections for the project site would then be able to be compared against the actual costs of the gas-to-gas replacement project that was completed, rather than against hypothetical gas-to-gas costs that were projected. PGW's mission is to advance "safety, reliability, sustainability, and affordability" in its operations (PGW 2023, 2); this research explores if one pathway PGW could consider in support of that ambition. Though focused on one, already completed neighborhood, the methodology and results from this analysis may inform PGW's approach for the dozens of gas main replacement projects it plans to complete in the years ahead.

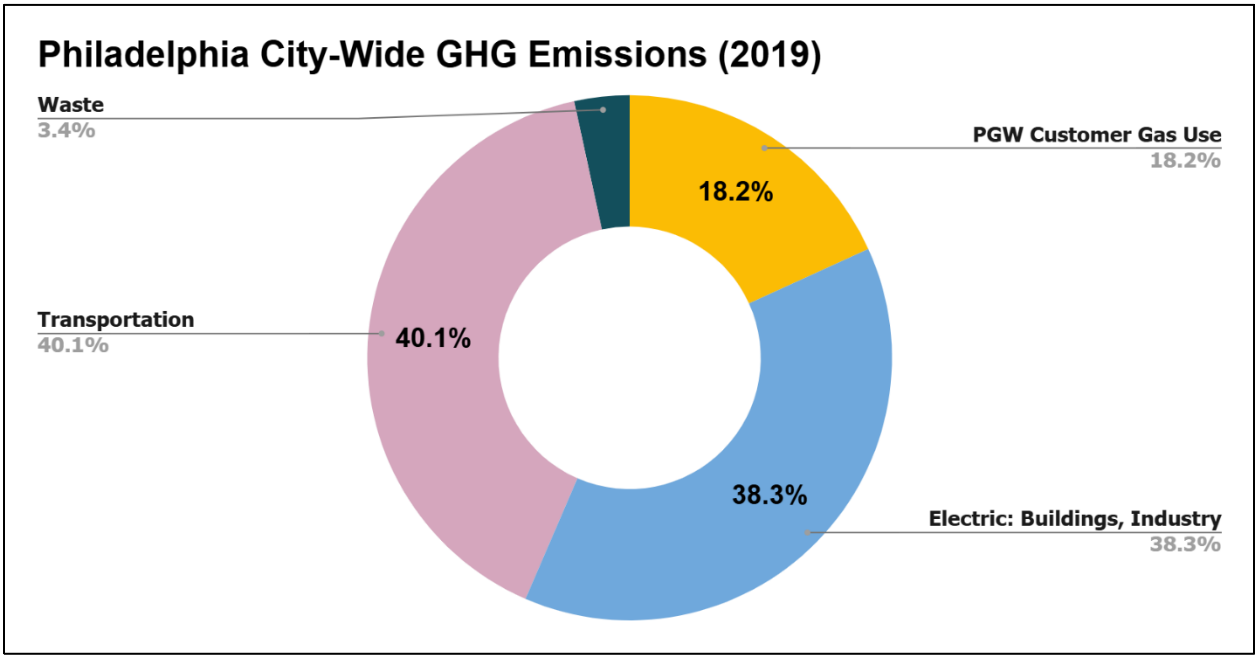
1.1 Background

Over the last two decades, Philadelphia has made considerable progress in reducing city-wide GHG emissions. Since 2006–Philadelphia's baseline GHG inventory year–the city has reduced emissions by 31 percent, outpacing both state and national GHG emissions reductions over the same time frame (Philadelphia Office of Sustainability 2025). According to the latest city GHG Inventory conducted for 2022, emissions from buildings and industry–labeled *stationary energy* in the Inventory–accounted for 65 percent of Philadelphia's GHG emissions, transportation for 28 percent, and industrial processes and product use for 6 percent (ibid). This represents a downward trend across all measured emissions in scope 1, 2, and 3, and across all sources, compared to both baseline year of 2006, and the previous inventory from 2019 (ibid). Despite this relative progress, the city's 2022 GHG inventory illustrates (6) the steep emissions reduction challenges between 2025 and 2050. The reductions from the last two decades are largely attributable to three factors: replacement of coal generated electricity with gas powered–at least 33 percent of reductions; closure of a large petroleum refinery plant in South Philadelphia–7 percent of reductions; and improvements to power transmission–55 percent of reductions (ibid).

Beyond 2025, with much of the lowest-hanging emission reduction fruit already seized from these three changes, additional far-reaching initiatives to cut emissions will be necessary for Philadelphia. Even if Philadelphia were to successfully implement all the current decarbonization policies and strategies, it would only achieve roughly 50 percent emissions reduction by 2050 (Philadelphia Office of Sustainability 2021). To achieve the mid-century carbon neutrality goal, additional and farther reaching decarbonization strategies must be incorporated.

Natural gas–a fossil fuel hereafter termed *gas* or *fossil gas*, accounts for 24 percent of the city's GHG emissions and poses an unignorable factor on the path to decarbonization (Energy & Environmental Economics, Econsult Solutions, and Portfolio Solutions 2021). Seventy percent of Philadelphia's residents rely on fossil gas for space and water heating (ibid) from PGW, the municipally owned utility. Gas consumed by PGW customers in 2019 accounted for 18.2 percent of Philadelphia's overall GHG emissions (Figure 1) (PGW 2024, 4).

Figure 1 - Philadelphia City-Wide GHG Emissions Sources



Source: Information from PGW GHG Emissions Reduction Report. Illustration by author.

There are many potential pathways for decarbonizing municipal gas networks. On the demand side, buildings can be made more energy efficient or "electrified." Energy efficiency interventions (EEIs) reduce the amount of fuel needed to heat, cool, and power (electricity) buildings. To electrify, fossil gas appliances like boilers, furnaces, and stoves can be replaced with electric alternatives. Renewable energy technologies like rooftop solar and battery storage can be installed in buildings to provide an onsite power source and reduce demand on the power grid. On the supply side, municipal fossil gas distribution networks can be transitioned to renewable energy sources like geothermal. A mix of all these demand and supply approaches–energy efficiency interventions, appliance electrification, solar and battery storage, and fuel switching–will likely be necessary for Philadelphia's clean energy transition. Indeed, the City of Philadelphia is pursuing many of these methods, but at an inadequate speed and scale to meet 2050 climate goals (Philadelphia Office of Sustainability 2021).

The extent of PGW's climate action is encapsulated in its GHG Emissions Reduction Plan. The plan includes six emissions reductions programs across scopes 1, 2, and 3 (Philadelphia Gas Works 2025). Of the six, the program that accounts for the greatest portion of emissions reduction potential is PGW's Main Replacement Program, which replaces old gas mains with new pipes–increasing reliability, reducing risks, and lowering fugitive methane emissions (PGW 2025a, 4). In PGW's 2024 GHG inventory, the Main Replacement Program accounted for nearly 63 percent of the annual reductions PGW had achieved (PGW 2025a, 6). But the Main Replacement Program addresses scope 1, a small portion of overall PGW emissions, and does nothing to address scope 3 emissions, the largest source of PGW emissions. PGW acknowledges this in its 2025 GHG Emissions Reductions Report, writing that the "Main Replacement Program continues to be the most effective tool for reducing the greatest portion of its Scope 1 and 2 emissions – pipeline fugitives. However, when including Scope 3 emissions, PGW's downstream customers' use of natural gas presents the greatest overall opportunity for PGW emission reductions" (PGW 2025a, 6). Indeed, scope 3 emissions account for nearly 95% of PGW's overall emissions, and the utility has no plan to address this (PGW 2024, 3). UTENs could reduce scope 3 emissions in addition to scope 1 emissions from old leaky gas mains that could be retired.

PGW's emission reduction achievements are a fraction of the emission reductions PGW must achieve if Philadelphia is to meet its 2050 climate goal. PGW has an annual objective to reduce at least 10,000 MMTCO2e. In the most recent year measured, PGW cut 10,622 MMCO2e. However, PGW's annual emissions in 2022 totaled 5.47 MMTCO2e: including 0.32 MMTCO2e from scope 1 and 2 (PGW 2023b, 3) plus 5.15 MMTCO2e from scope 3, i.e. customer use (PGW 2023a, 1). If PGW were to reduce its annual emissions at pace with the city's 2050 carbon neutral goal, it would need to cut 228,022 MMTCO2e per year for each of the next 24 years—assuming equal distribution of reductions during each of the 24 years—rather than its goal of 10,000 MMTCO2e per year. In this way, PGW's current 10,000 MTCO2e annual reduction objective equates to less than 5 percent of what the annual target should be. Of course, emissions reductions plans are not always linear, and this crude calculation assumes all else remains equal. It also precludes consideration that Philadelphia's "net zero" 2050 goal could include carbon offsets. Nonetheless, it is illustrative of the yawning gap between PGW's climate actions and the city's goals.

The projected financial cost of the Main Replacement Program is significant. Between 2017 and 2022, PGW added 27 miles of gas expansion to the network, which in 2021 had an average cost of $2.7 million per mile (Dorie Seavey 2023). From 2023 to 2027, PGW projected it would spend $600 million on gas infrastructure (Gona and Shah 2022), and through 2058, is projected to spend $6 to $8 billion nominal dollars on a total of 1,215 miles of pipe replacements (Dorie Seavey 2023). The current GHG emissions reduction plan will effectively direct billions of ratepayer dollars for new fossil fuel infrastructure that worsens climate change, working against the city's goals.

Unlike new gas infrastructure, UTENs could contribute to the achievement of the city's 2050 net zero goals, and beyond 2050 continue to be a lucrative asset rather than stranded assets, which some gas infrastructure potentially could become. Besides the long-term financial prudence of beginning to construct UTENs now, in lieu of new gas lines, doing so also yields environmental, climate, and social benefits. Geothermal is a carbon free, renewable energy source (Lund, J. 2007) that's ubiquitously available, consistently reliable (National Renewable Energy Laboratory, 2024) and highly efficient (Moscovici, Daniel et al. 2015), with low operation costs (Kann, Shayle, 2023) and considerable workforce opportunities (Energy & Environmental Economics, Econsult Solutions, and Portfolio Solutions 2021; Building Electrification Institute and Economy League of Greater Philadelphia 2023)..

Philadelphia faces stark energy affordability challenges. Forty percent of residents in Philadelphia are low-income–earning less than 200 percent of the federal poverty level (Seavey 2023). Twenty-six percent of households have a high energy burden (spend more than 6 percent of their income on energy costs) and 14 percent have a severely high energy burden (spend more than 10 percent) (ACEEE 2020). As load defection from gas continues, costs of maintaining the gas network will flow to a diminishing number of ratepayers, who will consequently have to pay more to maintain the system (Kind 2013). This will hit low-income, energy burdened households in Philadelphia–disproportionately Black and Hispanic–particularly hard (Schmidt 2024). Geothermal presents one pathway to potentially mitigate sustained gas network costs on a dwindling number of gas customers (Snyder 2018) by creating new revenue streams for the utility. However, realizing the potential climate and social benefits of geothermal hinges on at least one first step: determining the technical suitability of a site for a UTEN design.

1.2 Research Questions and Parameters

Taking the climate imperative and energy equity dynamics together, this thesis seeks to address the following question. What is the feasibility of installing geothermal networks to replace old gas mains in low-income Philadelphia neighborhoods? Specifically, I seek to answer: What is the technical suitability of a site in the Fairhill neighborhood of North Philadelphia for advancement to a full utility thermal energy network *design* phase? To determine technical suitability, I will assess the site characteristics and estimate the total annual and peak energy demand, "load," on the site.

Structure and Scope

The organization Vermont Community Thermal Networks (VCTN) categorizes the stages of UTEN development into five "Project Phases:" 1) Exploration 2) Planning 3) Design 4) Construction 5) Operations (Vermont Community Thermal Networks, Energy Action Network 2024, 63-69). This research completes steps within phases one and two–Exploration and Planning–to lay the groundwork for phase 3–Design.

Within any one of the phases there is an array of steps and considerations, including technical assessments, financial projections, regulatory landscape, stakeholder and community engagement, and political analysis. In this research, I collect data for the most essential information needed for the *technical* determination of UTEN suitability, one key step towards the completion of a project design, and for determining cost and overall UTEN feasibility.

Over 6,000 miles of gas mains and service lines snake underneath Philadelphia's 140 square mile area delivering gas to more than half a million customers (Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates 2021). This research is focused on one section of this network–less than 1 mile of pipe–within the Fairhill neighborhood in North Philadelphia. This focus area is hereafter referred to as the *project site* or *the site*. It includes a mix of 41 residential, commercial, and industrial parcels, and several vacant lots, the characteristics of which are factored into the suitability assessment.

Following the Introduction (Chapter 1), the Literature Review (Chapter 2) provides a wider aperture on the field of geothermal and the costs and benefits of thermal energy networks. I review Philadelphia's climate policy landscape, PGW's energy predicament, and the broader, burgeoning conversation about geothermal pilots and the future of gas in the U.S. The Methodology (Chapter 3) includes two main components. I preliminarily assess and select a project site. Then I conduct an energy demand estimate, "thermal energy load analysis," for all parcels on the site. In the Results (Chapter 4), I reveal the annual and peak energy load estimates. In the Discussion (Chapter 5), I explain the main takeaways for the site itself, and the research process. I name the limitations and offer recommendations for future researchers to refine this research process and build upon it. In the Conclusion, I recommend a specific approach for PGW to advance comprehensive gas-to-geothermal feasibility analyses and development in neighborhoods marked for gas replacement.

Chapter 2: Literature Review

The literature review includes the following subsections: Geothermal Systems Overview, Costs and Benefits of TENs, Philadelphia Climate Policy, About PGW, TEN Projects in Other Locales, and an overview of most consistent themes from Gas Transition Studies for U.S. Cities and States.

2.1 Geothermal Systems Overview

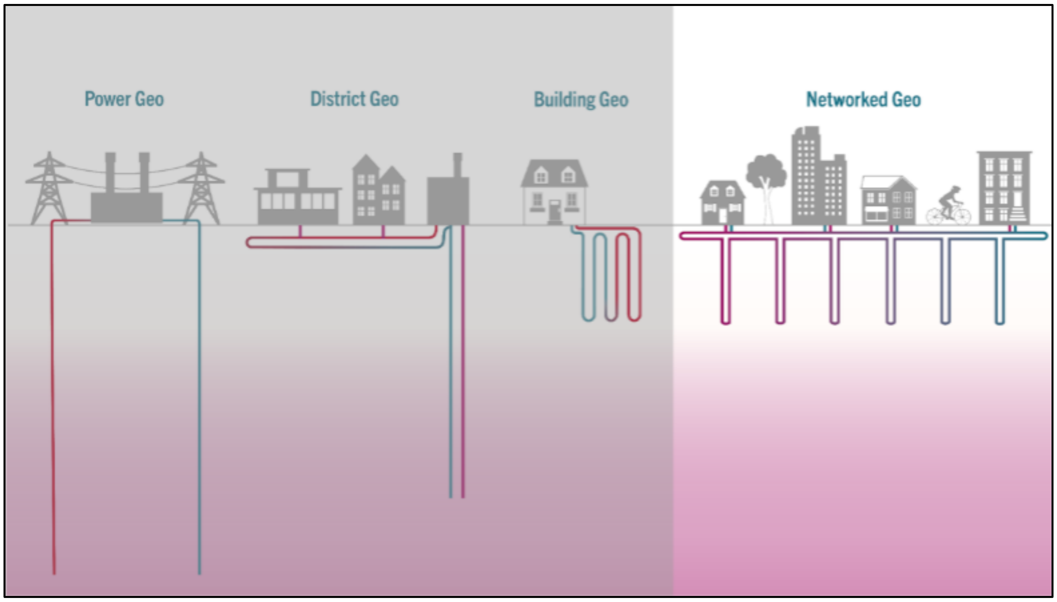
Geothermal is naturally occurring heat in the Earth's crust. Geothermal resources are typically classified in three categories: low temperature (<90C); medium (90-150C); and high temperature (150C) (IRENA and IGA 2023). Subsurface temperatures tend to increase further beneath the surface; though going deeper does not necessarily guarantee a *high temperature* zone will be reached. High temperature zones are often located in volcanic or tectonically active regions of the globe (ibid). Medium and low temperature zones are more prevalent across the globe (ibid). In most temperate climates, the subsurface temperature at just a few feet below the surface ranges from 4C-30C (Grossman, McFadyen, Nelson 2025).

Geothermal energy systems capture this thermal energy in water or other fluids by way of underground pipes that circulate fluids between the thermal source and the end use. The piping in geothermal technology is all one contiguous system, in which fluids never leave the system, but are rather pumped continuously through it to capture and release thermal energy at surface and subsurface locations. Hence, the pipe infrastructure is called "loops." The loops can take one of two forms: horizontal loops lie just a few feet below the earth surface, capturing low-moderate subsurface temperatures; vertical loops reach up to thousands of feet into the subsurface, capturing thermal energy from higher temperatures at greater depths. The holes for these vertical loops are called bores, and the location where multiple vertical loops are installed is called the "borefield" (or sometimes "well field").

Thermal energy can be deployed in one of two use-types: to generate electricity, or for direct utilization. Electricity generation is usually, though not exclusively, from high temperature wells (Lund 2007). In these power plants, steam, or a secondary hydrocarbon vapor, is directed to spin a turbine, the motion of which generates electrons (ibid). Direct utilization is the application of the geothermal energy for space and water heating and cooling by the end user. A geothermal heat pump (GHP) is used to transfer the thermal energy from the fluid to heat or cool water or space to the desired temperature (Phillips 2022). Direct utilization is more prevalent in low and moderate temperature geothermal zones than in high temperature zones. The geologic landscape in the Philadelphia region is a low temperature; even at depths of 2,000 meters, the temperature range is 55C-60C (NREL 2021, 29). Thus, this thesis research pertains to low-temperature (not medium or high) and direct-utilization (not electricity production) geothermal systems.

Geothermal systems tend to have one of four layouts (Figure 1): power geothermal, district geothermal, networked geothermal, or building geothermal. *Power* geothermal are utility-scale projects that generate electricity, often by use of deep bores that tap high subsurface temperatures. *Building* geothermal is the smallest form; it supplies thermal energy to a singular building, usually with the use of shallow boreholes or horizontal pipes (called "loops"), rather than deep boreholes and vertical loops. *District* geothermal and *networked* geothermal formations typically serve a few dozen properties in a neighborhood. These interconnected systems both capture thermal energy via loops that run through the thermal source. The nonprofit and geothermal pioneering organization HEET (Home Energy Efficiency Team) defines *district* geothermal as having one central borefield. Once built, the size of district geothermal systems cannot be expanded beyond the capacity of the central plant. District energy systems conventionally could provide heating but not cooling, or only one or the other at a time. A new "5th generation" of geothermal technology has emerged that expands the capabilities of district geothermal. These systems can provide heating and cooling simultaneously; enabled by use of ground source heat pumps at each building on the network (Fournier 2025). Buildings on these *networked* systems can both receive energy from a main thermal source like a borefield, and also can exchange thermal energy with other buildings on the network (ibid). These 5th generation systems are termed thermal energy networks (TENs) or, when owned or operated by a utility—utility thermal energy networks (UTENs). Throughout this thesis I use the term TEN or UTEN, in line with these definitions. TENs are suitable for zones with low temperature zones, like Philadelphia. (Networked Geothermal Wiki contributors 2025)

Figure 2: Forms of Geothermal



Source: HEET

2.2 Costs and Benefits of TENs

High upfront capital costs of installing TENs are a common obstacle (Kann 2022; Buro Happold 2020). Upfront capital costs projections have resulted in some plans to be discontinued. In Lowell, National Grid started one of four TEN projects that the MA Department of Public Utilities (DPU) had approved (HEET 2023), but the utility subsequently cancelled the project due to upfront capital costs that were higher than anticipated (Borkhetaria 2025). Another proposed project that would have included 132 units across 38 residential buildings in Wallingford, Connecticut was stalled (Northeast Energy Partnerships et al. 2024). Because the site was all-residential–lacking a diversity of energy load–it necessitated a larger borefield, which drove up projected costs. The projected gross capital cost for site design was $8.7M; the net cost after federal and state incentives would have been $4.7M (ibid). This was a considerable reduction but ultimately was still not enough to make the project feasible. Operating costs of TENs, however, are relatively low. Energy savings from operations can be used to pay back upfront capital investments. Federal financial incentives from the Inflation Reduction Act can also help defray high upfront costs (IGSHPA 2022). Despite the challenge of overcoming initial capital costs, maintaining business as usual at gas utilities is laden with great near-term and long-term costs, financial, and social. Prevalent across the literature are numerous significant benefits that TENs provide.

Geothermal has major environmental, energy, and climate benefits, compared to other forms of renewable energy, and to fossil fuels. Geothermal is a renewable energy source. It produces no GHG emissions and no indoor or outdoor air pollutants. TEN system components–pumps, GSHPs, and geothermal heat exchanger–require only electricity to operate (Networked Geothermal Wiki contributors 2025). If the grid from which that electricity is acquired is clean, then the operation of a TEN can be 100% emissions free. Geothermal requires no fuel for processing or transporting, and has a high conversion efficiency (Lund, 2007). GHPs use far less water than conventional ACs, as they do not lose water to evaporation (Networked Geothermal Wiki contributors 2025).

Energy Efficiency. Geothermal is exceptionally energy efficient. This is largely because geothermal systems transfer heat, rather than create it–which requires far more energy. GHPs typically have an efficiency rate of between 350 to 450 percent: i.e. for every unit of energy expended to power the GHP, 3.5 to 4.5 units of energy are generated (Moscovici et al. 2025). By comparison, the most efficient fossil fuel heating systems are about 95 percent (ibid).

Reliability. Earth subsurface temperatures are consistent year around, regardless of weather. So while the energetic output from renewables like wind and solar varies based on weather patterns and seasons, geothermal provides a steady supply of energy. Consequently, geothermal has a high “capacity factor” compared to other renewable energy and can be relied upon by utilities as a baseload energy source: providing a constant, unvarying energy supply across time (National Renewable Energy Laboratory 2026).

Space. In his widely referenced bulletin on geothermal, Lund finds that geothermal requires less land area than all other renewables. In a 2015 study *Can sustainability plans make sustainable cities? The ecological footprint implications of renewable energy within Philadelphia's Greenworks Plan*, Moscovici et. al. find that this is consistent for Philadelphia: geothermal would require less hectares per year per gigawatt of energy supplied than would be required for solar, hydroelectricity, wind, or biogas. This is because geothermal is generally constructed below the footprint of a building. Moscovici et al. (2015) also demonstrate that geothermal possesses the greatest potential for city-based energy generation. Moscovici et al. (2015) claim that city-based energy generation for local consumption has intrinsic sustainability advantages: it avoids sprawl and its negative environmental impacts, and it enables the city to become more energetically self-sufficient.

Energy Sharing and Storage. TENs have the ability to exchange heat between buildings and the capacity to store excess thermal energy from them. Surplus heat from one building is captured in the fluid in the system’s loops and can be transported to another building in the network with a heat deficit. This utilizes energy that otherwise is often wasted, and it reduces the demand for new energy production on a site. Excess energy from buildings can also be pumped deep down in the system’s vertical loops and stored there near the bedrock for future use– perhaps when seasons change (Networked Geothermal Wiki contributors 2025).

Energy transmission and peak reduction. Large-scale renewable energy projects and transmission, including utility scale geothermal, typically require time-consuming state and federal approval processes. Energy transmission projects often face local opposition and get held up in lengthy legal battles (Susskind et al. 2022). The localized nature of TENs could help Philadelphia avoid these energy development delays. Underground pipe distribution makes geothermal more resilient to weather events, as compared to above ground wire distribution. This localized form of energy supply also tends to help reduce congestion and peak demand for energy distributors (O'Neill-Carrillo et al. 2018).

2.3 Philadelphia Climate Policy

In 2019, the Philadelphia City Council passed a resolution committing the City to achieve 100% "clean renewable energy" by 2050 (Philadelphia City Council 2019). The resolution explicitly names wind, solar, and geothermal as examples of renewable energy sources and explicitly excludes gas and other fossil fuels. The resolution calls for 100% of all the city's electricity to come from renewables by 2035. Consistent with the city's Municipal Energy Master Plan, the resolution states that Philadelphia must aim to procure or produce 100% renewable electricity for city-owned assets of the built environment by 2030, and reduce GHG emissions from these same assets by that year (Philadelphia Office of Sustainability 2022). In 2021, then Mayor Jim Kenney announced that the City would commit to achieve 100 percent carbon neutrality by 2050, an even more expansive commitment (City of Philadelphia 2021).

At present, the City of Philadelphia's energy policies and programs are largely focused on energy in buildings. The city's greatest source of emissions is from the heating, cooling, and electricity needs from buildings (City of Philadelphia 2025). The city's Building Energy Performance Policy (BEPP) of 2019 requires that all nonresidential, large buildings (50,000 square feet and larger) reduce their GHG emissions by at least 80 percent by 2050. This policy is projected to cut 200,000 metric tons of carbon dioxide equivalent (mtCO2e) from the city's emissions annually (City of Philadelphia 2021). This entails about 3,000 buildings, which together account for 15 percent of citywide emissions (City of Philadelphia 2019).

Many climate and energy initiatives in Philadelphia are administered by the independent municipal entity called the Philadelphia Energy Authority (PEA). The PEA's work is integral to the city's decarbonization progress. The broadest reaching initiative from the PEA is the Philadelphia Energy Campaign, which in 2016 set out to invest $1 billion over 10 years in energy programs and policies across Philadelphia's municipal assets, schools, affordable housing, small businesses, and commercial and industrial sectors. The projects include the replacement of over 130,000 streetlights with low emitting diode bulbs, installing rooftop solar on over 3,000 homes, and creating 10,000 green jobs, across various initiatives (Philadelphia Energy Authority 2025). In 2024, the city began procuring power from a 70MW solar farm, accounting for 25% of electricity of the city's municipal buildings (ibid). The city has a project to procure another 1.5MW of power from a solar project at the city's Northeast Regional Airport (Philadelphia Energy Authority 2022). Across all initiatives, the Philadelphia Energy Campaign aims to impact 25,000 households and 2,500 small businesses (ibid). Though these accomplishments are sizable, relative to the small size of the PEA, they are small relative to the city's decarbonization goals.

Another prominent PEA initiative is Built to Last, a program that administers holistic home repairs–including weatherization and energy efficiency retrofits–for low-income households (Philadelphia Energy Authority 2022). Since its 2021 inception as a pilot program, Built to Last has received an aggregate $35.45 million from a mix of federal, state, and city funding, as well as innovative PEA financing (ibid; Walsh and Blumgart 2025). Between the 2021 inception and the end of 2024, Built to Last completed whole-home repairs in 200 low-income households (City of Philadelphia 2025, 8). In 2025, PEA aimed to service 400 homes through Built to Last (Schmidt 2024). This initiative is helping increase energy efficiency, which in turn can reduce gas demand. Built to Last advances energy equity by serving low-income households; this is particularly notable in a city in which more than half of renters and more than a quarter of homeowners pay at least one-third of their income on rent or mortgage, respectively (Eichel and Howell 2017), and otherwise will be unlikely to be able to afford home repairs. Nonetheless, Built to Last alone accounts for only a thin slice out of Philadelphia's decarbonization pie: hundreds of homes are on the waitlist for the program's services, while thousands of homes across Philadelphia are in need of whole-home repairs (Schmidt 2024).

The PEA also runs Solarize Philly, the largest rooftop solar program in the country. Since its launch in 2017, Solarize Philly has secured over 26,000 sign-ups and signed 486 leases equating to 8.01 megawatts (MW) of photovoltaic energy (Philadelphia Energy Authority 2022). In 2022, PEA began exploring potential for distributed energy resources from solar and battery technologies installed in homes. Nonetheless, less than 8% of Philadelphia's electricity supply was generated from renewable resources in 2019 (Philadelphia Office of Sustainability 2025).

Many of the remaining initiatives in the city are focused on the municipal assets including schools and city-owned office buildings. By 2030, the city aims to reduce GHG emissions from city-owned buildings by 50 percent, reduce energy consumption from city operations by 20 percent, and obtain 100 percent of electricity for city operations from renewable resources (City of Philadelphia 2025, 6).

2.4 About PGW

Philadelphia Gas Works owns and operates 6,000 miles of gas mains and service lines in Philadelphia. Seventy percent of Philadelphia's 1.6 million residents currently rely on fossil gas for space and water heating, including over 500,000 of whom are PGW customers. (Energy & Environmental Economics, Econsult Solutions et al. 2021). PGW's mission is to "[e]nhance the quality of life for all by delivering safe, reliable, and affordable energy in an environmentally responsible way" (PGW 2023, 2). PGW is a contributing member to fossil fuel trade groups including the American Gas Association (Schmidt 2022). A central and widely recognized challenge of transitioning gas networks to renewables is the resulting increase in energy costs for the dwindling number of residents that rely on gas.

In 2021, Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates completed a Business Diversification Study (2021) on behalf of PGW to explore paths towards reducing GHG emissions. The study provides a top line assessment of the potential for the utility to pursue non-gas alternatives. The report highlights four approaches towards reducing gas use, including the use of decarbonized gas (i.e. biogas), building electrification, building hybridization (a mix of gas and electric appliance use), and networked geothermal. While a multiplicity of approaches is necessary to decarbonize urban energy systems, many argue that they should not include carbon-based energy (Walsh and Bloomberg 2022; California Public Utilities Commission 2022). Biogas, which would come from wastewater, still can leak methane. Likewise, hybridization would still tether the city to gas use (Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates 2021).

Building decarbonization is an impactful way to reduce GHG emissions from buildings. PGW has several home energy efficiency initiatives, categorized under their Demand Side Manage (DSM) program, called "PGW Energysense," and the Low-Income Usage Reduction Programs (LIURP) (PGW 2025a, 5). The DSM programs include 5 individual initiatives including two that provide smart thermostats, their Commercial Equipment Rebates, Residential Equipment Rebates, and Residential New Construction. The LIURP programs include the Home Comfort Program and the Low-Income Multifamily Efficiency (LIME) program. Altogether, these programs in 2024 resulted in reducing 3,534 metric tons of CO2e (ibid).

Regarding geothermal, the Philadelphia Gas Commission, the body that oversees PGW, approved half a million dollars in 2022 for FY 2023 for PGW to conduct a geothermal feasibility study (Schmidt 2022)–a first step towards implementing this fourth approach named in the Business Diversification Study. In March of 2025, PGW issued a Request for Proposals (RFP) for a consultant to complete a geothermal feasibility study for the McCloskey School and Dorothy Emanuel Recreation center in Northwest Philadelphia. In October of 2025, PGW announced an engineering firm it had assigned to the project (PGW 2025b). To date this has not been completed.

PGW utility moves forward on repairing and replacing old gas infrastructure with new gas infrastructure. Between 2017 and 2022, PGW added 27 miles of gas expansion to the network with an average cost of $2.7 million per mile in 2021 (Seavey 2023). From 2023 to 2027, PGW projected that it would spend $600 million on gas infrastructure (Gona and Shah 2022). Over the long-term, through to 2058, PGW is projected to spend $6 to $8 billion on 1,215 miles of pipe replacements (Seavey 2023).

In January of 2025, PGW released a request for proposals for a firm to complete a Low Carbon Pathways study for the utility. The stated purpose of the study is to evaluate “potential decarbonization pathways for a long-term, sustainable energy transition, while continuing to balance safety, affordability, and reliability for its customers” (Government Bidhub 2025).

In August 2025, PGW selected Environmental Resources Management, Inc to complete the study (PGW 2025c)

In sum, the literature on Philadelphia's emissions reductions policies and projects reveals a wide gap between their anticipated outcomes, and the city's 2050 net zero climate goal. For power generation, the Office of Sustainability (2025) states that "in future years, there will need to be a secondary shift from natural gas to lower carbon electricity generation sources to continue reductions" (15). For emissions reductions from direct use in buildings in Philadelphia, PGW acknowledges "when including Scope 3 emissions, PGW's downstream customers' use of natural gas presents the greatest overall opportunity for PGW emission reductions" (PGW 2025a, 3). In rhetoric, the city and gas utility recognize gas use for power and direct use as a critical obstacle to achieving climate goals. This challenge is not unique to Philadelphia, and other places are exploring and pursuing TENs as a potential solution.

2.5 Projects in Other Parts of the U.S.

By 2030, utilities in the Northeast region of the U.S. are estimated to lose tens of millions of dollars in revenue due to load defection (Bronski et al. 2015). The economic reasons are not the only factor that fuels the utility death spiral. The Congressional Research Service identifies aging conventional energy infrastructure, development of new energy technologies that enable onsite generation, and increased regulation in favor of clean energy sources as other factors that influence the shift (Congressional Research Service 2016). This is the case for Philadelphia, where the utility is already significantly dependent on federal energy bill assistance programs, and rate surcharges in order to make up revenue that low-income customers cannot pay (Seavey 2023). In their 2015 report, *What's a Gas Utility Without Gas?*, Ashita Gona and Amar Shah claim that with forward thinking planning, PGW could now begin to explore and develop nonpipe solutions in order to mitigate the impending negative impacts that will result from continued investments in a gas system that is experiencing and projected to experience continued defection.

Several states and cities are taking steps to explore and implement new energy approaches to replace gas. While human use of geothermal has been around for centuries, TEN configurations are a relatively novel approach that is growing in the U.S. but not yet mainstream (Buro Happold 2020). The Building Decarbonization Coalition (2025) counts fifty-eight TENs or other geothermal networks currently in operation (20 projects), under design (23 projects), under construction (10 projects), or filed (5) for development U.S. (Building Decarbonization Coalition 2025).

Across the U.S. a growing number of states are passing or exploring legislative measures to help transition gas utilities to renewables. As of this writing, the states of Colorado, Massachusetts, Minnesota, and New York have passed laws that permit or require gas utilities to pursue UTEN pilots or projects to displace fossil gas. At least four states–Illinois, Maine, Vermont, and Washington, are exploring similar laws. Where laws have passed, there has been a boost in pilot projects to explore the viability of gas-to-geothermal. In NY, 13 projects have been announced since the passage of the Utility Thermal Energy Network and Jobs Act in 2022 (St. John 2024). In Massachusetts, a first-in-nation UTEN project began operating in June 2024 in the city of Framingham. The utility network entails 37 buildings, including 5 commercial and 32 residential, serving over 135 customers including single-family homes and low-income households (McKenna 2024). The project was a collaboration between the utility Eversource and the Home Energy Efficiency Team (HEET) organization, and has been granted $750,000 by the U.S. DOE to expand in the future (ibid). Additionally, the Massachusetts Clean Energy

Center has availed up to $500,000 for up to 10 communities to assess geothermal potential (HEET 2024).

In addition to the eight states that have passed or proposed legislation that permits or requires geothermal, several other jurisdictions across the U.S. are moving towards expansion of geothermal. The Public Service Commission of Washington D.C. and the Governor's Office of New Jersey have released RFPs and directives, respectively, for the exploration of fossil free heating projects for buildings and communities (HEET 2024). Meanwhile, a gas utility in Oregon completed a UTEN scoping study (ibid). In 2013, the town of West Union, Iowa completed a 132 borehole UTEN with 264 tons of heating and cooling capacity (Green Up West Union 2026). The West Union project at inception served 11 businesses but was connected to 57 parcels—opening the possibility for expansion. Other projects in Yale Acres, Connecticut and Whisper Valley, Texas demonstrate the potential of TENs to supply heating and cooling to hundreds of units, and how those systems can be coupled with building decarbonization and other renewable sources like solar, towards full community decarbonization (Building Decarbonization Coalition 2025).

An increasing number of TENs at U.S. colleges and universities provide models for utility thermal energy networks (UTENs) and demonstrate the use range and potential of these systems. The Colorado Mesa University has been a TEN pioneer since 2008 when it broke ground on its now 16-building TEN (Colorado Mesa University 2025). The University is currently expanding the system to incorporate 9 more buildings (ibid). The geothermal network at Weber State University in Utah has reduced GHG emissions by 31% and saved $1.9M in energy costs (HEET 2023). Smith College is completing a geothermal system that will reduce campus emissions by 90% by 2030 (Smith College 2022). Swarthmore College is completing a geothermal system that will displace a mostly fossil gas system and help the school meet its 2035 net zero emissions goal (Swarthmore College 2023). In Wisconsin, Marquette University and the local gas utility have applied for funds to study to explore the possibility of a TEN (HEET 2023).

On the level of the U.S. federal government--under Presidents Biden and Trump--there's generally been sustained support for geothermal. The Inflation Reduction Act of the Biden term provided residential and commercial tax credits for geothermal, commercial deductions, and home energy rebates that included rebates for geothermal (IGSHPA 2022). The One Big Beautiful Bill Act of the second Trump term ended some geothermal provisions, including one of the main residential tax credits but has left many of the other financial incentives intact, including tax credits for GSHP purchases (USGBC 2025). In April of 2023, the Geothermal Technologies Office at the DOE selected 11 communities to allocate a total of $13 million for neighborhood scale geothermal project feasibility studies (U.S. Department of Energy Office of Geothermal 2025). In addition to helping advance climate goals, this initiative was part of the Biden administration's Justice40 Initiative: all selected communities were low-income disadvantaged communities, and among those towards which 40 percent of the benefits from the Inflation Reduction Act were to be directed. Communities selected included island, rural, suburban and urban. At least three of those projects have been selected to receive funding for installation of the proposed projects (ibid). Table 1 provides a snapshot of three projects–two of which were confirmed for funding, and a third for which DOE funding is possible but unclear at the time of this writing. I illustrate these three projects, as their size, location, and building characteristics are similar to those being considered for the project site on which this thesis focuses.

Table 1 - Examples of Proposed or Completed TENs

Location	Scale	Energy Supply	Project Scope
Framingham, MA	Community scale, utility managed	Heating, cooling: 100% of demand.	37 buildings: 32 residential, 5 other. (Town of Framingham 2023)
Ann Arbor, MI	Community scale	Heating, cooling: 75% of demand.	262 low-income homes, 1 school, 1 community center, 1 municipal facility
Chicago, IL*	Networked community scale	Heating, cooling.	4 blocks. Up to 69 residential buildings and small museum space. (Schoenberg 2025)

*Source: Community Geothermal Heating and Cooling Design and Deployment | Department of Energy unless otherwise cited. *This Chicago project had been granted federal funding, but the allocation has been indefinitely frozen by the DOE.*

2.6 Gas Transition Studies for U.S. Cities and States

In recent years, an array of studies have been conducted to provide insight for how utilities, state agencies, legislatures, and communities could approach the gas utility decarbonization. Across the literature, themes have emerged in the findings and recommendations. The California Public Utilities Commission (CPUC) report titled *Staff Proposal on Gas Distribution Infrastructure Decommissioning Framework in Support of Climate Goals*, is particularly comprehensive and articulates many of the emergent themes. These themes include ensuring safety and reliability of infrastructure, reducing gas demand in alignment with municipal and state climate goals, creating social and economic benefits to the communities, and fostering a smooth transition by seizing low-hanging decarbonization opportunities now, and reaching "hardest-to-decarbonize" locations later (California Public Utilities Commission 2022).

I have observed several themes across the literature on how locales should go about achieving these fundamental goals. I closely examined seven documents where themes were especially prominent. Four of these studies were focused on Philadelphia:

1. *PGW Business Diversification Study* completed by Energy and Environmental Economics, EConsult Solutions Inc. and Portfolio Associates
2. *Philadelphia's Gas Pipe Replacement Plan: How much will it cost and does it make sense?* commissioned by HEET and completed by Dorie Seavey, PhD.
3. *What's a Gas Utility Without Gas?* completed by RMI.
4. *Philadelphia Building Decarbonization Workforce Impacts and Opportunities* study completed by the Building Electrification Institute and the Economy League of Greater Philadelphia.

The other highly relevant studies to this research, focused on various other locations, included:

5. *The Future of Gas in New York State* report by the Building Decarbonization Coalition;
6. *California's Gas System In Transition Equitable, Affordable, Decarbonized And Smaller*, completed by Gridworks, a consortium of 15 government agencies and NGOs that explored approaches for decarbonizing utilities in California.
7. *Leaked & Combusted: Strategies for reducing the hidden costs of methane emissions & transitioning off gas* nationwide analysis commissioned by HEET and compiled by Dorie Seavey, PhD.

The following are themes that emerged across this literature.

- *Utilities should immediately begin moving away from conventional gas replacement plans if they are to avoid costly stranded assets, cut pollution, and align energy emissions with municipal and state climate goals* (Kind 2013). Current gas replacement plans are projected to cost trillions of dollars across the U.S., with much of that infrastructure becoming stranded assets after 2050 (Seavey 2024). The Building Decarbonization Coalition estimates that gas utilities in New York State are projected to spend $28 billion on capital expenditures to replace old gas lines with new ones through to 2043 (Walsh and Bloomberg 2023). Dorie Seavey finds that PGW's Main Replacement Program for Philadelphia will cost a nominal $6 billion to $8 billion through 2058 ($5-$6 billion in real dollars) (Seavey 2023). Beyond projects of safety or reliability imperative, utilities should "minimize reinvestment, and target retirement" in the gas system (Gridworks 2019). Doing so could mitigate upfront capital costs and future maintenance costs of a system that must be phased out in less than three decades (ibid).

- *Legislative action could help expand gas utilities' ability to transition to renewables.* Two changes are strongly recommended. First, legislation to require all new construction be all-electric is proffered as a commonsense opportunity: "If you find yourself in a hole, the first thing to do is to stop digging" (ibid, 11). Second, the obligation to serve (gas)" statute in many state laws, including in Pennsylvania, must be modified. This statute requires that a gas utility must provide gas to any customer that requests it, within the utility's legally mandated area of service (Pennsylvania General Assembly 2024). It is recommended that this fuel-specific requirement ought to be broadened to an obligation to provide thermal energy. This could prevent situations in which a single customer preferring gas specifically, could block the transition of their home and those of any number of neighboring buildings from being moved off the gas network to a "nonpipe" heat alternative, such as geothermal, by strictly requesting gas (Gridworks 2019, 17-18).
- *Utilities should now start to develop managed, phased approaches to wean off gas, and align with net zero 2050 goals.* A "managed, phased" approach is a strategic process that considers local decarbonization activity in relation to bigger picture decarbonization goals in an area. An unmanaged approach is characterized by an every-home-for-themselves transition that leaves the transition up to market forces

(Seavey 2024), which results in lower income households that cannot afford to voluntarily switch, being left to disproportionately bear the cost burden of the old gas system (Gridworks 2019). The managed approach has at least three outstanding features: temporal, geographic, and financial considerations. Temporally, a managed transition incorporates concrete near- and medium-term benchmarks that must be established to support long-term (2050) net-zero success (Gona and Shah 2022). Geographically, managed-phased approaches can identify neighborhood-level or "zonal" decarbonization opportunities. This helps avoid scattershot decarbonization across space, and helps ensure everyone, not just the financially capable, can transition to clean energy (Seavey 2024). Financially, a managed-phased transition helps redirect present day investments from soon to be obsolete gas infrastructure that would cost more than it serves (Walsh and Bloomberg 2023).

- *Decarbonization plans should embed equity, ensuring low-income households are not burdened with high costs or excluded from accessing clean energy opportunities.* Utility rate structures can be adjusted in a variety of ways to help minimize how much of the costs of transitioning impacts low-income households, including: redistributing existing revenue, adding new or redirecting existing fees and charges to select ratepayers or across the rate base, seeking public funds including those availed through the Inflation Reduction Act, implementing on-bill financing schemes, or extending fees to electric customers who reap the benefits from an expanded electric grid (Gridworks 2019). To gather concrete lessons on navigating social challenges related to energy transitions, the authors of the Gridworks report suggest pilot programs, stating "Experience gained through… pilots may offer a model for community engagement to increase access to affordable energy options" (ibid, 19). In their report, the CPUC staff recommend criteria–technical and equity-based–for selecting neighborhoods to decarbonize, including prioritization of communities with the greatest pipeline risks, potential savings for ratepayers, technical feasibility, and community burdens–energy, health, rent and other (California Public Utilities Commission 2022).

These four points were made consistently across the literature including in the reports listed above. Additional themes are common in the literature.

- *"Decarbonized gas" approaches–e.g. renewable gas and hydrogen technologies–are not a financially or scientifically viable means for decarbonizing fossil gas networks.* Renewable gas is gas captured from sources like sewage, manure, wastewater, or landfills (Walsh and Bloomberg 2023). The PGW Business Diversification Study found that the decarbonized gas approach is the most expensive of the four fossil gas reduction paths they studied (Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates). Renewable gas is costly because the feedstocks that yield it are limited, production is expensive, and the costs tend to increase, rather than decrease with scale (Walsh and Bloomberg 2023). Hydrogen production is costly. Barring expensive and limited carbon capture and storage process, it usually has its own substantial GHG emissions. Once produced, there are costly barriers to enable its compatibility in existing pipeline networks (ibid).
- *Nonpipe energy alternatives are becoming increasingly financially viable due to shifting economics, fueled by popular demand and government financial*

incentives. The Air-Conditioning, Heating, and Refrigeration Institute has found that the demand for air source heat pumps (ASHPs) is outpacing that for gas furnaces: ASHP sales have increased annually since 2013 and in recent years has surpassed the sale of gas furnaces in the U.S. (Seavey 2024, 25-26). This shift, among others, towards building electrification "undermin[es] the primary ways in which gas utilities have historically kept rates affordable" (Walsh and Bloomberg 2023, 4). On the whole, electrification is cheaper than gas buildout. Seavey finds that when "the long-term harm fossil gas causes to our health, the environment, and the climate…are taken into account, gas is actually far more expensive than electricity" (Seavey 2024).

- *The shifts in clean energy economics and popularity, intertwined with shifting politics and policies, compromise the potential for long-term costs recovery of fossil gas assets, and make electrification strategies more economically prudent.* Walsh and Bloomberg (2023) found that "reduced gas consumption does not reduce gas distribution costs proportionally" (22). In other words, customer defection from gas networks means a smaller pool of customers will have to pay a greater proportion to maintain the system. As the costs of gas increase, more financially capable customers switch to clean energy alternatives which consequently become more financially competitive and attractive (Seavey 2023). This dilemma is commonly referred to as the utility "death spiral" (Gridworks 2019, 4). Looking ahead, Walsh and Bloomberg (2023) find that for New York–consistent with Seavey's (2024) findings on gas infrastructure for buildings nationwide–that the costs of maintaining the gas system beyond 2050 would be greater than pursuing aggressive electrification strategies.

A central consideration in transitioning energy systems is minimizing costs and maximizing benefits to ratepayers and industry workforce. As for workers, PGW employs 1,600 workers, including 1,100 union members (Energy & Environmental Economics, Econsult Solutions, and Portfolio Solutions 2021). The utility is obligated to pay millions of dollars to hundreds of pension holders, and at present, PGW holds about $1 billion in debt (ibid). PGW can seek ways to transition its fuel system in a way that minimizes layoffs of current workers and supports its fiduciary responsibilities to former employees. Numerous studies and researchers point out the overlap between the skills and equipment required for gas and geothermal networks, and the workforce transition opportunities – with planning and training – it could provide for workers (ibid; Kann 2022). The Building Electrification Institute and the Economy League of Greater Philadelphia found that by pursuing both building energy retrofits and thermal energy networks, Philadelphia could create up to 7,500 jobs annually between 2025 and 2050 (2024, 26). The *California's Gas System in Transition* study completed by Gridworks recommends several steps that can be taken to support smooth workforce transitions, including: procedural inclusion of the existing workforce in utility planning; severance, wage, and per diem offers that compensate worker relocation, forced retirement, or changes in responsibilities; training programs for new positions; incentives to other utilities to hire displaced gas workers (2019).

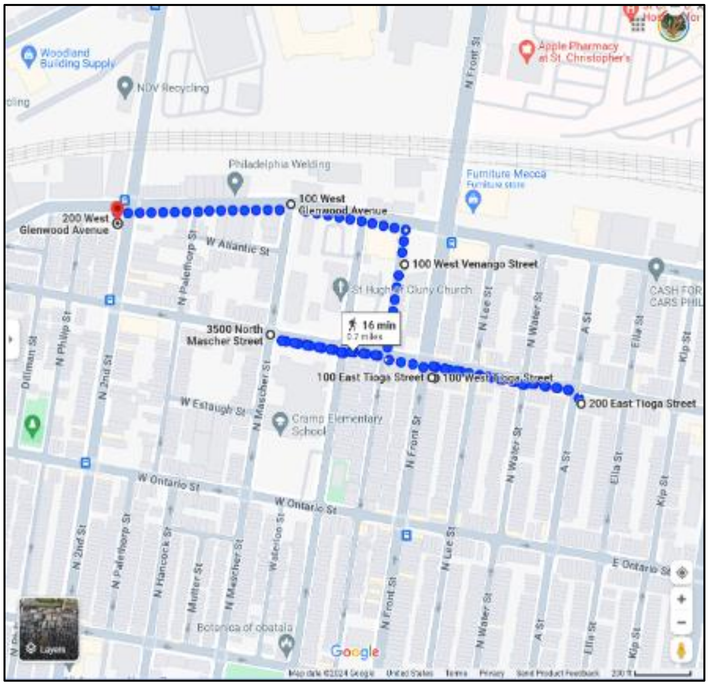
Chapter 3: Methodology

The Methodology is two-part. The first stage, site selection employed qualitative methods and the second stage, the energy load analysis employed qualitative. This Methodology chapter is organized into subsections on the *Site, Data*, and *Energy Calculations*. I will describe how I did the preliminary site assessment and selection. Then, I will describe how I completed calculations to estimate the thermal energy load.

3.1 Site Selection

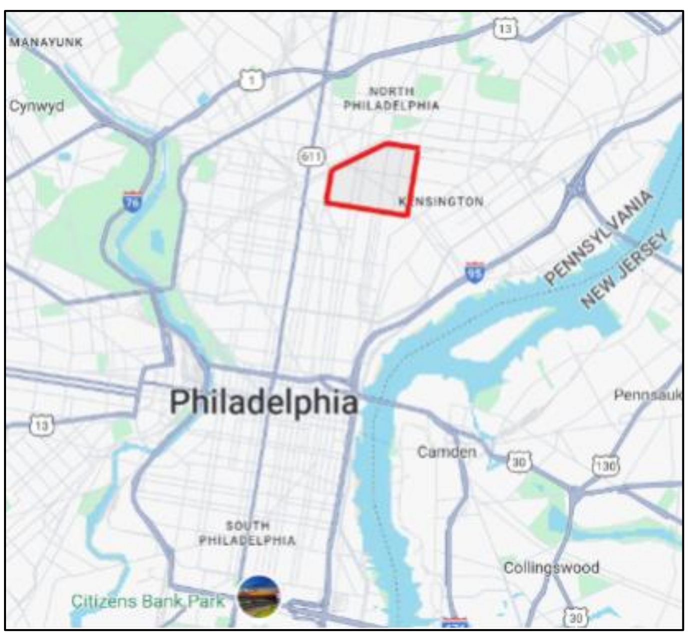
The project site (Figure 2 and Figure 3) is one of several locations noted in PGW's Annual Asset Optimization plans where old gas mains were replaced with new ones in 2022 (Pennsylvania Public Utilities Commission 2023, 4). This gas replacement project cost $2.8 million and was completed in 2022 (ibid) but is one of dozens of locations slated for gas main replacement across the city. The project site is in the Fairhill neighborhood of North Philadelphia, located within the 19140 zip code, one of Philadelphia's highest poverty areas (Eichel and Howell 2017).

Figure 3 - Image of Project Site



Google Maps. See Appendix F for full site composition details.

Figure 4 - Image of Project Site, Zoomed out



Google Maps

I chose to assess this site based on several of the neighborhood characteristics. The site has a diverse mix of building types–residential, commercial, and industrial, with the vast majority in active use (Appendix F). The site also has a high number of vacant parcels, which potentially could be useful for key components of a UTEN–space for drilling geothermal boreholes and installing geothermal exchange equipment. Present on the site is a medium-sized refrigeration warehouse, which I identified as the “anchor” institution for this site. Anchor institutions in networked geothermal refer to energy intensive buildings–like supermarkets, hospitals, ice rinks–that would provide significant thermal sources, diversify the site’s energy load, or be relied upon to provide long-term energy provision and planning at their location. Also, located one block from the site is William Cramp Elementary School, which could potentially serve as an anchor institution for the site if more load diversity and system reliability is needed.

Residential

There are a large number of residential parcels on the site. The presence of residential buildings is important because to advance energy equity–by making sure low-income communities are not left behind in an energy transition–I want to make sure their houses benefit from clean energy investments, like those typically entailed in UTEN development. All residential buildings are single-family, masonry structures built between 1920 and 1979 (City of Philadelphia Atlas 2024). All of these characteristics were key inputs to complete the energy load assessment as described in the later steps of this Methodology.

Commercial & Industrial

The presence of six parcels zoned for commercial use on the project site, five of which currently have actual commercial activity on a regular basis, influenced my decision to select this site. Typically, daily energy consumption patterns for commercial buildings are different from residential buildings. For instance, while many commercial properties are commonly in operation and consume energy around 9am - 5pm, residential buildings are usually occupied and in demand of energy from 5pm - 9am. Likewise, commercial properties are more likely to have more refrigeration, expending heat, while residential may have more heating demand, consuming displaced heat. There are many other factors that complicate this, but generally these diversities in time of usage and load demand are beneficial to TENs. I considered this same dynamic when preliminarily assessing the presence of industrial buildings on the site. There are five industrial parcels on the site, all of which are active. The anchor institution on the site, a refrigeration warehouse, is one of the industrial parcels, and was a key consideration in my preliminary site assessment and selection.

3.2 Data

In this section, I describe the data I needed to complete the energy load analysis, the time frames for which I needed the data, and the sources I referenced to ascertain or otherwise estimate the energy load.

Thermal Energy Load

To determine if a UTEN could meet the energy demand on the site, I calculated the total thermal energy demand–the energy "load"–for all parcels on the site. I factor the load for thermal end uses that geothermal could satisfy–this includes space and water heating and cooling. I exclude factoring thermal end uses that geothermal cannot satisfy, i.e. energy load from gas stove use. I exclude nonthermal end uses, i.e. electricity for lighting or appliances, with the exception of air conditioning. Where parcels already use energy efficient heating and cooling technologies like air source heat pumps, I did not factor in their thermal load since it would not need to be replaced with geothermal. While water cooling technically can be satisfied by a UTEN, I found no evidence that it is demanded for any of the parcels on my site, so, water cooling load is not factored. Table 2 summarizes the thermal energy loads factored in this research.

Table 2 - Thermal Loads Factored

	Building Energy End Uses	**End Uses Measured**
Thermal	Space heating & cooling	✓
	Water heating & cooling	✓
	Combustion stove cooking	X
Nonthermal	Lighting	X
	Plug loads	X

Time Frames Measured

The time frames for which thermal energy load data must be obtained are the annual load and the peak load. The annual figure is the total heating and cooling load that would be transferred to and from the geothermal system over a 12-month span. The peak load is the month in the year for which there would be the greatest thermal energy transfer. TENs must be designed to meet peak capacity (Bulldog Heat Pump 2018).

Sources

I calculated energy load for the residential, commercial, and industrial properties on the site using a mix of four source types: (1) surveys of estimate energy loads for buildings of particular categories, (2) HVAC industry energy use intensity estimates, (3) utility statements from and conversation with building owners and operators, and (4) energy modeling.

<u>City of Philadelphia, Property and City of Philadelphia, Atlas Webpages</u>

These two sources provided information on the characteristics of all parcels on the site including building age “vintage”, gross square footage, occupancy status, and use.

They identified which parcels were zoned residential, commercial, or industrial. I referenced these two sources to complete my preliminary site assessment and ultimately to select it for this UTEN technical suitability analysis. I referenced key data about the building characteristics–vintage, square footage, and number of buildings–to complete energy load estimate equations and energy modeling (described in the following subsection, "Energy Load Calculations.")

Google Maps and Site Visits

I used Google Maps and made site visits to gather essential data that was either unavailable on or inconsistent between the *City of Philadelphia Atlas* and *Property* websites. I also used Google Maps to measure the length of the main loop that would be installed, were a UTEN to be constructed.

HVAC Industry Standard Ranges and Climate Zone

I gathered energy use intensity data from HVAC industry webpages. This included the InspectAPedia (2025) Climate Zones & Btu Requirements webpage and the AC Direct (2025) webpages to determine reasonable estimates of British thermal units per square foot for residential buildings in climate zone 4A (that of the project site), and for buildings of the size of those on my site. I confirmed the climate zone of the region from International Energy Conservation Code maps.

Direct Contact with Property Managers

For several commercial and industrial properties I contacted property managers to gather and verify data that could not be obtained by other means. I made this contact through site visits and phone and email contact. For one of the two commercial properties with a thermal load, 141 E Tioga Street, the building operations provided energy use data. For the other, 119 E Tioga

Street, the owner declined to share utility data. For this property, I completed an energy model, described in the following *Energy Calculations* subsection of this Methodology chapter.

For two of the three industrial properties with thermal load, I was able to acquire energy use data directly from the property staff. For one of these two parcels–143-145, 153 W Glenwood Ave (one property)–the building owner provided PGW monthly bill statements for the property and a verbal description of the energy use patterns on the property. The property owner reported that the only thermal load at this site is during winter months of December, January, and February, and that that load is for modest space heating only. The property owner also shared the utility statement from January 2025 (Appendix E). For the second industrial property with energy load, 124 W Venango Street, the operations director emailed the 2024 total energy demand from both gas and electric used in 2024.

Energy Information Agency (EIA) Residential Energy Consumption Surveys (RECS)

To determine the monthly cooling load is not as simple as dividing the annual load by 12, since cooling and heating demand is not equally distributed across the course of a year.
To determine heating and cooling monthly usage patterns for residential buildings, I referenced the monthly usage data provided by the EIA Residential Energy Consumption Surveys. I referenced the *RECS Monthly household site electricity cooling consumption in the United States—averages* to determine the cooling load distribution (RECS Table CE8.7.M. 2020). I referenced the *RECS, Monthly household site natural gas space heating consumption in the United States—averages* to determine heating distribution (Table CE8.15.M.2020). For both of these, I calculated and employed the monthly percentage of energy load–not the raw figure–and applied those monthly percentages to the residential annual energy load data I had. This is further explained in the *Peak Load* section below, under the subsection *Energy Load Calculations.*

EIA Commercial Sector Energy Consumption

To determine monthly cooling and heating load in commercial and industrial buildings, I referenced the Commercial Sector Energy Consumption survey data, Table 2.3. In this table, I referenced the *Natural Gas* column as a proxy for heating, and I referenced the *Electricity* column as a proxy for cooling. Again, I applied the monthly load percentages–not the raw figures–to the commercial and select industrial annual site data I had obtained.

EIA Commercial Buildings Energy Consumption Survey (CBECS)

I referenced this source to determine the cooling load for the commercial building at 119 E Tioga Street (Appendix C).

Heating and Cooling of Buildings: Principles and Practice of Energy Efficient Design (Reddy et al. 2017) and Isabelle Coupet Consultation

I conducted energy modeling for two properties for which sufficient information to determine energy load could not be obtained otherwise. This textbook provides instructions and formulas for energy load modeling. To support my accurate interpretation of instructions and calculations, I consulted Isabelle Coupet, *Building Support and Training Engineer,* formerly with Green Building United.

3.3 Energy Load Calculations

As described in the previous *Data* subsection of this chapter, the key energy load figures I needed for the site were the annual load and the peak month load. I sought the annual load data first, the process and sources of which are largely covered in the *Data* subsection of this chapter. In this subsection, I explain my methods for five main calculations: the formulas I used for annual residential heating and annual residential cooling estimates, peak load calculations, the energy model, the unique considerations for assessing the load of the anchor site, and the rationale by which I determined an energy savings figure for hypothetical energy efficiency interventions (EEIs).

Annual Residential Load Calculations

For annual load for residential buildings, my formulas were as follows, for heating and cooling respectively.

For heating: 50 Btu * total sq ft - 10% energy efficiency interventions (EEIs)

Table 3 - Formula Inputs for Residential Annual Heating Load

Information Needed	**Factor**	**Source**
Climate zone	4A	IECC
Energy use intensity (EUI)	45-50 Btu/sq foot	HVAC Industry Standard Range
Total avg. sq. ft.	1,347	City of Phila Atlas, Property
Building vintage	45-110 years old	City of Phila Atlas
Load reduction from EEIs	10%	Literature Review

For cooling: 24,000 Btu * total buildings - 10% EEIs

Table 4 - Formula Inputs for Residential Annual Cooling Load

Information Needed	**Factor**	**Source**
Climate zone	4A	IECC
EUI	24,000 Btu/building	HVAC Industry Standard Range
Total residential buildings	41	City of Phila Atlas, Property
Load reduction from EEIs	10%	Literature Review

Peak Load

There was only one parcel for which I was able to obtain the precise monthly thermal energy load for each of the 12 months. For all the other parcels, I either obtained total annual energy load data or the energy load data for some number of months less than 12. I bridged these data gaps in one of two ways. For parcels for which I had less than all 12 months' load data, I had to estimate the annual load and the peak month load. For the parcels for which I had only the aggregate annual energy load data, I had to estimate monthly energy load distribution, then identify the peak month. To bridge these data gaps, I used the EIA energy consumption surveys mentioned in the *Sources* subsection of this chapter.[1] From the EIA tables, I converted the electricity (cooling) and gas consumption (heating) figures into percentages, with the percentage distribution across the 12 months equaling 100 percent. I then applied that percentage to the actual energy load figures I had for the residential, commercial, or industrial buildings on the site. For example, if I gathered in my primary data collection that there were 100 tons of cooling load annually for residential buildings; and the EIA surveys found that July accounted for an average of 15% of annual cooling load for residential buildings, then I could calculate that July consumed 15 tons on average in a given year for the residential buildings on my site. The calculations to bridge these data gaps for residential, commercial, and industrial buildings are illustrated in Appendices B, C, and D respectively.

Energy Modeling

I completed heat loss energy modeling for two buildings (Appendix E) for which I was otherwise unable to obtain enough primary energy use data about the site. One of the sites was the commercial property at 119 E Tioga Street. The other site was 147-161 W Glenwood Ave, where the owner was reluctant to share utility statements for his property. Here, I gleaned information from a mix of site visits and conversation with the owner, which I input into the energy model. The full energy models for both sites are included in Appendix G. The energy modeling explanation is as follows.

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[1] For the commercial property at 141 E Tioga Street, the data revealed, and the owners affirmed that the annual energy use patterns for the building are atypical. Thus, in this case and others like it, I did not graft typical usage percentages to fill data gaps. I instead applied the actual load figures from my primary data collection. (See Commercial Table 6 in Appendix E.)

The energy model determines the annual heating load. The key factors for the model include the *design day* temperature and the *heat loss coefficient*. The design day temperature is the difference between the set indoor temperature and the outdoor temperature. The energy model must factor for the peak (greatest difference) design day. The heat loss coefficient is the measure of heat loss through the building envelope. The following are the two formulas for the model. The formula for determining peak design day load is:

$Q_{h, max} = K_{tot}(T_i - T_o) - Q_{gain}$, where,

- $Q_{h, max}$: peak heating load
- K_{tot}: design heat loss coefficient*
- $T_i - T_o$: indoor temperature - outdoor temperature ("design day" temperature)
- Q_{gain}: internal heat gains during the coldest outdoor period

*K_{tot}: Heat loss coefficient (a measure of how well the building loses heat; dependent on building materials, insulation, brick, windows, doors). K_{tot} = Sum of all the U Areas.

The formula for determining heat loss–a key factor to determine peak heating load–is:

$Q = U * A * \Delta T$, where,

- **Q** = Heat loss (BTU/hr)
- **U(k)** = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- **A** = Area of the wall (ft^2)
- **ΔT** = Temperature difference across the wall (°F);

This formula is completed for the area of the whole building envelope and its materials–walls and roof (brick, steel, etc), windows, doors–then the total is aggregated.

Anchor Site

For the three industrial parcels that had thermal load, I obtained sufficient data from only one property to directly factor into the site energy load calculation. For the other two properties, I had to complete calculations to determine energy load estimates from limited data provided by the property staff. These two industrial sites were 124 W Venango Street and 147-161 W Glenwood Ave. For the latter, I conducted the energy modeling, described previously. For 124 W Venango Street, the anchor site, I factored the gas consumption data provided by the property owner to determine the heating load, and the electricity consumption to determine the cooling load. For the most precise figures, I could have subtracted the nonthermal electric consumption (i.e. lighting, which a UTEN could not satisfy) from the total electric load, in order to determine only the thermal electric load (heating and cooling, which a UTEN could satisfy). However, the vast majority of electric load on the site is for thermal use, while the portion of electricity consumed for nonthermal loads is relatively miniscule. I asked the site operations manager a series of questions to verify that nonthermal electric load was insignificant. These questions and responses are documented in Appendix D.

Energy Efficiency Intervention Reductions Methodology

Any UTEN pilot program should support the completion of home energy retrofits that can maximize the energy efficiency of buildings on the site, which reduces energy demand, and the amount of capacity needed from the UTEN system. Energy efficiency reduces energy demand. Less energy demand has implications for the size and components of the UTEN. Considering this, it was important to factor in estimate energy use reductions from EEIs, into my calculation of the project sites total energy demand projections. Extracting a generalizable average of potential energy savings following most residential EEIs is complicated. There are numerous intervention measures, the impacts of which vary depending on a host of environmental and social factors, such as the local climate, the building characteristics, resident behavior, and energy costs. There remain large gaps in the research on the impacts of residential EEIs. The existing research assesses buildings in geographies across the globe (i.e. various climates, cultures, conditions) and there is a lack of uniformity of methods that enable easily generalizable conclusions.

Nonetheless, some crude estimations can be gleaned that can help bring the total load closer to what it likely would be after EEIs. I reviewed 17 studies on energy savings from EEIs in residential buildings, many of which I sourced from the analysis, "Residential Energy Efficiency Interventions: A Meta-analysis of Effectiveness Studies" completed by Miriam Berretta, Joshua Furgeson, Yue (Nicole) Wu, Collins Zamawe, Ian Hamilton, and John Eyers (2021). I extracted information from six of the studies referenced in this metanalysis. These six studies, published between 2013 and 2018, assessed energy savings in millions of single-family homes that underwent EEIs across five countries (Adan, Fuerst 2016; Beacon, Boland, O'Donnell 2018; Grimes, Preval, Young, Arnold, R., Denne, Howden-Chapman, and Telfar-Barnard 2016; James, Ambrose 2017; Liang, Qiu, James, Ruddell, Dalrymple, Earl, and Castelazo 2018, Hamilton, Steadman, Bruhns, Summerfield, and Lowe 2013). Five of the six studies included buildings located in the same Koppen global climate zone as Philadelphia. The EEIs that I reviewed were some of the most common: wall insulation, loft and attic insulation, heating controls, door and window treatment, and draft and duct sealing. Other popular energy efficiency and electrification measures were included in some of these studies, but it was not possible to fully control for these measures. Overall, the energy savings ranged 1.3 percent to 58 percent, with average energy savings of 15.7 percent and a median of 11.4 percent.

Considering my purpose is to provide an estimate total load, rather than precision, and to err conservative in those estimates, I elected to factor in 10 percent energy savings onto the project site's energy demand savings post-EEIs. There were several reasons why I chose a conservative estimate figure. Much of the literature highlights that energy savings tend to be less than engineered models, and other factors, like education and behavioral interventions, can result in significant positive changes in realized energy savings from EEIs (Zivkin, Novan 2016). I do not consider the potential impacts of behavior change because none of the existing Philadelphia energy efficiency programs compliment EEIs with behavioral education. Furthermore, the data show low-income households commonly have lower realized energy savings after interventions, as compared to non-low-income households that receive interventions (James, Ambrose 2017).

With all this data, I was able to estimate the total annual energy load and the peak month for the site. The next chapter shows the Results of this methodology.

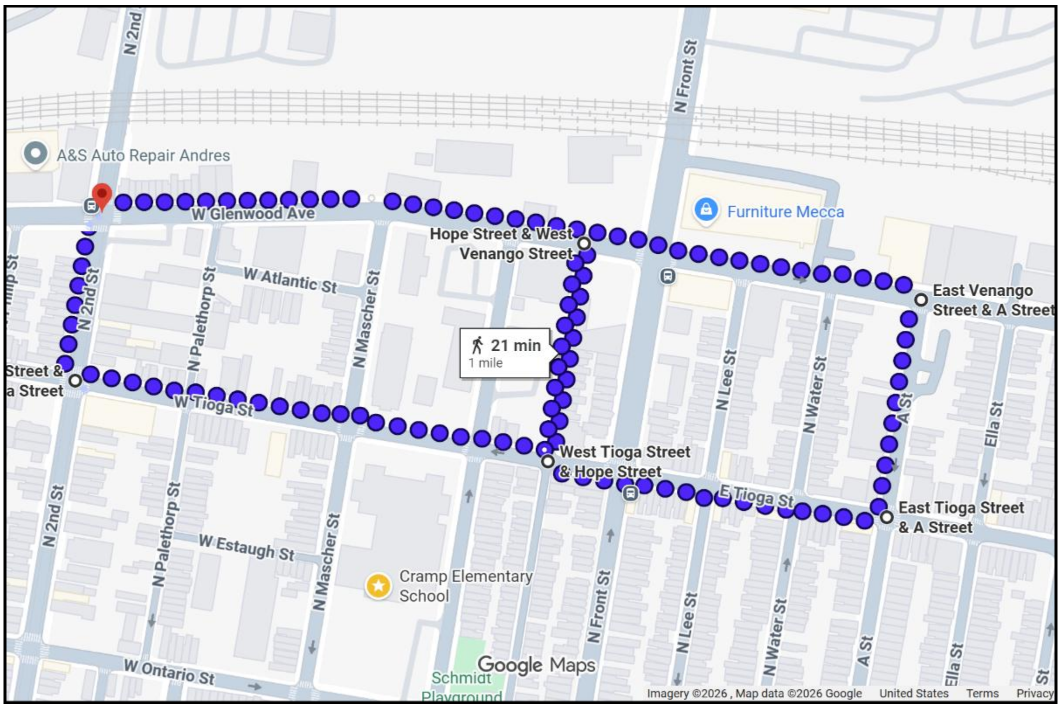
Chapter 4: Results

In this chapter, I report the results from both stages of the research: Selecting the Project Site and Estimating Energy Load.

4.1 Project Site

The site includes a mix of residential, commercial, and industrial parcels (Table 5). Residential accounts for the greatest square footage with thermal energy load. The commercial and industrial parcels offer some load diversity that could help balance large heating demand (cooling displacement) from residential buildings. This includes a meat distribution warehouse with large heat displacement, which could play a role as an anchor location on the site. Located adjacent to the site is William Cramp Elementary, a 21,000 square foot school that could potentially provide more load diversity. The site spans roughly seven square blocks, includes 52 parcels (City of Philadelphia Property 2024), and would require approximately 5,036-foot single ambient loop for a UTEN (Google Maps 2024). I used Google Maps to calculate the length of the loop (Figure 4). Full site details are in Appendix F.

Figure 5 - Hypothetical Thermal Loop



Google Maps.

There are 19 parcels with open space spread across the site, totaling over 187,000 square feet (City of Philadelphia Atlas 2024) that potentially could be explored for the placement of networked geothermal infrastructure, namely bore fields, geoexchange system, and pump stations.

Table 5 - Project Site Characteristics

	Total Parcels	Parcels with Thermal Load	Total Sq. Ft.	Sq. Ft. with Thermal Load
Residential	41	41	53,887	53,887
Commercial	6	2	8,410	4,729
Industrial	5	3	90,491	30,366
Total	52	**46**	152,788	**88,982**

See Appendix F for full site composition details.

4.2 Energy Load Estimates

In this section, I describe the results of the calculations for annual and peak energy loads, for the residential, commercial, the industrial parcels, and the aggregate for all three.

4.2.1 Residential Energy Load Results

The total annual energy load for residential buildings (Table 6) before estimated load reductions from energy efficiency interventions is 305 tons, including 225 tons for heating and 80 tons for cooling. After factoring the 10 percent load reductions from hypothetical energy efficiency interventions (EEIs), and adding heating and cooling together, the total estimated annual residential load is 274 tons.

Table 6 - Residential Annual Heating and Cooling Load

	Btu	Tons	Final Total *(tons after 10% EEIs Reduction)*
Total Heating Load *50 * total sq. Ft.*	2,694,350	225	202
Total Cooling Load *24,000 * total buildings*	960,000	80	72
Total Residential Annual Load	3,654,350	305	**274 tons**

See Appendix B for the full detailed Residential calculations, from which the figures in this table are derived.

Peak Thermal Load

I distinguished the annual cooling and heating loads and determined the monthly and peak month load distribution (Table 7). After EEIs, the peak residential heating load would be 42 tons, occurring in January.

Table 7 - Residential Monthly and Peak Heating Load

Month	Gas Usage, National *MMBtu**	Percentage	Monthly Load *tons***
January (peak)	**12.00**	**20.98**	**47.20**
February	10.80	18.88	42.48
March	6.90	12.06	27.14
April	5.20	9.09	20.45
May	2.30	4.02	9.05
June	0.20	0.35	0.79
July	0.10	0.17	0.39
August	0.00	0.00	0.00
September	0.30	0.52	1.18
October	2.10	3.67	8.26
November	5.30	9.27	20.85
December	12.00	20.98	47.20
Annual total	57.20	100.00	225.00
EEI Reduction	-	-	10%
Total After EEI	-	-	**42.48**

**Source: Energy Information Agency RECS Table CE8.15.M.2020*
***Factored from total annual heating load of 225 tons.*

After EEIs, the peak cooling load would be 23 tons, occurring in July (Table 8).

Table 8 - Residential Monthly & Peak Cooling Load

Month	**kWh / household***	**Percentage**	**Monthly Load **** *tons*
January	0.02	0.32	0.25
February	0.02	0.32	0.25
March	0.02	0.32	0.25
April	0.02	0.32	0.25
May	0.30	5.66	4.53
June	0.90	16.98	13.58
July (peak)	**1.70**	**32.07**	**25.66**
August	1.40	26.41	21.13
September	0.70	13.21	10.57
October	0.20	3.77	3.02
November	0.02	0.32	0.25
December	0.02	0.32	0.25
Annual total	5.30	100.00	80.00
EEI Reduction	-	-	10%
After EEIs	-	-	**23.09**

**Source: Energy Information Agency RECS Table CE8.7.M.2020*
***Factored from the total annual cooling load of 80 tons.*

The greater of the two seasonal peak loads is January, during the heating season. The residential peak thus is January. The aggregate residential energy load results are in Table 9.

Table 9 - Residential Energy Load, Total Annual and Peak (Tons)

	Annual (tons)			**Peak** (tons)	
	Heating	Cooling	Total	Heating (January)	Cooling (July)
Residential	202	72	274	43	23
Commercial	-	-	-	-	-
Industrial	-	-	-	-	-
Total	-	-	-	-	-

4.2.2 Commercial Energy Load Results

The project site includes a total of five parcels with *designated* commercial zoning, but six with *actual* commercial use. Of the six commercial use parcels, two have thermal energy demand that should be factored, four do not. Of the four, three–135, 137, and 139 E Tioga Street–are garages that have no thermal energy demand. The fourth–126 E Tioga Street–is a corner store with all electric heating and cooling, where gas is consumed only for cooking. I did not factor this building into the energy load calculations since the building already uses energy efficient air source heat pumps to satisfy its thermal energy demand.

For one of the two commercial buildings where I factored the thermal load, 119 E Tioga Street, I completed heat loss energy modeling to estimate the heating load (Appendix E). I referenced CBECS data to estimate the cooling load. The annual heating load for this building is 5.26 tons, the annual cooling load is 6.27 tons, the total annual load is 11.53 tons. The peak heating load is 0.86 tons and the peak cooling load is 1.39 tons (Table 10).

For the second of the two commercial buildings with an applicable thermal load, 141 E Tioga Street, I was able to acquire utility statement data for 2024 usage directly from the building operations manager (Appendix C). I found for 141 E Tioga that the annual heating load is 0.67 tons and the annual cooling load is 1.21 tons, totaling 1.88 tons. The peak heating load is 0.21 tons and the peak cooling load is 0.23 tons (Table 10).

Table 10 - Commercial Energy Load, Annual and Peak (Tons)

	Location	**Use**	**Gross Floor Area** (sq. ft.)	**Annual** (tons)		**Peak** (tons)	
				Heating	Cooling	Heating (January)	Cooling (July)
1	119 E Tioga*	Restaurant	917	**5.26**	**6.27**	0.86	**1.39**
2	126 E Tioga	Corner store	1,061	-	-	-	-
3	135 E Tioga	Garage	1,227	0	0	0	0
4	137 E Tioga	Garage	1,227	0	0	0	0
5	139 E Tioga	Garage	1,227	0	0	0	0
6	141 E Tioga	Community center	2,751	**0.67**	**1.21**	0.21	**0.23**
	TOTAL	Sq. ft.	8,410				
		Load		**5.93**	**7.48**	1.07	**1.62**
		Annual		**13 tons**		-	-

See Appendix C for the full detailed commercial calculations, from which the figures in this table are derived.

In aggregate, and rounded to the nearest whole ton, the commercial load totals 13 tons. The peak month is July, the cooling season, with an aggregate 2 tons. The final commercial figures, together with the final residential figures, is in Table 11.

Table 11 - Commercial Energy Load, Total Annual and Peak (tons)

	Annual (tons)			**Peak** (tons)	
	Heating	Cooling	Total	Heating (January)	Cooling (July)
Residential	202	72	274	43	23
Commercial	**6**	**7**	**13**	**1**	**2**
Industrial	-	-	-	-	-
Total	-	-	-	-	-

4.2.3 Industrial Energy Load Results

The project site includes five industrial parcels. All five are active sites, but only three have thermal energy load. For two of the three properties with thermal load, I was able to acquire energy use data from the property staff. For *143-145, 153, W Glenwood*, one of these two parcels, the only thermal demand is for space heating during winter months; there is no space or water cooling, and no cooking on the site at any point in the year. Thus, the data on the gas utility statement that I obtained from the owner was conclusive for calculating thermal load. The annual load (which was only for the months of December, January, and February) is 1.54 tons and the peak month, January, is 1.13 tons (Table 12).

For the second industrial property, the warehouse at 147-161 W Glenwood Ave, there is no cooling demand, only heating. The heating demand is only for the months of December, January, and February. During these months only, the heat is set to a relatively low 55F. That is the extent of the thermal demand for the site. Despite the relatively low temperature setting, the thermal load is relatively high due to two factors: the large size of the warehouse (15,000 square feet); and the envelope materials, which allow considerable heat loss. The annual heating load is 34.34 tons and the peak load is 13.08 tons (Table 12).

The third industrial parcel, 124 W Venango is the wholesale meat distribution facility with a large cooling load. This would be the anchor for the project site: the building has a high cooling load year-round–i.e. a high heat displacement–because the majority of the square footage is for industrial refrigeration and freezers. The annual heating load is for a small office area, and is 3.2 tons. The annual cooling load is 10.49 tons and the peak month load is during the cooling season, July, and is 7.12 tons. With its uniquely large cooling load, 124 W Venango is a significant source of load diversity for the project site (Table 12).

Table 12 - Industrial Buildings Data

	Location	Use	Gross Floor Area (sq. ft.)	Annual		Peak	
				Heating	Cooling	Heating (January)	Cooling (July)
1	100-110 W Venango	Supply shack.	817	0	0	0	0
2	129-141 W Glenwood	Scrapyard.	59,308	0	0	0	0
3	143-145, 153, W Glenwood	Metal repair shop.	3,011	1.54	0	1.13	0
4	147-161 W Glenwood	Warehouse.	14,954	34.34	0	13.08	0
5	124 W Venango St	Refrigerated warehouse, small office.	12,401	3.20	10.49	2.55	7.12
	TOTAL	Sq. ft.	90,491				
		Load		**39.07**	**10.49**	**16.77**	7.12
		Annual Load		**49.56**		-	-

See Appendix D for the full detailed industrial calculations, from which the figures in this table are derived.

In aggregate, and rounded to the nearest whole ton, the total annual thermal energy load from the industrial parcels on the site is 50 tons. The peak cooling load occurs in the month of January and is 17 tons. The industrial data are summarized in Table 13 below, and are presented with the final residential and commercial load figures, with the total site energy load aggregated.

4.2.4 Total Aggregate Site Load

The final total annual load for the site including residential, commercial, and industrial buildings is 337 tons. The heating peak in January is greater than the cooling peak in July, and totals to 60 tons. The differential between the total annual heating load (247 tons) and cooing load (90 tons) is 1: 2.74 (Table 13).

Table 13 - Total Site Energy Load, Annual and Peak (Tons)

	Annual (tons)			**Peak (**tons)	
	Heating	Cooling	Total	Heating (January)	Cooling (July)
Residential	202	72	274	42	23
Commercial	6	7	13	1	2
Industrial	39	10	50	17	7
Total	247	90	**337 tons**	**60 tons**	32
Heating to Cooling Differential	**2.74x**		**-**	**-**	-

Chapter 5: Discussion

In this chapter, I explain what the key findings from this research suggest for the site's future energy planning and I share limitations and recommendations for the research process and the project site.

5.1 Suitability for UTEN *Design* Phase

The buildings on the site are situated close to one another. There is a large quantity of open space that potentially could be used for borefields, and pump stations and a geoexchange system–the most spatially demanding components of a UTEN. The square footage of the site and the distance along which the main pipe "ambient loop" would be laid are consistent with the range of sizes of other successful UTENs. The annual energy load of 337 tons for 46 buildings totaling 0.9 million cubic feet is well within the realm of many existing thermal energy networks listed in the Building Decarbonization Coalition database (Building Decarbonization Coalition 2025). Table 14 provides a general point of reference for the key figures between the hypothetical project site in Philadelphia and the first *utility* operated TEN in the U.S., located in Framingham MA. The relativity between these two sets of figures cannot be interpreted as a guarantee that a geothermal network would function on the project site. But this comparison, together with Table 1 in the Literature Review, illustrates that the key figures of the project site are within the realm of a functioning UTEN, or other planned TENs.

Table 14 - Project Site Comparison to Existing UTEN

	Project Site	**Framingham, MA**
Buildings w/ Thermal Load	46	36
Total Cubic Feet	~0.9M	1.8M
Total Annual Load	337 tons	375 tons
Thermal loop	~1 mile	~1 mile
Majority sq. footage	Residential	Residential

The 2.74:1 heating to cooling difference is outside the ideal range for a UTEN. The range typically sought by UTEN engineers ranges from a 1:1 balance to a 1:1.5 difference (Aaron Pike 2026). However, at this exploration and planning phase of the research, the 2.74 difference is not prohibitive. This is because neither the 2.74 heating to cooling difference nor the annual load of 337 tons are the final load figures to which the UTEN system would need to be built. This is because UTENs exchange thermal energy between buildings. This has not yet been factored and is typically factored in the design phase of TEN development by using software.

This research was focused on completing steps within phases one and two, *exploration* and *planning,* of the five phases of UTEN development, as categorized by VCTN (Vermont Community Thermal Networks 2024, 63-69). The central inquiry was to determine the technical suitability of the gas replacement project site for advancement to phase three, *design.* A key step in the *design* phase is to "[e]ngineer preliminary system design, including: [p]iping, equipment, and installation costs estimate *(based on user loads, heat sources, and equipment capacities*" and "*preliminary energy analysis and system sizing*") (italics are my emphasis) (Vermont Community Thermal Networks 2024, 66). My research provides the foundational information–*user loads, heat sources, preliminary energy analysis,* and *some of the system sizing*–from which preliminary system design can be completed. The bridge from the foundational data I gathered to the full "preliminary system design" is the use of geothermal design software. An appropriate software program for completing *design* of the project site would be *GLD Premier Version 5.1* (Celsia LLC 2008, Walton 2025). The technical characteristics of the site provide the key information for deciding if the site is generally suitable to advance to the UTEN *design* phase. My results suggest that it is.

5.2 Limitations and Recommendations

I name five limitations of this research and recommendations for future research on UTEN planning and development in Philadelphia neighborhoods.

1. Inquire About Building Future Energy Plans in the *Exploration* Phase

I recommend that future research on UTEN feasibility assess whether there are plans from owners of cooling dominant buildings to expand their operations. I found that the anchor building on the project site—the industrially refrigerated meat distributor at 124 W Venango Street—is expanding its operations, opening a second facility. This building had the largest cooling load on the project site. The results from my research, although preliminary, suggest a greater cooling load could be beneficial to the site heating to cooling balance. An added refrigeration warehouse could help with this. In this case, the company is not planning to build the new facility on the site. Nonetheless, researchers should inquire about these types of future construction plans from building owners, to identify potentially beneficial opportunities to the site.

2. Incorporate the Energy Load from the School Adjacent to the Project Site

I chose not to include the William Cramp Elementary school, located beside the site, in my energy load analysis since I had already identified an anchor institution on the site. However, I recommend future researchers analyze and factor the energy profile of this building into the *planning*. If the preliminary load results from the school are favorable to the load balancing needs on the site, the school could be included in the *design* phase of the feasibility study. Schools also potentially provide other benefits to TENs and can make ideal anchor institutions with their long-term planning administration and large parking lots that can potentially be used for borefields. Schools are sometimes cooling dominant due to high internal heat gains, and provide temporal load diversity—the hours of greatest energy demand are when residential buildings have the least (Jack Dienna 2026). Beyond the potential load balance benefits, replacing gas with clean energy at learning institutions has social benefits: it can remove harmful pollutants and reduce safety risks associated with onsite fossil fuel combustion, and can provide real-world energy education opportunities for students.

3. Find Localized Data for Sharper EEI Savings Estimate

The estimate energy savings figure that I factored (10 percent) that could follow EEIs was a conservative figure derived from a broad literature review (see Methodology chapter). In the *design* phase of TEN development, contractors typically conduct energy audits on buildings to assess insulation and air infiltration. That process is likely to yield the most accurate estimates. Nonetheless, I recommend future researchers search for more localized data for sharper estimates of energy efficiency savings from EEIs.

4. Assess Site Geology and Wastewater Resources

This study does not assess the characteristics of geology directly beneath the site. Initial information on the geology beneath the site can be useful for planning borehole drilling.

I also do not assess the presence of thermal resources from water on the site. As such, there could be barriers or opportunities pertaining to the site geology and thermal resources for which this study does not account. Wastewater, either “black” (sewage) or “gray” (non-sewage) can be a source of thermal energy that could contribute to UTENs (National Grid 2024). In the case of this project site, the presence of more heat resources could plausibly help lower the differential between heating and cooling on the site. I recommend future researchers assess the geological characteristics beneath the site and the presence of wastewater resources on and around it.

5. Obtain Load Data Directly from Utility Statements

My energy load figures are derived from a mix of methods including estimate calculations based on HVAC industry formulas I used, two energy models I completed, and four utility statements I obtained. The results from these methods satisfy the goal of this research, to assess how technically suitable the site is for advancing to the UTEN design phase. However, I recommend future researchers pursue approaches that from the outset yield direct energy load data. This could reduce time spent on data analysis and increase the precision of metrics. The most straightforward way to gather load data is by analyzing the utility statements of the buildings being assessed—if one can access them. PGW, and the electric utility, are best positioned to do this. I recommend PGW take a lead in advancing UTEN *exploration, planning*, and where suitable, UTEN *design*, utilizing the informational resources at its disposal to produce full feasibility studies. I expand upon this recommendation in the Conclusion.

5.3 Recommendation for PGW Gas to Geothermal Strategy

Here, I recommend a fuller strategy for PGW to carry out UTEN feasibility studies in low-income Philadelphia neighborhoods slated for gas main replacement. This recommendation extends beyond the strict findings of the central methods of this thesis.

Third-party research on neighborhood gas-to-networked geothermal feasibility, unless partnered directly with the active gas utility, can quickly come up against informational constraints. This was my experience in this graduate research process. These constraints were not paralyzing; I was able to gather dependable data and generate results that provide insight on my research question. The gas utility however, has direct access to utility data, energy industry expertise, and financial resources. PGW particularly has often stated its goals to protect safety, reliability, affordability, and sustainability (Phillips 2023). Relative to third party researchers, PGW is well-positioned to support the advance of UTEN feasibility studies. Conceivably, the utility could redirect some of the $8 billion projected to fulfill its gas-to-gas main replacement plans (see Introduction and Literature Review) to increase gas-to-geothermal feasibility studies.[2] The final recommendation of this thesis is for PGW to work proactively with other city agencies to assess UTEN feasibility and where fitting, install networks, in the lowest-income Philadelphia neighborhoods, in a way that simultaneously tackles energy transition, social equity challenges, and Philadelphia's vacant lot dilemma.

In 2019, the City of Philadelphia estimated that there were over 40,000 vacant properties across the city, accounting for 5 percent of the city's acreage (Philadelphia Land Bank 2019). Roughly 65 percent of these properties are open lots (ibid). These vacated, abandoned, or tax

[2] In August 2022, $500,000 was allocated in PGW's operating budget for the completion of a geothermal feasibility study (Abby Weiss 2026). In October of 2025, PGW announced that Alderson Engineering was selected to conduct the study (ibid). Over three years have passed since the funds for study were approved. The study has not yet been publicly shared as of this writing.

delinquent properties increase blight, pose hazards, reduce the value of nearby property, and drain what could otherwise be tax revenue for the city (Philadelphia Land Bank 2019). This has cost the city tens of millions of dollars in unpaid property taxes and maintenance cost of untended properties (Econsult Corporation 2010). Nearly one-quarter of the 40,000 vacancies are publicly owned. The Philadelphia Land Bank works to transition unproductive publicly owned vacant properties into productive use, but it has been a slow, painful process (Blumgart and Walsh 2025).

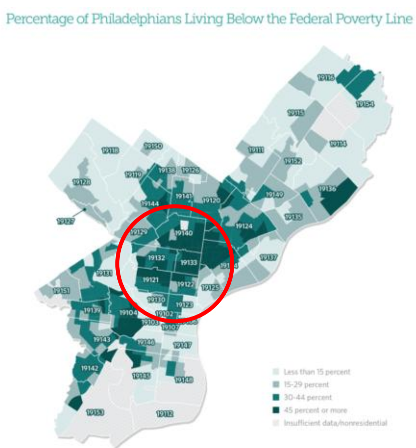
PGW could work with the Philadelphia Land Bank to transform blighted, tax-delinquent, vacant lots towards use for UTEN development. The most prominent uses would likely be ground space for bore fields, ground loops, pump stations, or otherwise for the expansion of existing businesses or the placement of new ones, that have complementary energy load. The project site that this study assesses has at least five vacant lots, totaling over 38,000 square feet. This characteristic is not unique to the project site.

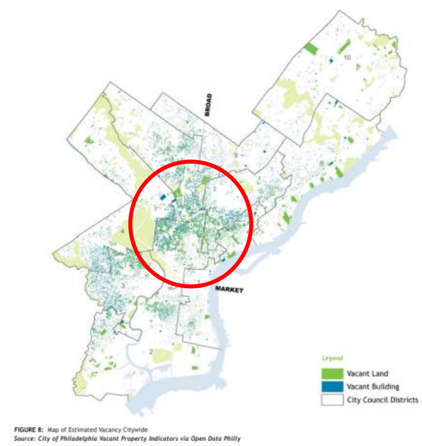
PGW could begin a dedicated assessment of UTEN feasibility in the lowest income neighborhoods in the city, which are in the zip codes 19104, 19140, 19133, and 19134 (Eichel and Howell 2017). These locales are densely populated with varying mixes of residential, commercial, and some industrial properties. These areas of the city represent the highest concentrations of poverty (Figure 5). They entail high concentrations of vacant properties (Figure 6); specifically, vacant properties that are publicly owned (Figure 7). There are already tens of gas-to-gas pipeline replacement projects in this area that could be assessed for UTEN feasibility (Figure 8).[3] Figures 5-8 provide a crude snapshot of the overlay of these social,

[3] The projects illustrated in Figure 8 are current replacement projects already underway, or those breaking ground in the next two years. This illustrates a missed opportunity. PGW does not provide a map of the proposed replacement projects through to 2058. That information would be needed to analyze overlay with the other characteristics illustrated in figures 2-4 and identify opportunities for the future.

environmental, and urban development needs and potential opportunity. Together, these dynamics represent a concoction of social, financial, and energetic need by residents and potential cheap land opportunity which could help reduce the upfront capital costs that frequently pose an obstacle to UTEN development.

Figure 6 - Concentration of Poverty (left)
Figure 7 - Concentration of Vacant Properties (right)

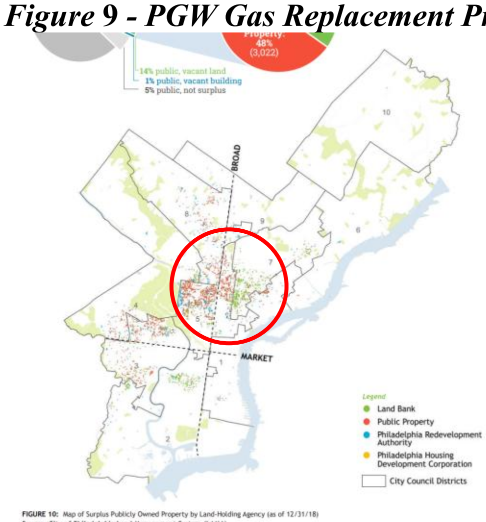


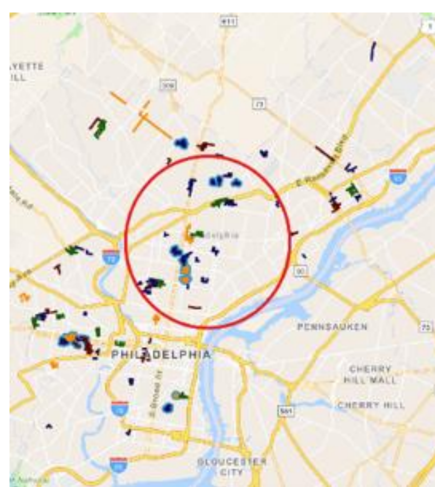


Source: Eichel and Howell 2017
Lighter green: ≥20% residents below poverty line
Darker green: ≥40% residents below poverty line

Source: City of Philadelphia 2016

Figure 8 - Concentration of Municipally Owned Vacancies (left)
Figure 9 - PGW Gas Replacement Project Sites (right)





Source: (ibid)

Source: PGW Pipeline Improvement Map

(Red spheres added by author to highlight overlap.)

Philadelphia Gas Works should launch UTEN pilot programs to help transition Philadelphia's poorest communities off of gas and the whole city towards its 2050 climate goal. Doing so can help avoid investments in new gas mains that may have to become stranded gas assets, it could support a transition for PGW utility workers, advance clean energy access for low-income neighborhoods, transfer vacant land into productive use, cut GHG emissions, improve air quality, and contribute to the scaling geothermal, helping to unleash the vast potential of the heat beneath our feet.

Conclusion

To achieve its 2050 climate goals and address energy equity, the City of Philadelphia will need to reduce gas emissions, expand clean energy alternatives, and direct opportunities to the most economically disadvantaged communities. In this research, I sought out to explore if geothermal networks—renewable energy systems that exchange thermal energy between the earth and connected buildings to satisfy heating and cooling end uses—could be a solution for low-income communities. Specifically, I assessed the technical suitability of a project site in the Fairhill neighborhood of North Philadelphia for advancement to the *design* phase of the utility thermal energy network development process. The site I assessed is one of dozens that was slated for replacement of old gas mains with new gas mains through to the year 2058, by the municipal gas utility, PGW. These gas replacement projects present opportune intervention points for PGW to consider clean energy alternatives, rather than default to new gas infrastructure that will cost billions of dollars. This study provides lessons that can be applied to dozens of Philadelphia neighborhoods where gas main replacement is planned but not yet initiated, and for which PGW could pursue the gas-to-geothermal path.

I focused this research on steps within the earliest phases of UTEN development—the *exploration* and the *planning* phases. The data I collected lays the groundwork for and helps determine the site suitability to advance the site to the third, *design,* phase of UTEN development. The data that emerged in my research results, when compared to key data from other existing or proposed TENs in the U.S., I argue, are well within the realm of projects that have advanced to the *design* phase. The site is comprised of 46 residential, commercial, and industrial buildings with thermal load, and thousands of square feet of open space for UTEN system equipment and borefields. The site had been slated for gas main replacement and is in an economically disadvantaged community that otherwise is unlikely to access clean energy and home retrofits that often accompany TEN development. There is an ideal anchor institution with high cooling load located on the site, and another potential anchor institution adjacent to it.

I share four recommendations for how future researchers could improve upon this research process, and a central fifth recommendation that PGW take a lead in supporting the advancement of UTEN feasibility studies in Philadelphia. I recommend researchers during the *exploration* and *planning* phases of UTEN development ask building owners' about future development plans—not only present conditions—in order to identify any information about forthcoming load. I also recommend researchers obtain localized data to yield sharper estimates of load reductions that might result from energy efficiency interventions in buildings on the site. Similarly, I name the value in completing assessments of the thermal resources from wastewater on the site. I recommend future researchers incorporate the nearby school, an additional potential anchor, into the energy load analysis for this site.

The entity that is best equipped to advance studies to support a managed, phased energy transition is the gas utility itself. PGW has energy use data at its disposal, the full map of projected gas replacement projects, millions of dollars in rate-payers revenue that it could allocate to clean energy exploration, piloting, and scaling, and an interest in minimizing future stranded gas assets and employee layoffs. I finish with a fifth recommendation that the utility take the lead in assessing and implementing UTEN in lieu of new gas infrastructure, starting with the lowest income neighborhoods slated for gas replacement. Done right, this could advance Philadelphia towards its climate goals and bring energy equity to Philadelphia's most burdened communities.

Appendices

Appendix A – Unit Conversion Formulas & Monthly Load Percentages

Energy Conversion Formulas

Conversion Formulas	
CCF to BTU	1 CCF = 103,700 Btu
KWH to BTU	Btu = kWh × 3412.14163312794
BTU to Tons	Tons = Btu / 12,000

Monthly Load Percentages

Residential -- Cooling Percentages

Monthly Estimate Cooling Load and Summer Peak			
Month	**Electricity Usage** (kWh / hh) *	**Percentage**	**Monthly load** (tons) **
Jan	0.02	0.32	64.57
Feb	0.02	0.32	64.57
Mar	0.02	0.32	64.57
Apr	0.02	0.32	64.57
May	0.30	5.66	1,159.96
Jun	0.90	16.98	3,479.87
Jul (peak)	**1.70**	**32.07**	**6,573.08**
Aug	1.40	26.41	5,413.13
Sep	0.70	13.21	2,706.56
Oct	0.20	3.77	773.30
Nov	0.02	0.32	64.57
Dec	0.02	0.32	64.57
Annual total	5.30	100.00	**20,493.32**

**Source: Energy Information Agency (EIA) Residential Energy Consumption Survey. Residential Monthly Household Site Electricity Consumption Avgs (per household) for 2020, Pennsylvania.*
***Based on annual residential cooling load of 80 tons.*

Residential -- Heating Percentages

Month	Gas Usage, National (MMBtu)*	Percentage	Monthly load (tons)**
Jan (peak)	**12.00**	**20.98**	**50,062.14**
Feb	10.80	18.88	45,055.93
Mar	6.90	12.06	28,785.73
Apr	5.20	9.09	21,693.59
May	2.30	4.02	9,595.24
Jun	0.20	0.35	834.37
Jul	0.10	0.17	417.18
Aug	0.00	0.00	0.00
Sep	0.30	0.52	1,251.55
Oct	2.10	3.67	8,760.87
Nov	5.30	9.27	22,110.78
Dec	12.00	20.98	50,062.14
Annual total	57.20	100.00	**238,629.53**

**Source: EIA Residential Energy Consumption Survey. Residential Monthly Household Site Natural Gas Space Heating Consumption Avgs (per household) for 2020, Pennsylvania.*
***Based on annual residential heating load of 225 tons*

Commercial and Industrial – Cooling Percentages

Month	Electricity*	Percentage
Jan	402.00	8.22
Feb	368.00	7.52
Mar	376.00	7.68
Apr	366.00	7.48
May	397.00	8.11
Jun	431.00	8.81
July (project site peak month)	470.00	**9.61**
Aug (co mmercial peak month)*	474.00	9.69
Sep	430.00	8.79
Oct	408.00	8.34
Nov	377.00	7.70
Dec	394.00	8.05
Annual total	**4,893.00**	100.00

**Source: EIA Commercial Sector Energy Consumption survey, which shows monthly electricity consumption patterns (kBtu) for buildings with similar use profiles as some of the Commercial and Industrial parcels on my site. Electricity as proxy for cooling.*

***The national peak month is August for population of commercial buildings from which these percentages are derived. But the residential parcels on my site account for the bulk of thermal demand on the project site. When I factor the residential summer/cooling peak it far outweighs the aggregate of other–Industrial and Commercial–summer/cooling peaks. Thus, the aggregate peak month for my site is July.*

Commercial and Industrial – Heating Percentages

Month	**Gas Usage** (tBtu)*	**Percentage**
Jan	564	**16.33**
Feb	432	**12.51**
Mar	361	**10.45**
Apr	257	**7.44**
May	183	**5.30**
Jun	159	**4.60**
Jul	152	**4.40**
Aug	154	**4.46**
Sep	160	**4.63**
Oct	220	**6.37**
Nov	328	**9.50**
Dec	483	**13.99**
Annual Total	3453.00	100.00

**Source: EIA Commercial Sector Energy Consumption. Gas as proxy for heating.*
*** Although this factors gas consumption for cooking needs, not just heating, changes in gas consumption are predominantly associated with more space and water heating as the seasons change. Furthermore, I applied percentages from these estimates, then applied to my actual site's load figures.*

Appendix B - Residential Load Calculations

Residential Buildings - Key Characteristics			
	Quantity	**Total Sq. Ft.**	**Avg Sq. Ft.**
Pre 1940	31	39,902	1,287
1940-1979	9	13,985	1,554
Total with Thermal Load	**40**	**53,887**	**1,347**

Annual Residential Load Calculations

(See Appendix A for Monthly and Peak Residential Load Calculations.)

Total Residential Thermal Load (Cooling & Heating)		
	Buildings	**Total Sq. Ft.**
Pre 1940 Total	31	39,902
1940-1979 Total	9	13,985
Total Res Sq Footages		53,887
Avg sq ft / household		1,347
Estimate total annual heating load (Btu)		2,694,350
...(tons)		225
Tonnage after EEIs		**202**
Estimate total annual cooling load (Btu)*		960,000
...(tons)		80
Tonnage after EEIs		**72**
Total tonnage before EEIs**		**305**
Avg energy savings from EEIs		10%
Total Estimated Tonnage		**274**

** Source: Cooling would be 2 tons (24,000 btu) per household. This is based on Cooling table, row "Zone 4" subrow "1050-1350 sq ft," in source https://inspectapedia.com/heat/Heating-Cooling-Climate-Zone-BTU-Requirements.php*

***Energy efficiency interventions. See final section of Methodology for how EEI figure was derived.*

Appendix C - Commercial Load Calculations

Location	Use	Gross Floor Area, Sq Ft	Unit	Heating		Cooling	
				Annual	Peak January	Annual	Peak July
119 E Tioga*	Restaurant: gas range, space and water heating	917	CCF	0.61	0.10	n/a	n/a
			BTU	63,074	10,302	19,100,000	1,834,660
			HDD; CDD**	*already factored*	*already factored*	75,226.47	16,678.73
			Tons	**5.26**	**0.86**	**6.27**	**1.39**
126 E Tioga	Corner store: gas range	1,061	CCF	n/a	n/a	n/a	n/a
			BTU	n/a	n/a	n/a	n/a
			Tons	n/a	n/a	n/a	n/a
135 E Tioga	Garage	1,227	CCF	0	0	0	0
			BTU	0	0	0	0
			Tons	0	0	0	0
137 E Tioga	Garage	1,227	CCF	0	0	0	0
			BTU	0	0	0	0
			Tons	0	0	0	0
139 E Tioga	Garage	1,227	CCF	0	0	0	0
			BTU	0	0	0	0
			Tons	0	0	0	0
141 E Tioga	Community center: sparse gas range, hot water	2,751	CCF	431.00	24.00	n/a	n/a
			BTU	44,694,700.00	2,488,800.00	3,681,700.82	303,680.61
			HDD ; CDD	8,026.49	2,572.40	14,500.59	2,760.73
			Tons	**0.67**	**0.21**	**1.21**	**0.23**
TOTAL	SQ. FT.	**8,410**					

	Load		**5.93**	**1.07**	**7.48**	1.62
	Annual Load (Tons)		**13.40**			

**119 E Tioga has commercial first floor use and residential second floor. The energy modeling accounts for only the first-floor square footage. The second, residential floor is factored into the Residential energy load estimates.*
***HDD: Heating Degree Day; CDD: Cooling Degree Day.*

119 E TIOGA ST

119 E Tioga: Monthly Cooling Load*			
*Based Off of Annual Cooling Load (kBtu)***			*19,100 kBtu*
Month	**Electricity Usage, National*****	**Percentage**	**Monthly Cooling Load**
Jan	402.00	8.22	1,569.22
Feb	368.00	7.52	1,436.50
Mar	376.00	7.68	1,467.73
Apr	366.00	7.48	1,428.69
May	397.00	8.11	1,549.70
Jun	431.00	8.81	1,682.42
Jul (project site peak month)	470.00	9.61	**1,834.66**
Aug (Commercial peak month)	474.00	9.69	1,850.28
Sep	430.00	8.79	1,678.52
Oct	408.00	8.34	1,592.64
Nov	377.00	7.70	1,471.63
Dec	394.00	8.05	1,537.99
Annual Total	4,893.00	100.00	**19,100.00**

**Source: I used a different source to determine the monthly load distribution at 119 E Tioga, than I used for other Commercial and Industrial load distribution, as illustrated in Appendix A. Here I used the EIA Commercial Sector Energy Consumption survey, which shows monthly electricity consumption patterns (kBtu) for buildings with similar use profiles as 119 E Tioga specifically.*
***Source: CBECS energy consumption data for Food Service category of Commercial buildings. https://www.eia.gov/consumption/commercial/pba/food-service.php*
****Electricity as proxy for cooling.*

119 E Tioga: Annual Heating Load			
*Based Off of Peak Heating Load of 63,074 Btu***			
Month	**Gas Usage** (tBtu)*	**Percentage**	**Monthly Cooling Load**
Jan	564	16.33	10,302.22
Feb	432	12.51	7,891.06
Mar	361	10.45	6,594.15
Apr	257	7.44	4,694.45
May	183	5.30	3,342.74
Jun	159	4.60	2,904.35
Jul	152	4.40	2,776.48
Aug	154	4.46	2,813.02
Sep	160	4.63	2,922.62
Oct	220	6.37	4,018.60
Nov	328	9.50	5,991.36
Dec	483	13.99	8,822.65
Annual Total	3,453.00	100.00	**63,073.70**

**Source: EIA Commercial Sector Energy Consumption. Gas as proxy for heating. Same source as Commercial and Industrial Heating Load Percentages in Appendix A.*
***Source: Derived from the heat loss energy modeling I completed.*

119 E Tioga: Annual Heating Load (Btu)		
*Based Off of Peak (Jan) Heating Load of 63,074 Btu**		
Month	**Percentage of Annual Gas Usages****	**Distribution of Load (kBtu)**
Jan	16.33	21,116.00
Feb - Dec	83.67	108,192.02
Annual Total	100	**129,308.02**

Source: Derived from the heat loss energy modeling I completed.

HDD and CDD for 119 E Tioga		
Annual		
HDD (2025) to 68F	2025-01-01	2025-12-31
	already calculated in model	
CDD (2025) to 78F	2025-01-01	2025-12-31
	253.9	
Peaks		
HDD Peak Month (Jan 2025) to 68F	2025-01-01	2025-01-31
	already calculated in model	
CDD Peak Month (July 2025) to 78F	2025-07-01	2025-07-31
	110.5	

141 E TIOGA STREET

141 E Tioga: Electric Utility (PECO) Usage Data for 2024 (kWh)				
	Floor 1	**Floor 2**	**Floor 3**	**Total**
Jan	51	26	1	**78**
Feb	57	2	0	59
Mar	59	3	2	64
Apr	76	24	22	122
May	72	9	18	99
Jun	66	13	7	86
Jul	72	8	9	**89**
Aug	*65*	*4*	*10*	79
Sep	*75*	*8*	*12*	95
Oct	72	11	11	94
Nov	84	11	12	107
Dec	82	10	15	107
Annual Total	831	129	119	**1,079**

Source: Data pulled from electric utility statement shared by building operations manager.

141 E Tioga: Gas Utility (PGW) Usage Data	
Month	**CCF**
January	24
February	21
March	222
April	19
May	19
June	16
July	17
August	18
September	16
October	18
November	18
December	23
Total Annual	431
Avg. Monthly	35.91666667

Source: Data pulled from gas utility statement shared by building operations manager.

Appendix D – Industrial Load Calculations

	Location	Use	Gross Floor Area, Sq Ft	Unit	Fossil thermal demand (Heating Load)		Electric Thermal Demand (Cooling Load)	
					Annual	Peak January	Annual	Peak July
1	**100-110 W Venango**	Supply shack. No thermal demand.	817	CCF	0	0	0	0
				KBTU	0	0	0	0
				Tons	0	0	0	0
2	**129-141 W Glenwood**	Scrapyard. No thermal demand	59,308	CCF	0	0	0	0
				KBTU	0	0	0	0
				Tons	0	0	0	0
3	**143-145, 153, W Glenwood**	Metal repair shop. 3/12 month thermal demand.	3,011	CCF	294	112	0	0
				BTU	30,456,690	11,614,400	0	0
				Divided by HDD; CDD (1)	18,443	857	0	0
				Tons	1.5	1.1	0	0
4	**147-161 W Glenwood**	Warehouse. 3/12 month thermal demand.	14,954	CCF	-	-	0	0
				BTU	412,100	157,000	0	0
				Divided by HDD; CDD (1)	*already factored*	*already factored*	0	0
				Tons	34	13	0	0
5	**124 W Venango St**	Wholesale meat warehouse & small office. Large cooling load.	12,401	CCF	*1,750*	*285,838*	-	
				BTU	181,475,000	29,641,442	1,552,524,443	149,128,651
				Divided by HDD; CDD (2)	38,356	30,637	125,824	85,441
				Tons	3	3	10	7

	TOTAL		**90,491.00**					
		LOAD			**39.07**	**16.77**	**10.49**	7.12
		ANNUAL LOAD (Tons)			**49.56**			

(1) HDD was already factored into the energy model. This location does not have space cooling.
(2) HDD: set to 68F and = 4,731.3. CCD set to 25F (the avg of the refrigeration/freezer) and = 12,338.9.

147-161 W GLENWOOD AVE

147-161 W Glenwood: Monthly Heating Load (kBtu)			
Based Off of Annual Heating Load (in kBtu) =*			*412*
Month	**Percentages of Annual Load**	**Percentage Scaled to 3 Month Usage***	**Distribution of Load (kBtu)**
Dec	13.99	32.66	135
Jan	16.33	**38.13**	**157**
Feb	12.51	29.21	120
March - Nov	0.00	0.00	0
Annual Total	42.83	100.00	**412**

**Annual heating load derived from 147-161 W Glenwood energy model (Appendix G).*
***This parcel has a heating load for only 3 months of the year: December, January, and February.*

Key Utility Statement Data provided from Owner of 147-161 W Glenwood

147-161 W Glenwood	
Winter only	13 weeks
Ops: 8hrs/day, 5 days/wk =	40 hours
Days of heating. 40 hours/week	520 hours heating/year
Area	14,954
Height; cubic area	24', 358,896

Design Day (temp setting):	55F-14F = 41F
HDD	1,651.40

143-145, 153 W GLENDWOOD AVE

143-145, 153 W Glenwood Ave Data from PGW Statement: 1/8/25 - 2/6/25	
Dec 2024	Usage in CCF: 71.0
Jan 2025	Usage in CCF: 112

Source: Derived from utility statement provided by owner.

143-145, 153 W Glenwood Ave: Monthly Heating Load		
Based off of Peak Load (CCF) =*		*112*
Annual Load (CCF):**		**685.69**
Month	**Percentage of Annual Load**	**Percentage Scaled to 3 Month Usage**
Dec	13.99	95.91
Jan (peak)	**16.33**	**112.00**
Feb	12.51	85.79
Annual Total (3 month)	42.83	**293.70**
March - Nov (hypothetical)	57.17	**-**
March - Nov (actual)	0	-

**Derived from utility statement from 143-145, 153 W Glenwood Ave for January (2025).*
***Source: EIA Commercial Sector Energy Consumption survey shows that January accounts for an estimated 16.33% of annual gas usage for buildings with similar use profiles.*
I.e. 112/x = 16.33/100.

124 W VENANGO STREET

124 W Venango St	
QUESTION	ANSWER OPERATIONS MANAGER
For 2024, Electric:	455,000
...Gas:	1,750
What % of the total sq footage at 124 W Venango is refrigerated space? (An estimate is fine: 40%... 60%.. 80%?)	75% of the square footage is refrigerated.
At what temp is the refrigerated / freezer section(s) kept?	15% of the square footage is used for low temp (less than 10 degrees Fahrenheit) while the remaining 60% is used for medium temp (32 degrees Fahrenheit to 40 degrees Fahrenheit).
Is a steady temperature maintained, or are the temperature settings adjusted?	The set points are not changed (steady temp targets year round).
If adjusted, what is the temperature range? And can you provide roughly what percentage of time the system is at the each of the different temperatures?	N/A
Does the refrigeration run 24/7/365?	Yes
The refrigeration system is run off electric, not combustion fuels?	Yes
Do you happen to know the name and model of the refrigeration system?	There are a variety of Kramer and Trenton refrigeration units in the building.

Source: Info from Brian Gitlin, Operations Head, via email exchange.

124 W Venango: Monthly Heating Load			
*Based Off of Annual Heating Load 181,475,000 Btu **			
Month	**Gas Usage, National** (tBtu)**	**Percentage**	**Monthly Heating Load** (kBtu)
Jan (peak)	564	16.33	**29,641,442**
Feb	432	12.51	22,704,083
Mar	361	10.45	18,972,625
Apr	257	7.44	13,506,827
May	183	5.30	9,617,702
Jun	159	4.60	8,356,364
Jul	152	4.40	7,988,474
Aug	154	4.46	8,093,585
Sep	160	4.63	8,408,920
Oct	220	6.37	11,562,265
Nov	328	9.50	17,238,286
Dec	483	13.99	25,384,427
Annual Total	3453.00	100.00	**181,475,000**

**Source: The property owner emailed the annual gas consumption figure, based off of gas utility statements.*

***Source: EIA Commercial Sector Energy Consumption survey shows monthly gas consumption for buildings with similar use profiles. Gas as proxy for heating.*

124 W Venango: Monthly Estimates for *Cooling* Load			
*Based Off of Annual Cooling Load: 1,552,524,443 Btu**			
Month	**Electricity Usage, National****	**Percentage**	**Monthly Cooling Load*****
Jan	402	8.22	127,552,591
Feb	368	7.52	116,764,561
Mar	376	7.68	119,302,921
Apr	366	7.48	116,129,971
May	397	8.11	125,966,116
Jun	431	8.81	136,754,146
Jul (project site peak month)	470	9.61	**149,128,651**

Aug (Industrial peak month)	474	9.69	150,397,831
Sep	430	8.79	136,436,851
Oct	408	8.34	129,456,361
Nov	377	7.70	119,620,216
Dec	394	8.05	125,014,231
Annual Total	4,893	100.00	**1,552,524,443**

**Source: The property owner emailed the annual electricity consumption figure, 455,000kWh which = 1,552,524.44 Btu.*
***Source: EIA Commercial Sector Energy Consumption survey shows monthly electricity consumption patterns (kBtu) for buildings with similar use profiles. Electricity as proxy for cooling.*
****The nonthermal electric load (lighting) has not been disaggregated from the thermal electric (cooling). The figures are still useful for the purposes of this energy load analysis, because non thermal electric should account for a relatively small portion of the building's electric load: 75% of the square footage of 124 W Venango is for 24/7 refrigeration and freezer space; 25% of the building is office space that operates only 40 hours / week; a large portion of that 25% is for office space cooling.*

Heating Degree Day and Cooling Degree Day Calculations

HDD and CDD for 124 W Venango (2024)		
Annual		
HDD to 68F		
2024-01-01	2024-12-31	**4731.3**
CDD to 25F		
2024-01-01	2024-12-31	**12338.9**
Peak		
HDD Peak Month to 68F		
2024-01-01	2024-01-31	**967.5**
CDD Peak Month to 25F		
2024-07-01	2024-07-31	**1745.4**

Appendix E – Heat Loss Energy Models

Heat Loss Energy Model formula derived from:
T. Agami Reddy; Jan F. Kreider; Peter S. Curtiss; Ari Rabl. Heating and Cooling of Buildings: Principles and Practice of Energy Efficient Design. Taylor & Francis Group, LLC, 2017.

147-161 W GLENWOOD AVE – Heat Loss Energy Model 1 of 2

147-161 W Glenwood Energy Load Model Houston Thesis.pdf

Patrick Houston

UEP Thesis

August 2025

Energy Modeling for Peak Heating Load at 147-161 W Glenwood Ave

Problem: Determine the Heating Load of a Warehouse with the given conditions

Approach: Use the peak heating load calculation to determine the heating needs. To use this calculation we will need to determine the heat loss, heat gains, and temperature difference is design conditions.

$$\dot{Q}_{h,\max} = K_{tot}(T_i - T_o) - \dot{Q}_{gain}$$

Determining Heat Loss:

K_{tot} = Heat Loss through all Walls and Roof

WALL 1:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U(k) = Overall heat transfer coefficient (BTU/hr * ft^2 * °F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Warehouse Temp – DesignDay Temp = 55 – 14 = 41°F

U = Stud Wall + Metal Siding

U_{Wall1} 2 x 4 inch Wood Studs placed 16 inches apart

$$\left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

A = Area of wall = Wall length multiplied by height

50 feet x 30 feet = 1500 ft^2

$$Q = 0.597 \frac{BTU}{hrft^2} * 1500ft^2 * (41°F) = 12{,}537\ BTU/hr$$

WALL 2:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Warehouse Temp – DesignDay Temp = 55 – 14 = 41°F

U = Stud Wall + Metal Siding

U_{Wall1} 2 x 4 inch Wood Studs placed 16 inches apart

$$\left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

U_{Door} =0.43 BTU/hrft2

A_{doors} = (10' x 10') + (7' x 3') + (15' X 20') = 100 + 21 + 300 = 421ft^2

A_{wall} = Area of wall = Wall length multiplied by height – Area of Doors

(171' x 30') – 421ft^2 = 4709 ft^2

$$Q_{doors} = 0.43 \frac{BTU}{hrft^2} * 421ft^2 * (41°F) = 7422\ BTU/hr$$

$$Q_{wall} = 0.597 \frac{BTU}{hrft^2} * 4709ft^2 * (41°F) = 115{,}262\ BTU/hr$$

$$Q_{tot} = Q_{wall} + Q_{door} = 7{,}422 \frac{BTU}{hr} + 115{,}262 \frac{BTU}{hr} = 122{,}685\ BTU/hr$$

WALL 3:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Warehouse Temp – DesignDay Temp = 55 – 14 = 41°F

U = Stud Wall + Metal Siding

U_{Wall1} 2 x 4 inch Wood Studs placed 16 inches apart

$$\left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

A_{wall} = Area of wall = Wall length multiplied by height

(62' x 30') = 1860 ft^2

$$Q_{wall3} = 0.43 \frac{BTU}{hrft^2} * 1860ft^2 * (41°\text{F}) = 32{,}792\ BTU/hr$$

WALL 4:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)

- ΔT = Temperature difference across the wall (°F)

ΔT = Warehouse Temp – DesignDay Temp = 55 – 14 = 41°F

U = Stud Wall + Metal Siding

U_{Wall1} 2 x 4 inch Wood Studs placed 16 inches apart

$$\left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

A_{wall} = Area of wall = Wall length multiplied by height

(179' x 30') = 5,370 ft^2

$$Q_{wall\ 4} = 0.43 \frac{BTU}{hrft^2} * 5370ft^2 * (41°\text{F}) = 94{,}673\ BTU/hr$$

ROOF:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Warehouse Temp – DesignDay Temp = 55 – 14 = 41°F

U = Roof Membrane + Metal Roofing

U_{Wall1} 2 x 4 inch Wood Studs placed 16 inches apart

$$\left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

A_{roof} = Area of roof = (50*160) + (19*50/2) = 8475ft^2

$$Q_{roof} = 0.43 \frac{BTU}{hrft^2} * 8475ft^2 * (41°\text{F}) = 149{,}414\ BTU/hr$$

Total Heat Loss:

$$Q_{total} = Q_{wall\,1} + Q_{wall\,2} + Q_{wall\,3} + Q_{wall\,4} + Q_{roof}$$

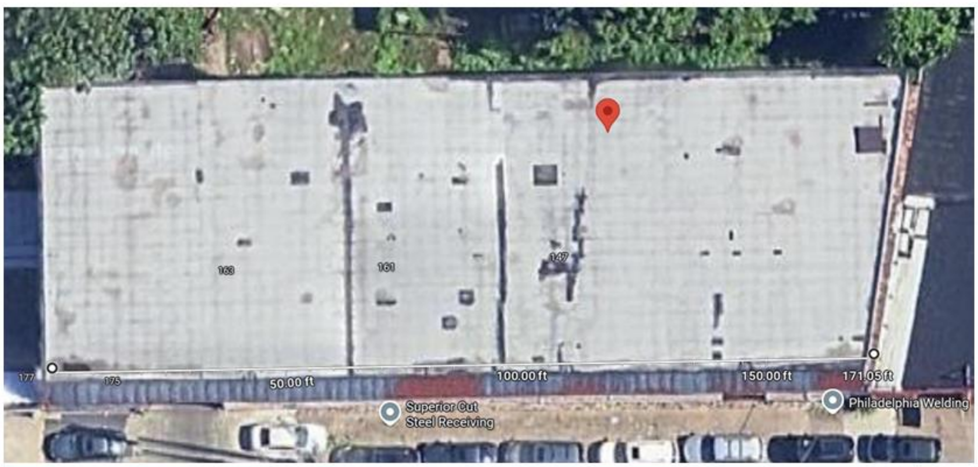
$$Q_{total} = 12{,}537\frac{BTU}{hr} + 122{,}685\frac{BTU}{hr} + 32{,}792\ BTU/hr + 94{,}673\ BTU/hr + 149{,}414\ BTU/hr$$

= 412,101 BTU / hr

Total Energy used for heating:

Amount of hours heating is used in a year: 520 hours

$$520\ hrs * \frac{412{,}101\ BTU}{hr} = 214{,}292{,}520\ BTU = 214.3\ MBTUs\ used\ annually\ for\ heating\ the\ warehouse$$



119 E TIOGA STREET – Heat Loss Energy Model 2 of 2

119 E Tioga Restaurant Energy Load Model Houston Thesis.pdf

Patrick Houston

UEP Thesis

August 2025

Energy Modeling for Peak Heating Load at 119 East Tioga

Problem: Determine the Heating Load of a restaurant with the given conditions

Approach: Use the peak heating load calculation to determine the heating needs. To use this calculation we will need to determine the heat loss, heat gains, and temperature difference given design conditions.

9.3 Design Heating Load Calculation Procedure

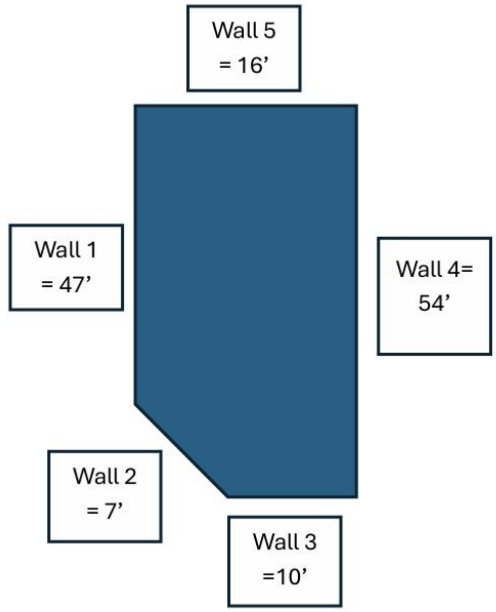
Since the coldest weather may occur during periods without solar radiation, it is advisable not to rely on the benefit of solar heat gains when calculating peak heating loads (unless the building contains long-term storage). If the indoor temperature T_i is constant, a static analysis is sufficient, and the calculation of the peak heating load $\dot{Q}_{h,\max}$ is very simple: Find the design heat loss coefficient K_{tot}, multiply by the design temperature difference $(T_i - T_o)$, and subtract the internal heat gains known to occur during the coldest period:

$$\dot{Q}_{h,\max} = K_{tot}(T_i - T_o) - \dot{Q}_{gain} \quad (9.5)$$

$\dot{Q}_{h,\max} = K_{tot}(T_i - T_o) - \dot{Q}_{gain}$ **= Calculation of the peak heating load**

Ktotal = Heat loss coefficient (a measure of how well the building loses heat; dependent on building materials, insulation, brick, windows, doors). Ktot = Sum of all the U*Areas

Determining Heat Loss:



119 E Tioga St

WALL 2 (Wall 1 calculation is below):

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U(k) = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Restaurant Temp – Design Day Temp = 70 – 14 = 56°F

U_{wall} = Brick and Mortar wall + Gypsum Board + Framing

Udoor = Door

U_{Wall2} : Brick and Mortar

$$k_{brick\ and\ mortar} = 0.347 \frac{BTU}{hr} ft2$$

U_{Wall2} : 2 x 4 inch Wood Studs placed 16 inches apart

$$k_{wood\ studs} = \left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

U_{Wall2} : Gypsum Board

$$k_{gypsum\ board} = 0.0982 \frac{BTU}{hr} ft2$$

$$k_{brick\ and\ mortar} + k_{wood\ studs} + k_{gypsum\ board} = 0.0982 + 0.597 + 0.347 = 1.0422$$

U_{Door} = 1.3 BTU/hrft2

A_{doors} = (6' x 3') = 18ft^2

A_{wall2} = Area of wall = Wall length multiplied by height – Area of Doors

(8' x 7') – 18 ft^2 = 38 ft^2

$$Q_{doors} = 1.3 \frac{BTU}{hrft^2} * 18\ ft^2 * (56°\text{F}) = 1310.4\ BTU/hr$$

$$Q_{wall} = 1.0422 \frac{BTU}{hrft^2} * 38\ ft^2 * (56°\text{F}) = 2{,}217.8\ BTU/hr$$

$$Q_{tot} = Q_{wall} + Q_{door} = 1310.4 \frac{BTU}{hr} + 2{,}217 \frac{BTU}{hr} = 3{,}527.4\ BTU/hr$$

WALL 1:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Restaurant Temp – DesignDay Temp = 70 – 14 = 56°F

U_{wall} = Brick and Mortar wall + Gypsum Board + Framing

Udoor = Door

U_{Wall1} : Brick and Mortar

$$k_{brick\ and\ mortart} = 0.347 \frac{BTU}{hr} ft2$$

U_{Wall1} : 2 x 4 inch Wood Studs placed 16 inches apart

$$k_{wood\ studs} = \left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

U_{Wall1} : Gypsum Board

$$k_{gypsum\ board} = 0.0982 \frac{BTU}{hr} ft2$$

$$k_{brick\ and\ mortar} + k_{wood\ studs} + k_{gypsum\ board} = 0.0982 + 0.597 + 0.347 = 1.0422$$

U_{window} = 0.8 BTU/hrft2

A_{window} = (2' x 4') = 8ft^2

A_{wall} = Area of wall = Wall length multiplied by height – Area of Doors

(8' x 47') – 8 ft^2 = 376 ft^2

$$Q_{window} = 0.8 \frac{BTU}{hrft^2} * 8\ ft^2 * (56°\text{F}) = 358.4\ BTU/hr$$

$$Q_{wall} = 1.0422 \frac{BTU}{hrft^2} * 376\ ft^2 * (56°\text{F}) = 21{,}944.6\ BTU/hr$$

$$Q_{tot} = Q_{wall} + Q_{window} = 358.4 \frac{BTU}{hr} + 21{,}944.6 \frac{BTU}{hr} = 22{,}302.9\ BTU/hr$$

WALL 3:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)

- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Restaurant Temp – DesignDay Temp = 70 – 14 = 56°F

U_{wall} = Brick and Mortar wall + Gypsum Board + Framing

Udoor = Door

U_{Wall1} : Brick and Mortar

$$k_{brick\ and\ mortart} = 0.347 \frac{BTU}{hr} ft2$$

U_{Wall1} : 2 x 4 inch Wood Studs placed 16 inches apart

$$k_{wood\ studs} = \left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

U_{Wall1} : Gypsum Board

$$k_{gypsum\ board} = 0.0982 \frac{BTU}{hr} ft2$$

$$k_{brick\ and\ mortar} + k_{wood\ studs} + k_{gypsum\ board} = 0.0982 + 0.597 + 0.347 = 1.0422$$

U_{window} = 0.8 BTU/hrft2

A_{window} = (2' x 4') = 8ft^2

A_{wall} = Area of wall = Wall length multiplied by height – Area of Doors

(8' x 10') – 8 ft^2 = 72 ft^2

$$Q_{window} = 0.8 \frac{BTU}{hrft^2} * 8\ ft^2 * (56°\text{F}) = 358.4\ BTU/hr$$

$$Q_{wall} = 1.0422 \frac{BTU}{hrft^2} * 72\ ft^2 * (56°\text{F}) = 4{,}202.2\ BTU/hr$$

$$Q_{tot} = Q_{wall} + Q_{window} = 358.4 \frac{BTU}{hr} + 4{,}202.4 \frac{BTU}{hr} = 4{,}560\ BTU/hr$$

WALL 4:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft^2·°F)
- A = Area of the wall (ft^2)
- ΔT = Temperature difference across the wall (°F)

ΔT = Restaurant Temp – DesignDay Temp = 70 – 14 = 56°F

U_{wall} = Brick and Mortar wall + Gypsum Board + Framing

U_{Wall1} : Brick and Mortar

$$k_{brick\ and\ mortart} = 0.347 \frac{BTU}{hr} ft2$$

U_{Wall1} : 2 x 4 inch Wood Studs placed 16 inches apart

$$k_{wood\ studs} = \left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

U_{Wall1} : Gypsum Board

$$k_{gypsum\ board} = 0.0982 \frac{BTU}{hr} ft2$$

$$k_{brick\ and\ mortar} + k_{wood\ studs} + k_{gypsum\ board} = 0.0982 + 0.597 + 0.347 = 1.0422$$

A_{wall} = Area of wall = Wall length multiplied by height – Area of Doors

(8' x 54') = 432 ft^2

$$Q_{wall} = 1.0422 \frac{BTU}{hrft^2} * 432\ ft^2 * (56°F) = 25{,}212.9\ BTU/hr$$

$$Q_{tot} = Q_{wall} = 25{,}212.9\ BTU/hr$$

WALL 5:

Q=U·A·ΔT

Where:

- Q = Heat loss (BTU/hr)
- U = Overall heat transfer coefficient (BTU/hr·ft²·°F)
- A = Area of the wall (ft²)
- ΔT = Temperature difference across the wall (°F)

ΔT = Restaurant Temp – DesignDay Temp = 70 – 14 = 56°F

U_{wall} = Brick and Mortar wall + Gypsum Board + Framing

U_{Wall1} : Brick and Mortar

$$k_{brick\ and\ mortart} = 0.347\frac{BTU}{hr}ft2$$

U_{Wall1} : 2 x 4 inch Wood Studs placed 16 inches apart

$$k_{wood\ studs} = \left(\frac{1}{5.78} * \frac{1.5}{16}\right) + \left(\frac{1}{1.56} * \frac{14.5}{16}\right) = 0.597\ BTU/hr \cdot ft^2$$

U_{Wall1} : Gypsum Board

$$k_{gypsum\ board} = 0.0982\frac{BTU}{hr}ft2$$

$$k_{brick\ and\ mortar} + k_{wood\ studs} + k_{gypsum\ board} = 0.0982 + 0.597 + 0.347 = 1.0422$$

A_{wall} = Area of wall = Wall length multiplied by height – Area of Doors

(8' x 16') = 128 ft²

$$Q_{wall} = 1.0422\frac{BTU}{hr ft^2} * 128\ ft^2 * (56°F) = 7470.5\ BTU/hr$$

$$Q_{tot} = Q_{wall} = 7{,}470.5\ BTU/hr$$

$$Q_{total} = Q_{wall\ 1} + Q_{wall\ 2} + Q_{wall\ 3} + Q_{wall\ 4} + Q_{wall\ 5}$$

$$Q_{total} = 3{,}527.4 + 22{,}302.9 + 4{,}560 + 25{,}212.9 + 7{,}470.5 = 63{,}073.7\ BTU/hr$$

Design Heat Load Coefficient

$$k_{tot} = 1{,}137.6\ \mathrm{BTU/hrF}$$

Annual Energy Usage from Heating using Heating Degree Day Method

$$Q_{h,yr} = \frac{K_{tot}}{\eta_h} \text{HDD}(T_{bal})$$

$$HDD\ (T_{bal}) = 5{,}568.4$$

$$\eta_h = efficency\ of\ existing\ heating\ system = 0.6$$

$$= \frac{1{,}137.6\frac{BTU}{hrF} * 5{,}568.4\ F \cdot days * 24\ \frac{hr}{1\ day}}{0.6} = 253.4\ MBtus$$

Appendix F – Site Composition

Full Site Building Inventory and Composition

<u>Zoning Key for the Following Table</u>

- *RM* = Residential (green)
- *CMX* = Commercial (orange)
- *I* = Industrial (blue)

	Address	Zone	Bldg Type	Active "# Y/N"	Age	Fl	Bldg Sq. ft.	GFA	Parcel Sq. Ft.
100 - 200 E Tioga *(even)*									
1	100	RM-1	row mixed-com/res-blt as res	1Y	1945	3	946	2838	1000
2	102	RM-1	row typical	1Y	~1930	2	668	1336	825
3	104	RM-1	row typical	1Y	~1930	2	586	1172	815
4	106	RM-1	row typical	1Y	~1930	2	646	1292	845
5	108	RM-1	row typical	1Y	~1930	2	639	1278	820
6	110	RM-1	row typical	1Y	~1930	2	654	1308	810
7	112	RM-1	row typical	1Y	~1930	2	630	1260	825
8	114	RM-1	row typical	1Y	~1930	2	684	1368	848
9	116	RM-1	row mixed-com/res-blt as res	1Y	1930	2	965	1930	947
10	118	RM-1	row mixed-com/res-blt as res	1Y	1930	2	906	1812	869
11	120	RM-1	row typical	1Y	~1930	2	529	1058	797
12	122	RM-1	row typical	1Y	~1930	2	538	1076	772
13	124	RM-1	row typical	1Y	~1930	2	598	1196	775
14	126	CMX-2	built RM. Now CMX/RM corner store on 1st floor.	1Y	1930	1	1061	1061	813
		RM actual use (2nd Fl)				1	1061	1061	
15	128	RM-1	row typical	1Y	1930	2	780	1560	830

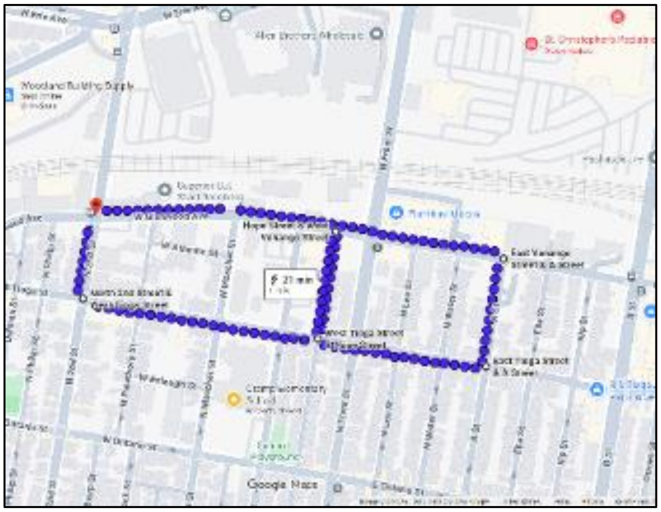
16	130	RM-1	row typical	1Y	~1930	2	724	1448	797
17	132	RM-1	row typical	1Y	~1930	2	680	1360	
18	134	RM-1	row typical	1Y	~1930	2	663	1326	1,578
19	136	RM-1	n/a	1Y	*~1930*	1	824	824	824
20	200	RM-1	row typical	1Y	1935	2	1,195	2390	962
100-200 E Tioga (odd)								0	
21	111	RM-1	row typical	1Y	~1945	2	722	1444	1,135
22	113	RM-1	row typical	1Y	~1935	2	686	1372	911
23	115	RM-1	row typical	1Y	~1945	2	793	1586	929
24	117	RM-1	row typical	1Y	~1945	2	788	1576	945
25	119	RM-1	row mixed-com/res-blt as res	1Y	1935	1	917	917	956
		CMX actual use restaurant				1	917	917	
26	121	RM-1	row typical	1Y	~1945	2	728	1456	1,023
27	123	RM-1	row typical	1Y	~1945	2	754	1508	1,037
28	125	RM-1	row typical	1Y	~1945	2	708	1416	1,045
29	139	CMX-2	warehouse garages (Google maps image)	1Y	1920	1			1,160
30	137	CMX-2	warehouse garages (Google maps image)	1Y	1920	1	3,680	3680	2,494
31	135	CMX-2	warehouse garages (Google maps image)	1Y	1920	1			2,345
32	141	CMX-2	twin conventional Zoned for CMX. Property of	1Y	~1945	3	917	2751	1,586

			Phila Gospel Mvmt. Used sparingly.						
3500 Mascher St -- no address found on Atlas nor Property. no bldg exist. intersection of Mascher, Tioga Sts						n/a	n/a	n/a	n/a
100 W Venango -- One bldg that includes 100-10 W Venango									
33	100-10	I-2	vacant land, industrial: an open lot with cars on it, and a 1 level shack occupying <20% of site's ground area.	1Y	n/a		817		13,336
100 - 200 W Glenwood Ave: *list below is complete, Evens are nonexistent, unless listed.*									
	100-128	*non existent per Atlas, Property Phila, and Google maps*							
34, 35	129-41	I-3	Warehouse. Open air.	1Y1N	1940	1	0	0	59,308
36	143-45	I-3	office warehouse. 1 story per G maps, with at least electricity.	1Y	1926	1	3,011	3,011	4,516
37	147-61	I-3	warehouse	1Y	1920	1	14,954	14,954	15,508
38	175	RM-1	warehouse (but appears to	1Y	"0"	0	0	0	715

			actually be half warehouse, half open junkyard)						
39	177	RM-1	priv garage 1 story masonry	1Y	1945	1	637	637	525
40	179	RM-1	row typical	1Y	~1945	2	762	1,524	602
41	181	RM-1	row typical	1Y	~1935	2	502	1,004	644
42	183	RM-1	row typical	1Y	~1935	2	506	1,012	653
43	185	RM-1	row typical	1Y	~1935	2	668	1,336	721
44	187	RM-1	row typical	1Y	~1935	2	632	1,264	805
45	189	RM-1	row typical	1Y	~1935	2	534	1,068	797
46	191	RM-1	row typical	1Y	~1935	2	503	1,006	837
47	193	RM-1	row typical	1Y	~1935	2	512	1,024	804
48	195	RM-1	row typical	1Y	~1935	2	429	858	611
49	197	RM-1	row typical	1Y	~1935	2	490	980	696
50	199	RM-1	row typical	1Y	~1935	2	1,003	2,006	1,262
51	124 W Venango St	I-2	Ashley Foods. warehouse	1Y	1921	1	12401	12,401	17,393
Total				49 active 2 inactive			**65,948**	**92,662**	**152,051**
Total Sq. ft. with thermal load								**88,982**	
Total estimate cubic ft with thermal load								**889,820**	

Sources (4): City of Philadelphia Atlas, City of Philadelphia Property, Google Maps, site visits

SINGLE THERMAL LOOP LENGTH ESTIMATE



Google Maps

North 2nd Street & West Glenwood Avenue to North 2nd Street & West Glenwood Avenue - Google Maps		**Total length** (feet)
A	*N 2nd St & W Glenwood Ave* <--> E Venango St & A St	1,679
B	E Venango St & A St <--> E Tioga St & A St	449
C	E Tioga St & A St <--> W Tioga & Hope St	covered in row "F"
D	W Tioga & Hope St <--> Hope St & W Venango	449
E	Hope St & W Venango <--> Hope St & W Tioga	449
F	A St & E Tioga St <--> W Tioga St & N 2nd St	1,669
G	W Tioga St & N 2nd St <--> *N 2nd St & W Glenwood Ave*	341
TOTAL foot length of system for a single loop (feet)		**5,036**

Source: Google Maps

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