Scaling Decarbonization with Thermal Energy Networks: Leveraging Computational Tools and Stakeholder Engagement for Informed Project Siting and Techno-Economic Feasibility

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ABSTRACT

Thermal energy networks (TENs) are key solutions to reduce energy consumption and scale decarbonization across the built environment. These systems circulate water at ambient conditions through underground pipes that convey thermal energy to heat and cool a network of buildings - enhancing community-scale resilience and reducing health and safety risks associated with fossil fuel-based systems. TENs offer a market transformation opportunity for gas utilities and workers to leverage their experience and skillsets to build, maintain, and operate these networks.

While TENs efficiently deliver decarbonized thermal energy to large groups of buildings, uncertain capital costs, operational performance, and site suitability can stymie widespread adoption. To understand where TENs are most cost-effective compared to other methods of neighborhood-scale decarbonization (e.g., air-source heat pumps [ASHPs]), this work highlights the results of parametric assessments of neighborhoods of varying typologies, densities, thermal resources, and climate zones. Our results show that TENs can lower energy and power demand, minimize grid stress, and limit the need for transmission and distribution upgrades. These gains are further seen when paired with thermal reservoirs or waste heat sources, such as flowing rivers or data centers, respectively. A review of existing projects show how TENs can align gas utilities, advocates, and communities to create coalitions supporting clean, affordable energy.

These results, presented in conjunction with lessons learned from designers, operators, and financers of TENs, can aid planners, advocates, and policymakers in making informed decisions about siting critical infrastructure and shaping new policy to support climate goals.

Introduction

Buildings account for roughly one-third of U.S. greenhouse gas emissions, with 43% of those emissions stemming from on-site fossil fuel combustion for uses included space and water heating (EPA 2025). As states and utilities pursue increasingly ambitious climate targets, electrification of building thermal loads has become a key decarbonization strategy. To scale decarbonization and meet climate goals, a managed transition electrifying entire zones or neighborhoods is vital. To date, most policy and market activity has focused on appliance-by-appliance electrification, primarily through deployment of air-source heat pumps (ASHPs) within individual buildings, rather than groups of buildings or urban zones.

Recent work modeling the impacts of building-scale electrification has highlighted the potential strain these retrofits may place on the electricity grid, highlighting the need to consider electrification on an integrated, community scale (Buonocore 2022). Thermal energy networks (TENs) are an emerging application of existing technologies to support the reduction of energy consumption and greenhouse gas emissions associated with space heating and cooling. TENs circulate fluids through buried pipes carrying non-combustible thermal energy to heat and cool a network of interconnected buildings. Inside each building, heat pumps tap into this steady thermal source from the ground, water, wastewater, or other waste heat, so they only need to boost the temperature slightly, which lets them achieve very high coefficients of performance compared with typical standalone HVAC systems.

TENs represent an opportunity to transform the energy landscape of entire communities, improving their energy resilience while also reducing the health and safety risks associated with fossil fuel-based systems. While these systems are a highly efficient method for delivering decarbonized thermal energy to neighborhoods, the lack of precedent projects and supporting regulations across a diverse stock of communities has slowed their widespread deployment. Even though many examples exist, the lack of generalizable precedents means that uncertainty around capital costs, lifecycle performance, and site suitability remains a barrier for kickstarting new projects piloting this technology.

While utilities and city- and state-level planning agencies across the United States are commissioning work to understand where these systems are most cost-effective (New York 2022; Minnesota 2024; New Jersey 2024; CPUC 2026), optimal site selection requires thoughtful evaluation of many selection criteria, including geological conditions, utility and infrastructure coordination, thermal load balancing, and community support. As a result, identifying priority geographical zones and socio-economic opportunities for the development and expansion of TENs remains a challenge. This paper presents the results of a parametric assessment comparing TENs to standalone ASHPs – the leading alternative neighborhood-scale electrification strategy. TENs avoid the downsides of uncoordinated (e.g., building-by-building) electrification which can exacerbate peak electric demand, miss opportunities to decommission sections of the costly gas distribution system, and strain local distribution systems. Moreover, unmanaged electrification risks accelerating the decline of gas utility rate bases, increasing costs for customers who remain on the gas system, particularly low-income households and renters who lack access to capital or face split incentives.

Both TEN- and ASHP-driven neighborhood-scale decarbonization offer a managed transition off legacy gas infrastructure, capturing economies of scale, increasing access to cooling, lowering energy bills, and reducing infrastructure redundancy as a non-gas pipeline alternative (NPA). TENs, particularly those designed for utility ownership and expansion, can serve as a shared platform that aligns and advances the priorities of electric and gas utilities, organized labor, utility commissions, and ratepayers. This paper examines TENs across a range of scenarios to highlight where they are best suited for scalable decarbonization.

Background

Thermal energy networks represent the latest evolution in district energy technology. These systems, also referred to as “fifth generation district heating and cooling” or ambient loop systems, use a shared network of low-temperature, water-filled pipes (occasionally with glycol to avoid freezing), and water-source heat pumps that transfer heat in and out of buildings (Figure 1). Because these networks distribute water close to ambient conditions (~5-35 °C), they have fewer thermal losses along the length of the network – improving their efficiency over old generation networks that utilize steam or hot and chilled water (CIBSE 2025).

Because of their ambient operating temperatures, these systems also allow buildings to exchange heat with a number of energy sources, such as lakes and rivers, energy-intensive buildings, wastewater systems and other industrial waste heat sources, and shallow geothermal boreholes. These additional system components, which can provide thermal energy on a consistent or seasonal basis, can help decouple heating and cooling loads with electricity demand, reducing the strain of all-electric buildings on the grid.

Today, 65 thermal energy networks are in operation across the United States and Canada (BDC 2026a). These systems have been deployed by utilities, public agencies, and private third-party owner/operators in residential communities, university campuses, and commercial and industrial hubs.

Figure 1. Fifth generation thermal energy network diagram

Whisper Valley is a 2,000-acre master-planned community outside of Austin, Texas that has developed a thermal energy network to meet the thermal demands of 7,500 homes, schools, and commercial buildings (BDC 2026b). Because all buildings are networked together, the system can leverage the benefits of load diversity (i.e., simultaneous heating and cooling) to reduce the total borehole capacity of the development and improve seasonal performance relative to standalone air- or water-source heat pump systems. And, as was demonstrated during Winter Storm Uri in 2021, because the network's infrastructure is buried below the frost line and relies on stable source temperatures from the geothermal system, the network is inherently robust to extreme cold conditions and thus operated without interruption (Whisper Valley 2026).

Whereas the Whisper Valley TEN was developed in conjunction with a greenfield development, Eversource Energy's utility-owned thermal energy network in Framingham, Massachusetts was built into an existing mixed-use neighborhood of single-family homes and municipally owned commercial buildings. As a regulated utility-owned pilot project aiming to determine if a TEN can cost-effectively replace a neighborhood gas service, Eversource owns and operates both the subsurface and distribution infrastructure and has provided new heat pump equipment to participating customers, who in turn pay a fixed monthly charge for service. Since the start of operations, the network has reported coefficients of performance (COP) exceeding 6 (Eversource 2026) - establishing the project as an example for a replicable “gas-to-geo” transition in neighborhoods across the Northeast.

Policy and Regulatory Landscape for TENs

Over the past five years, one-in-four states across the country have enacted legislation to enable, pilot, or study TENs as part of broader building decarbonization and gas system transition strategies (BDC 2025). Collectively, these signal a shift in how policymakers view the role of gas utilities in delivering thermal energy rather than strictly delivering methane gas. In many states, these efforts aim to prove TENs are a viable business model for gas utilities, leverage existing gas workforce skills, and maintain affordability for ratepayers.

To date, TENs legislation supports their development and adoption via three pathways:

1. Authorization and direction of regulated utilities to pilot, own, and operate thermal energy infrastructure
2. Financing and grant mechanisms to reduce capital cost barriers, and
3. Regulatory reforms to modernize utility obligations and integrate TENs into clean heat standards.

Utility authorization and pilots. Massachusetts was the first state to explicitly authorize gas utilities to develop geothermal network pilots through its 2021 climate legislation (Massachusetts 2020), and a 2022 bill clarified that these TEN pilots could be funded through the state’s Gas System Enhancement Plan (GSEP) (Massachusetts 2022), allowing utilities to deploy geothermal networks as an alternative to replacing aging gas infrastructure (i.e., non-pipeline alternative). In 2024, additional legislation a) modernized the definition of a gas utility to include the sale and distribution of non-emitting thermal energy, b) allowed the Department of Public Utilities to assess new gas infrastructure proposals for consistency with the state’s climate goals, and c) reformed the “obligation to serve” to permit delivery of non-combusting thermal energy in lieu of methane gas (Massachusetts 2024). Massachusetts now has multiple pilot projects, including the first utility-operated TEN in Framingham (BDC 2026c).

New York’s 2022 Utility Thermal Energy Network and Jobs Act (UTENJA) similarly authorized both gas and electric utilities to own and operate thermal energy networks (New York 2022). The law required utilities to propose pilot projects and embedded strong labor and workforce provisions, reflecting a coalition that included environmental organizations, environmental justice advocates, labor unions, consumer advocates, and utilities. By late 2025, the New York State Public Service Commission had authorized nine utility thermal energy network pilot proposals to proceed beyond initial scoping into detailed engineering and design.

California’s 2024 Priority Neighborhood Decarbonization Act authorizes gas utilities to pilot up to 30 neighborhood-scale decarbonization projects, including TENs, in lieu of pipeline replacement (California 2024). The act requires at least 67% of affected customers to consent before a project can proceed, ensuring that neighborhood-level transitions only move forward with clear, majority community support.

Other states have followed with pilot mandates. Colorado’s (2023) Thermal Energy Act requires large gas utilities to propose at least one TEN pilot and allows thermal energy networks to count toward clean heat standard compliance. Washington's (2024) legislation requires gas utilities to propose TEN pilots within a defined timeframe, permits rate base recovery, and enables gas utilities to meet their "obligation to serve" through thermal energy networks subject to commission approval. Lastly, Maryland's (2024) WARMTH Act mandates that large gas utilities propose one-to-two pilots and requires that at least 80% of participating customers qualify as low- or middle-income.

Financing mechanisms and incentives. Several states have paired pilot authority with dedicated funding or financing tools. In 2022, Colorado passed a bill to establish a geothermal energy grant program (Colorado 2022). Washington, in 2024, allocated $25 million in grant funding to support project diversity and knowledge sharing (Washington 2024). Illinois' 2025 Clean and Reliable Grid Affordability Act directs up to $20 million toward TEN pilots through coordination between the Commerce Commission and the state's Climate Bank (i.e., Illinois Finance Authority) and establishes additional renewable energy credit mechanisms for geothermal systems (Illinois 2025). Minnesota, in 2024, directly invested in TENs development via an omnibus bill that appropriated $500,000 for a statewide TENs suitability study. The bill also appropriated funds for technical assistance to local governments and a Public Utilities Commission TENs working group (Minnesota 2024).

In other states, legislation has focused on study and evaluation rather than funding for immediate deployment. New Jersey directed its Board of Public Utilities to conduct a feasibility study of large-scale geothermal systems, consulting with early-adopter states (CUPR 2025). Maine established a commission to evaluate technical feasibility, grid impacts, and funding pathways for a potential statewide TEN program (Maine 2025).

Regulatory modernization and utility transition. Several states have revised statutory definitions to allow utilities to distribute thermal energy, clarifying that TENs can be rate-based assets, which allows utilities to treat TENs as any other capital investment project that can earn a rate of return. Others have allowed rate base mergers or explicit cost recovery mechanisms for pilots. These reforms address a central regulatory barrier: traditional gas utility statutes often limit utilities to selling methane, complicating investment in non-combustion infrastructure.

At the same time, many laws integrate equity and workforce requirements. Prevailing wage standards, project labor agreements, apprenticeship programs, and commitments to local hiring are common. Some states require pilot projects to prioritize low- and moderate-income customers or disadvantaged communities. This policy design reflects an understanding that TENs are not solely infrastructure projects but instruments of a managed energy transition that can improve affordability for customers and maintain high-paying jobs for organized labor.

Policy summary. While implementation details vary, the trend is clear: states are creating legal, financial, and regulatory pathways for utilities and communities to deploy thermal energy networks as part of broader decarbonization strategies. Looking forward, states will evaluate pilot performance, cost trends, and system-level benefits, such as avoided gas infrastructure and reduced electric peak demand, that can inform future planning and rate design. In summary, TEN policies across states focus on these key areas:

- **Pilots as proof points**. Most states begin with pilots to evaluate cost, performance, workforce implications, and customer acceptance to inform broader rollout and set up market conditions for utilities and other owners to develop TENs on their own.

- **Integration with gas system planning**. TENs are increasingly framed as alternatives to gas pipeline replacement or expansion, particularly where infrastructure is aging.
- **Workforce transition**. Labor standards and apprenticeship programs are central to legislative support.
- **Long-term affordability planning**. Many statutes include low-income participation targets, tenant protections, and community engagement funding.

Thermal Energy Network Cost Drivers and Uncertainty

From pre-construction through operation and maintenance, there are major cost drivers for a typical TEN project. The focus of this section is on major costs specific to TENs, limiting discussion of common costs borne by all projects (e.g., design, permitting). While TENs in many contexts are technologically proven systems, their limited adoption to date means costs are not yet well understood and uncertainty from utilities, developers, labor, and other stakeholders comes with a cost premium that will decline as adoption continues to grow.

Thermal loop. The ambient loop in a fifth-generation thermal energy network is a significant upfront investment that will allow buildings connected to the network to operate with exceptional energy efficiency year-round, sheltered from extreme seasonal air temperatures that reduce the efficiency of fossil fuel furnaces, air conditioners, and ASHPs. Installing the horizontal distribution and service pipework is the largest cost, typically ranging from $200 per linear foot up to $800 per foot (BDC 2026d). The variability comes from local labor costs, ground composition, pipe diameter, and congestion from other underground utilities. Higher density networks with more buildings connected to the loop offer more operational cost savings to pay back the investment. Strategically selecting projects as non-pipeline alternatives can make this thermal loop cost neutral compared to replacing aging or leak-prone gas pipelines.

Boreholes. For thermal energy networks that need boreholes for load balancing and thermal energy storage, drilling costs and total borehole length across the entire borefield are the main cost drivers. Drilling costs can vary significantly based on the local workforce availability, geology, and drilling method. Typical drilling costs range from $25-$60 per vertical foot (BDC 2026d). Optimal network designs that include diverse loads and waste heat sources (e.g., data centers, wastewater and/or sewer heat recovery) can limit borehole needs and therefore reduce overall costs. In the long-term, emerging drilling technologies and workforce development can bring down costs as the growing popularity of TENs adds steady demand for drillers.

Central pumphouse. To circulate the ambient water or glycol mix through the thermal loop, TENs require a central pumphouse or distributed pumping stations. These facilities house circulation pumps, variable frequency drives, controls, heat exchangers (as needed), and monitoring equipment. The pumping capacity, building type, and redundancy requirements are key cost drivers, leading to a wide range of potential costs, typically $250k to $2M, depending on the overall system size (BDC 2026d).

Heat exchange. Although heat sources require upfront costs for connections, heat exchangers, and monitoring equipment, the "free heat" can significantly cut operational costs by providing load balancing and improving heat pump performance, particularly during the heating season (see Results section). Costs vary by heat source and capacity, which can include thermal reservoirs (e.g., aquifers, lakes, rivers) and/or waste heat sources (e.g., data centers, wastewater treatment plants, ice rinks, breweries, manufacturing facilities).

Load balancing equipment. To fine-tune the distribution loop temperature, load balancing equipment can add or remove heat when loads on the network are imbalanced (e.g., all buildings are in cooling mode). Depending on the network's configuration, load balancing equipment can include cooling towers, dry coolers, or boilers. This conventional equipment is common in commercial and industrial buildings and is often priced per ton or kilowatt of heating or cooling capacity. These costs can range from $150-600 per ton of cooling, and $50-$150 per kilowatt of heating (BDC 2026d). Optimal network composition to balance loads can minimize capacity requirements for load balancing equipment and operational costs to maintain loop temperatures.

Avoided utility infrastructure (gas and electric). A major but often undercounted economic factor in TEN projects is the avoided cost of conventional energy infrastructure. As a large-scale decarbonization solution, TENs can replace large sections of gas distribution infrastructure that are aging, leak-prone, or otherwise due for replacement. Gas distribution infrastructure spending has grown significantly in the past decade, reaching as high as $8.5M per mile (Synapse 2025), driving up gas bills for residents and building owners as those infrastructure costs are passed on to ratepayers. By decommissioning gas pipelines and replacing them with a thermal loop, utilities can direct capital and construction efforts towards decarbonized infrastructure, allowing the same workforce to do comparable field work.

On the electric side, high-efficiency water-source heat pumps can significantly cut peak power demand from buildings, particularly during peak times when the grid is constrained and paying for costly peaker plants to provide the last kilowatt of capacity. At scale, thermal energy networks can act as non-wires alternatives, limiting the need for distribution or transmission infrastructure to meet additional electrical loads from new construction, electric vehicles, and/or electrification of loads in existing buildings. Marginal electrical capacity costs vary greatly by local conditions. In California, the levelized value of energy can peak as high as $6/kWh in the summer (CPUC 2024), largely driven by transmission and distribution (T&D) capacity costs. Studies have shown marginal T&D costs of new grid demand range from $40-$80 per kW-year (Jhaveri 2024, Synapse 2024) and can exceed $100-150 (Brattle 2018, NY PSC 2024).

Building energy savings. Buildings connected to ambient loops with water-source heat pumps can achieve significantly higher seasonal efficiency compared to air-source equipment, especially during extreme weather. These efficiency gains translate into energy savings and lower energy costs, which benefit the buildings on the network throughout the life of the system, which can extend beyond 60 years. For example, at Colorado Mesa University, a geo-exchange-based ambient loop whose expanding system has been in operation since 2012 has reported COPs ranging from 3.1-6.1 and has reduced its annual utility costs by $1.5 million USD (CMU 2026). And, reports of high COPs from the Framingham UTEN in Massachusetts show how these systems can similarly lower utility costs in mixed-use neighborhoods (Eversource 2026).

Opportunities for TENs

Economies of scale. Thermal energy networks unlock multiple layers of economies of scale that standalone, building-scale HVAC systems cannot achieve – particularly related to both capital cost and operations and maintenance. As network size increases, per-building costs for geothermal drilling, piping, permitting, and engineering design decline, improving upfront cost efficiency (in $/kW installed) over single-building systems. Larger networks also increase opportunities for load diversity and waste heat recovery, which can further reduce load balancing equipment costs, borehole needs, and other equipment costs. Better load diversity and waste heat recovery also lowers operational expenses by improving system energy efficiency. In addition, larger projects can more efficiently deploy trade crews, who stay mobilized for longer periods, resulting in lower per-building and heating, cooling, and capacity costs.

Environmental, health, and safety considerations. Beyond the energy and economic benefits, TENs offer a pathway towards scalable electrification aligned with many local and state-level decarbonization plans. Whether installed as new networks leveraging waste heat recovery and thermal exchange sources or redeveloped as part of a phased transition away from combustion-based systems, moving towards all-electric networked systems allows connected buildings to reduce pollution. This reduced combustion improves local air quality and reduces negative health impacts for people in the surrounding neighborhood.

Access to space cooling. Across the United States, 34% of residential households do not have access to centralized space cooling (EIA 2022). However, by upgrading the existing HVAC system to a heat pump, whether through air-, ground-, or water-source, homes will have the added benefit of providing cooling. Space cooling is an important demand profile needed to optimize the performance of a TEN; heat rejection resulting from cooling buildings on the network helps balance its annual thermal load profile, reducing the need for auxiliary heating systems. By providing cooling to residential buildings, TENs can reduce exposure to dangerous indoor temperatures resulting from increasingly common extreme heat events rather than relying on piecemeal and often less efficient upgrades by individual owners and renters.

Workforce modernization. Because the installation, operations, and maintenance of TENs utilize similar skillsets to those used in gas utilities, these systems are a practical way to modernize an existing workforce towards a cleaner energy economy. TENs typically rely on pipe infrastructure made of high-density polyethylene (HDPE) at similar depths and alignments to gas utility distribution. Similarly, for systems with boreholes, the process of drilling and pipefitting builds on existing technologies developed for the oil and gas industry. Thus, the skillset needed for TENs is largely the same, greatly simplifying the workforce transition.

Methods

Model Overview

To understand where TENs are best suited for development across the United States, we used an Excel-based feasibility modeling tool to conduct a parametric assessment across a range of input assumptions and site conditions. These parameters included climate zones, building energy demand, network size, and heat injection and/or rejection components to produce estimates of energy consumption, greenhouse gas emissions, and total costs of ownership (i.e., capital costs, operating expenditures, and fuel/utility costs) for both TENs and alternative standalone ASHPs. While this paper focuses on results and impacts of the findings, more details on the tool architecture, inputs/outputs, and methods can be seen in Buro Happold 2025.

Parametric Analysis Approach

Because of the large quantity of inputs available for a modeler to toggle in the Excel tool, a parametric analysis allows us to better understand the impact of different project variables on total energy use and peak power demand for ASHPs and TENs. The set of ~2,000 simulations explored key variables with the largest impact on results, including:

- Seven U.S. project locations to explore climate and seasonal ground temperatures, including CA, CO, MA, MN, NY, TX, and WA.
- "Free heat" capacity to explore the impact of low-energy cost heat injection (pumping costs only), such as from boreholes or a data center. We modeled 12 increments of constant heat capacity ranging from 0 to 1,000 kW from a sample data center.
- Six neighborhood typologies summarized in Table 1 to explore heating and cooling load profiles and magnitude.

Other variables such as thermal loop setpoint, neighborhood size, and geology had less impact on the energy and power results, so they have been excluded from the Results and Discussion. These remain important variables in terms of lifecycle cost, economies of scale, and other characteristics affecting the viability of TENs. As previously discussed, we did not focus on modeling costs due to their high variability and uncertainty at this stage of TEN adoption.

Table 1. Modeled neighborhood typologies

Neighborhood	Building Area	Composition
Office Park	500,000 ft²	3 large offices
Hospital Campus	500,000 ft²	1 hospital
Urban Residential	740,000 ft²	2 high rise multifamily
Urban Public Housing	540,000 ft²	32 low rise multifamily, 17 high rise multifamily, and 1 meeting hall
Urban Mixed Use	430,000 ft²	4 retail, 3 low rise multifamily, and 14 single family homes
Suburban Residential	500,000 ft²	266 single family homes

Results and Discussion

Modeling Results

Results from our parametric modeling of six different neighborhood typologies across climates and heat injection capacities highlight the value of "free heat," demonstrate the energy savings benefits of siting TENs in extreme climates, and show the variability neighborhood composition (i.e. load diversity, density, and energy demand profile) introduces in thermal network performance. These results are illustrative only to identify trends and guidance for TEN siting and design. As with all large-scale, long-term infrastructure and building projects, costs and performance can vary significantly project-to-project based on local economic factors, weather conditions, bedrock conditions, long-term utility costs, and other unforeseeable circumstances.

Model results do not explicitly quantify capital or operational expenses due to the uncertainty and geographic variation in current cost estimates for TENs. As such, lifecycle cost metrics and net present value analyses are only available for early demonstration projects with inflated costs that vary widely across projects. As adoption grows and additional pilots move to operation, future work can review evolving TENs economics. In general, TENs will have a significant upfront expense compared to an ASHP-based electrification approach as discussed in the Background section. The potential electricity peak and overall consumption savings point to significant volumetric ($/kWh) and, for commercial and industrial rate structures, demand charge ($/kW) savings which will provide ongoing benefit for the life of the thermal network and limit the impact of future rate increases and price volatility. For customers, these reductions translate into more predictable, lower total energy bills and improved resilience to price spikes, while for utilities they reduce the need for expensive peak capacity and grid upgrades, support system reliability, and help meet regulatory decarbonization targets without imposing disproportionate cost increases on ratepayers, especially in areas with electrical capacity constraints.

Impact of free heat injection on TENs electricity use. A "free heat" source (e.g., boreholes, data centers) can significantly lower overall and peak power demand for thermal energy networks, as shown in Figure 2. The added heat offsets the need for auxiliary heat sources such as ASHPs, boilers, or other equipment to add heat to the ambient loop to maintain its temperature when the connected buildings are predominantly in heating mode in the winter. When load balancing (some buildings are heating while others are cooling) across the connected buildings is misaligned, boreholes or waste heat sources can fill the heating capacity gap. This additional heat has diminishing returns, shown as flattening lines in the figure as heat injection increases. Once the "free heat" offsets the need for auxiliary heat injection for most of the hours in the year, additional heat has minimal impact. These heat sources also offer energy resilience by providing redundant heating for the loop and lowering peak power needs to support electric grid operations during winter peaks.

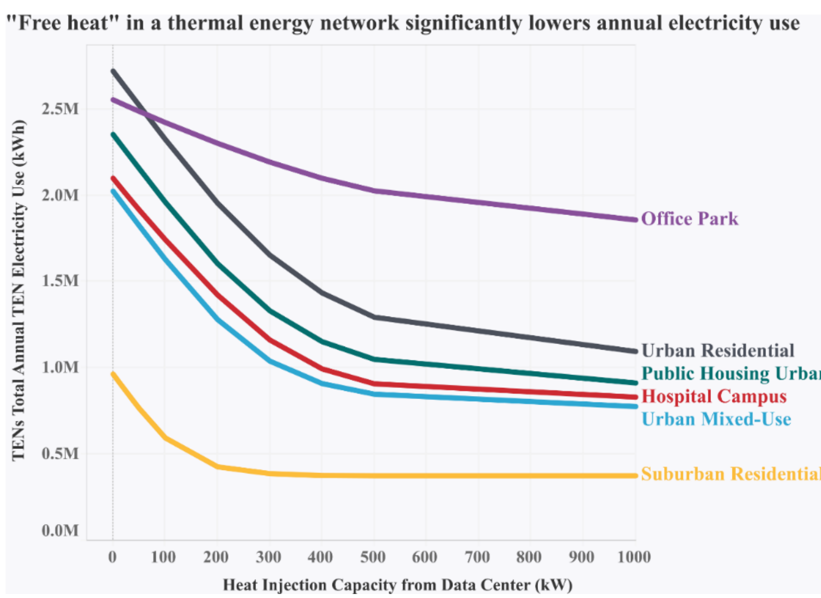

Figure 2. Impact of heat injection capacity on overall TEN electricity use.

Total electricity use and peak power demand. Our modeling shows that the relative electricity use of TENs compared to ASHP-based decarbonization varies primarily based on climate, neighborhood composition, and "free heat" availability, as plotted in Figure 3. In mild climates with no "free heat" source such as boreholes or heat exchange off a data center, TENs tend to use more electricity compared to ASHPs due to similar heat pump efficiencies and the added electricity use from TENs operations such as pumping and auxiliary heat injection from costlier boilers. In hotter or colder climates, the efficiency difference between water-source heat pumps and ASHPs means TENs have greater electricity savings, offsetting the auxiliary energy consumption of running the thermal network.

Regarding peak power demand (bottom of Figure 3), the results follow a similar pattern – without "free heat," TENs draw more peak power to condition buildings and maintain loop temperature setpoints. With "free heat," more balanced loads, and colder winters or hotter summers, TENs outperform ASHPs in both peak power draw and total electricity use.

Figure 3. Distribution of electricity use (top) and peak power (bottom) differences between TENs and ASHPs across simulations

Key Recommendations for TENs

Our results highlight several conditions under which TENs are best suited as a neighborhood-scale decarbonization solution:

Locate TENs where they can offset utility infrastructure. TENs can be non-pipeline- and non-wires-alternatives, providing significant cost savings from avoided gas pipeline replacements ($0.5-$8.5 million per mile of gas main), and/or limit electric grid infrastructure upgrades and minimize grid capacity costs (10-150 $/kW-year). Recent policy action in California, and proposed policy in New York, resulted in maps plotting priority zones where neighborhood-scale decarbonization solutions could offset large infrastructure costs otherwise borne by ratepayers.

Select dense neighborhoods with mixed building types. These projects offer load diversity to limit load balancing equipment costs and minimize operational costs by limiting load balancing energy use. Geographically dense neighborhoods further limit capital expenses by minimizing costly distribution piping installation.

The bigger, the better. Larger neighborhoods support load diversity, improve economies of scale for construction, and lower risk for developers who will rely on getting customers connected to the network to recover capital costs. Larger networks also have more inherent thermal mass in the distribution loop, stabilizing temperatures and improving system efficiency.

Start with a single owner. A single owner (e.g., a utility, campus, or private developer) simplifies project logistics and economics and minimizes risks (BDC 2026e). Multi-owner models, such as co-ops, can be successful and better distribute power to communities tied to the network, like in West Union, Iowa (BDC 2026f). All networks should be designed to ensure interconnectivity and scalability for long-term growth.

Site projects in cold climates with high winter peak loads. Cold climates maximize water-source heat pump efficiency year-round, unlike ASHPs, which can lose efficiency in extreme temperatures. In mild climates, the efficiency advantage of TENs is minimal, limiting their operational cost savings. Our modeling shows that TENs cut peak power demand compared to ASHPs by 15-66%, which can avoid grid infrastructure upgrades and limit costly capacity requirements for power providers.

Secure a waste heat source. As shown in the modeling, "free heat" injection can swing the total energy use balance in favor of TENs vs. ASHPs by cutting the TENs overall electricity use by 27-61%. This heat can cut or eliminate the need for heat injection into the thermal loop from other sources, which may be from air-to-water heat pumps, boilers, boreholes, or other equipment with their own upfront and operational costs. In some cases, the "free heat" from the waste heat source can benefit the waste heat source, such as a data center or ice rink, by taking excess heat and improving the efficiency of the cooling systems at those waste heat sources.

Conclusion

TENs are emerging as a credible, scalable pathway for neighborhood-scale building decarbonization that complements and, in specific contexts, outperforms standalone ASHP electrification. This paper presented a parametric assessment comparing TENs with building-by-building ASHP retrofits across a range of climates, neighborhood compositions, and “free heat” capacity scenarios. The results demonstrate that TENs are not universally superior, but under the right conditions, they can deliver meaningful reductions in peak electric demand and lifecycle utility costs while simultaneously enabling managed retirement of gas infrastructure. In contrast to well-established energy modeling, costs around TENs remain highly variable and were therefore excluded from the modeling. Future work is needed to explore lifecycle costs after more pilots advance and cost premiums from uncertain builders, designers, and operators subside as the TENs market matures.

With these conclusions in mind, demonstration projects are essential to move beyond theoretical feasibility and prove the real-world viability of TENs, generating the performance, cost, and customer-acceptance evidence needed to build confidence among utilities, regulators, and communities. To implement these projects, city planners and utilities should aim to deploy TENs in dense neighborhoods with significant heating and cooling loads, access to “free” or low-cost thermal resources or heat reservoirs, and areas with either aging gas pipelines or constrained electric infrastructure, where avoided replacement and capacity costs are highest. State policymakers and regulators should continue to treat TENs as non-pipeline and non-wires alternatives, creating clear pathways for rate-base recovery, integrating TENs into gas and electric planning, and requiring robust reporting on costs, performance, and customer outcomes from early pilots. And, statutes and pilot design should maintain strong equity and labor provisions, such as low-income participation targets, tenant protections, prevailing wage, and apprenticeship requirements, so that TENs can help lower energy burdens and support a just workforce transition.

Overall, neighborhood-scale projects like these reinforce the need for electrification and broader decarbonization to move beyond appliance- or building-scale projects and instead towards coordinated, network-scale solutions that can support infrastructure-wide transitions. Where dense neighborhoods, aging gas infrastructure, high peak demand, and accessible thermal resources converge, TENs can deliver durable economic, workforce, environmental, and grid benefits. As states evaluate early pilots and refine regulatory frameworks, evidence suggests that thermal energy networks can serve as a cornerstone of a coordinated, community-scale approach to building decarbonization that aligns infrastructure investment, workforce transition, environmental goals, and long-term energy affordability.

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