U.S. DEPARTMENT OF
ENERGY

Pathways to Commercial Liftoff: **Geothermal Heating and Cooling**

Geothermal family of reports: Report #2

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Comments

The Department of Energy welcomes input and feedback on the contents of this Pathway to Commercial Liftoff. Please direct all inquiries and input to liftoff@hq.doe.gov. Input and feedback should not include business sensitive information, trade secrets, proprietary, or otherwise confidential information. Please note that input and feedback provided is subject to the Freedom of Information Act.

Authors

Authors of the Geothermal Heating & Cooling Pathways to Commercial Liftoff:

Dr. Charles G. Gertler, **Loan Programs Office** (*Lead*)

Dr. Timothy M. Steeves, **Geothermal Technologies Office** (*Lead*)

Dr. David T. Wang, **Geothermal Technologies Office** (*Lead*)

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Cross-cutting Department of Energy leadership for the Pathways to Commercial Liftoff effort:

Undersecretary for Infrastructure: David Crane

Office of Technology Transitions: Dr. Vanessa Chan

Loan Programs Office: Jigar Shah

Geothermal Technologies Office: Lauren Boyd

Office of Energy Efficiency and Renewable Energy: Alejandro Moreno

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Geothermal Technologies Office: Doug Blankenship, Lauren Boyd, Dr. Alexis McKittrick, Sean Porse

Office of Energy Efficiency and Renewable Energy: Dr. Anna Hagstrom

Office of Policy: John Agan

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Office of Technology Transitions: Dr. Vanessa Chan

Loan Programs Office: Jigar Shah, Rachel Enright, Sonali Razdan, Ian Hamos

Office of Policy: Jason Frost, Rachel Reolfi, Dr. Nicole Ryan, Zoe Lipman, Dr. Erin Mayfield, Ava Kalina, Betony Jones, Steve Capanna, Carla Frisch

Office of Clean Energy Demonstrations: Megan Timmons

Geothermal Technologies Office: Jennifer Livermore, Lindsey Baker, Arlene Anderson, Alexandra Prisjatschew

Building Technologies Office: Dr. Bandana Kar, Dr. David Coffey, Ram Narayanamurthy, Hayes Jones, Sven Mumme

Office of Energy Efficiency and Renewable Energy: Dr. Carolyn Snyder, Dr. Colin Cunliff, Ben Miller, Dr. Nicholas Montoni, Dr. Becca Jones-Albertus

Office of the General Counsel: Kathryn McIntosh, Ani Esenyan

Office of Minority Economic Impact: Dr. Monika Roy

Office of Electricity: Dr. Mohamed Kamaludeen

Energy Information Administration: Greg Lawson

National Renewable Energy Laboratory: Dr. Nicholas Long, Eric Wilson, Dr. Koenraad Beckers, Dr. Juliet Simpson, Dr. Saqib Javed, Dr. Matt Mitchell, Marlena Praprost

Oak Ridge National Laboratory: Dr. Xiaobing Liu, Dr. Mini Malhotra

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Executive Summary

Geothermal heating and cooling technologies are important and underutilized solutions for supporting a more resilient and efficient national energy system, as well as reducing emissions from buildings.

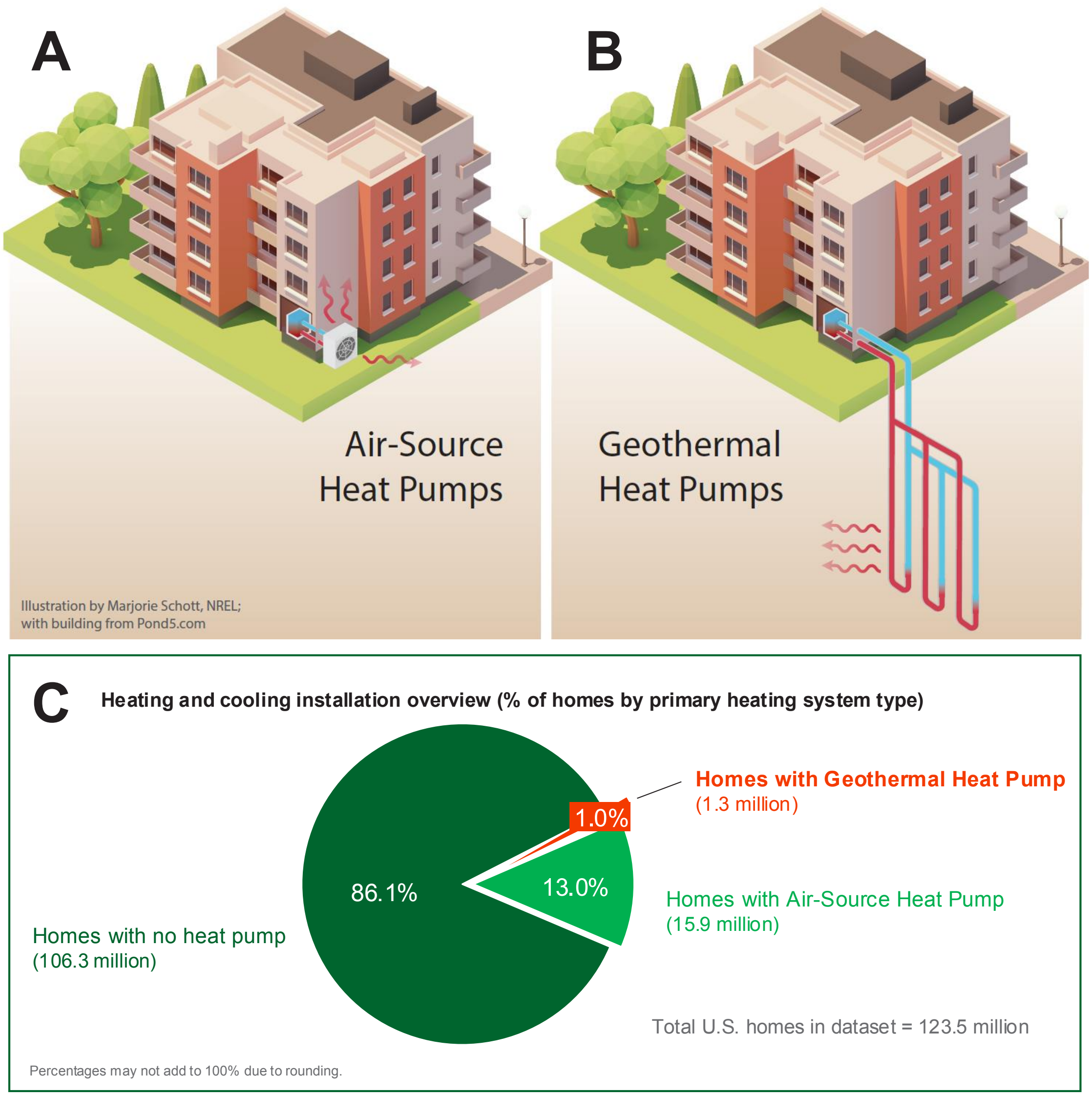
Geothermal heating and cooling technologies can reduce peak electricity demand, increase resilience, and lower ratepayer energy bills. By 2050, the technical potential[i] for geothermal heating and cooling systems equates to up to ~80 million homes (~200 million refrigeration tons[ii]) across residential and commercial buildings in the United States; however, actual adoption will likely be lower. At full deployment, summer and winter peak demand could be hundreds of gigawatts (GW) lower than for a scenario with less efficient building electrification at similar levels. The peak demand reduction could potentially lower energy payments by tens of billions of dollars nationally due to grid system cost savings, with average annual savings in the hundreds of dollars for homeowners and renters (ES Figure 2).

Geothermal heat pumps (GHPs) operate similarly to air-source heat pumps (ASHPs)—using a refrigeration cycle to move heat for heating or cooling—but use the ground as a source and sink of heat, rather than outdoor air. In many cases or regions, GHPs are more efficient, have lower operating costs, and confer greater grid benefits than traditional heating and cooling alternatives. The GHP market share currently represents just 1 percent of installed residential heating compared to 13 percent for ASHPs (see Executive Summary (ES) Figure 1). While the thermodynamic principles of GHPs and ASHPs are the same, the ground provides a more constant temperature for heat exchange than outdoor air, increasing the efficiency of GHPs.

Deployment of GHPs with ASHPs and other energy efficiency measures can achieve key energy resilience, energy affordability, and national decarbonization goals. This Liftoff Report focuses on geothermal heating and cooling that employs heat pumps, rather than direct heat, and the potential to broaden consumer adoption, accelerate installation rates, and substantially improve market depth in the United States. Widespread deployment of GHPs and integration with smart, grid-connected grid-edge technologies also provides peak load reduction, load shifting, load shaping, and demand flexibility benefits that help avoid distribution and bulk system upgrades, with savings that accrue to both utilities and ratepayers. GHPs also help meet national energy efficiency goals as set forth in the DOE's National Blueprint for the Buildings Sector, including a threefold increase in demand flexibility and a doubling of energy efficiency, particularly for buildings such as large commercial buildings, campuses and multifamily buildings.

i Refers to economic potential as defined in the NREL dGeo model–positive payback within 30 years compared to heating/cooling systems in existing building stock (see Figure 24).

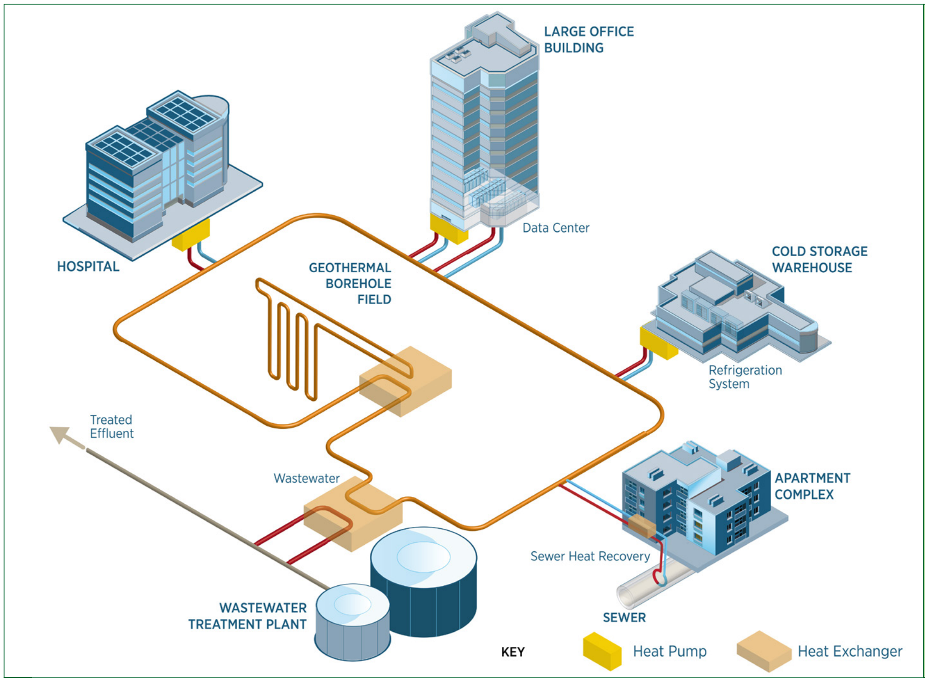
ii A refrigeration ton is equivalent to 12,000 Btu per hour (3,517 watts) of cooling or heating capacity, roughly capable of servicing about 700 square feet. Here and throughout, this report assumes a typical home size of 1,750 square feet.



Executive Summary (ES) Figure 1: Overview of heat pump technologies and current market share. A) Air-source heat pump overview and explanation of functioning principles for spring/summer cooling mode, B) Geothermal (ground-source) heat pump overview and explanation of functioning principles for spring/summer cooling mode, C) Market share of geothermal heat pumps, air-source heat pumps, and all other heating and cooling technologies.

Notes: Images adapted with permission from Marjorie Schott, National Renewable Energy Laboratory. Sources: EIA RECS 2020; L. Davis (2023) NBER Working Paper No. w31344; Atlas Buildings Hub (2023). Dataset represents all occupied dwelling units in the United States; excludes vacant units and vacation homes.

By connecting buildings via piped fluid at ambient temperatures, Thermal Energy Networks (TENs) can leverage the benefits of GHPs (ES Figure 2). TENs can employ shared geothermal boreholes and heat exchangers that are connected to a shared network of piped fluid. GHPs boost or lower the working fluid temperature to the operational temperature at the building level for heating or cooling. TENs can also leverage combinations of other heat sources such as waste heat from sewer water, data centers, industrial process, or power generation to provide efficient heating.



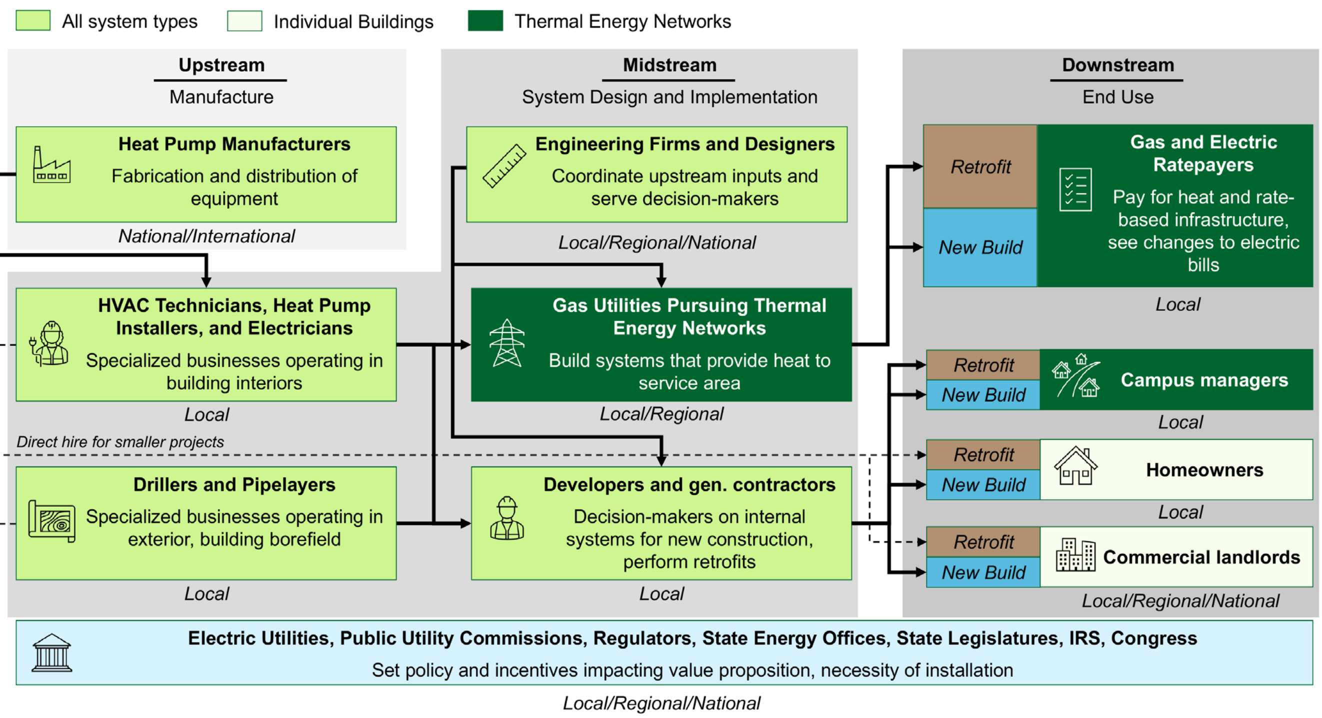
TENs principles:

- Couple heating and cooling loads across different applications via piped fluid, allowing for systems to use one another as a sink or source for heat
- Geothermal heat pumps in use for heating and cooling distribution within each building and connected to the shared loop
- Utilize or store heating or cooling potential that would otherwise be wasted
- Geothermal ground loops can be used as a versatile source or sink of heat, and borehole storage can be used to store up excess heating and cooling between seasons

ES Figure 2: Thermal Energy Networks (TENs) principles

Notes: Source: Graphic adapted with permission by NREL from Marjorie Schott.

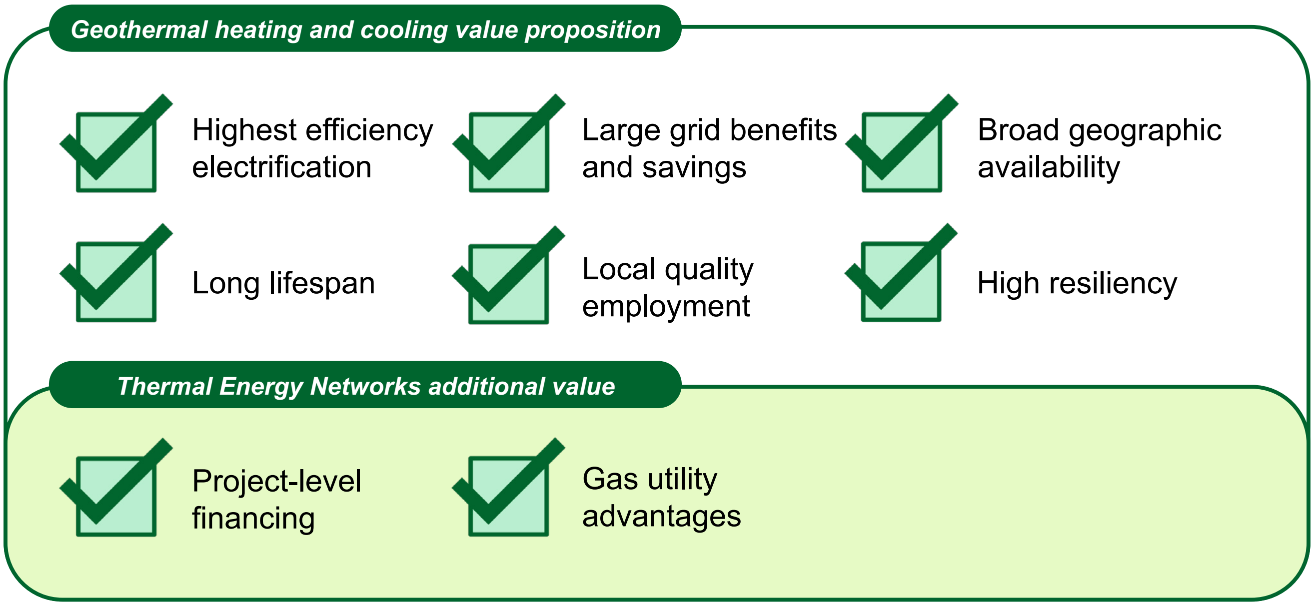
The construction of geothermal heating and cooling systems involves numerous stakeholders and decisionmakers at every level of the value chain (ES Figure 3). These stakeholders have distinct roles and responsibilities. The way they collaborate depends on whether construction is for 1) a single building vs. for a TEN, and 2) a new build vs. retrofit. While some actors operate at the national or international level, many only operate locally, which can contribute to inconsistencies in supply chain, knowledge, and pricing. Thus, the pathway to scale for GHPs must account for the various complex interactions along the value chain depending on installation type.



ES Figure 3: Geothermal heating and cooling value chain

Geothermal heating and cooling systems have a multi-pronged and unique value proposition among building decarbonization technologies (ES Figure 4). In addition to the efficiency and grid benefits described above, geothermal heating and cooling systems require many of the same skills and occupations utilized in the fossil industry and gas distribution system, providing a transition path and good jobs for displaced fossil workers. Additional benefits are summarized in ES Figure 4.

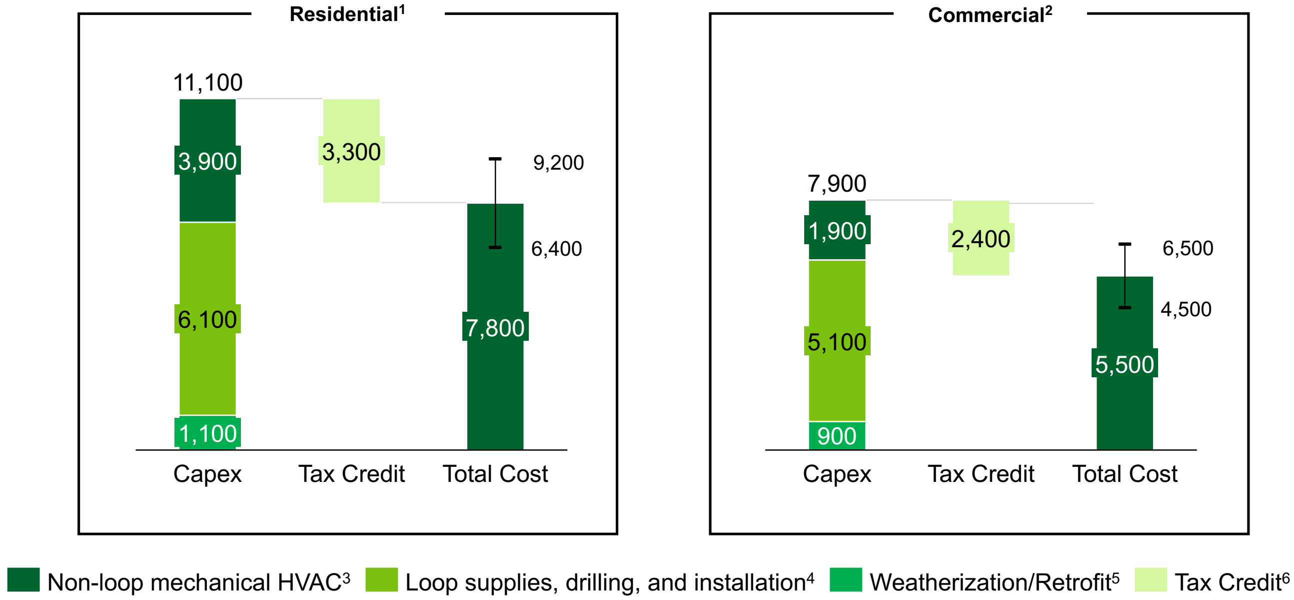
TENs have additional benefits and advantages. Because the construction of a TEN involves multiple buildings and systems, project-level financing and rate-basing these investments can serve many customers who may not be able to pursue a single-building system. **Furthermore, gas utilities with decarbonization goals can consider TENs as a potential low-carbon option for new infrastructure, providing heating and cooling as a service for business models to support decarbonization, or as less expensive alternatives to new or replacement gas pipelines approaching end of life.** When deployed, TENs also have significant additional benefits, such as decreasing energy burden and increasing energy resiliency.



ES Figure 4: Geothermal heating and cooling value proposition. See Figure 17 notes for assumptions and methodology.

Geothermal heating and cooling solutions may be deployed during retrofits or new building construction, with differentiated requirements and costs. In general, the additional activities required to retrofit buildings are more expensive and complicated than the integrated planning for new construction. However, the majority of buildings that will be in use in 2050 have already been constructed, so any impactful approach to deploying this technology must include both new builds and retrofits.

While GHP systems in many situations have a lifetime net positive value to owners, the upfront (or first) cost of GHPs in single buildings can be high relative to some other heating and cooling solutions, particularly for residential installations, at a national median cost of $7,800/ton, or $19,000 for a typical home after incentives. Federal tax incentives, including a 30 percent or greater tax credit, are valuable economic drivers to help defray initial capital costs. Much, but not all, of the cost premium is attributable to the ground loop (ES Figure 5). Safely drilling or moving earth to install the ground loop requires skilled labor and equipment, which can be in high demand for other purposes, such as water, gas, and sewage infrastructure. GHP installation can be hindered by high and geographically varying up-front costs. Local utilities may also face challenges adopting new business models for TENs.



ES Figure 5: Median national cost estimates for single-building geothermal heat pumps ($/ton).

Values for cost were selected to be an illustrative and simplified median estimate aligning broadly with costs of actual projects as well as data and estimates provided by industry. Values are also consistent with NREL's National Residential Efficiency Database[1]. Median values only shown for CAPEX and Tax Credit, error reflected in error bar in Total Cost bar. These data are median and meant to show a "typical" costing scenario. Notes on specific values below highlight areas where cost can greatly increase or reduce based on specific situations related to a project, but in general significant differences based on size and age of the building, regional cost of specialized labor, and the relevant geology and local governance of subsurface work will dictate the cost of any project. Notes: 1. Residential defined as single family detached homes with one HVAC system. 2. Commercial defined as any building owned and operated by one or more commercial entities. 3. This includes all mechanical equipment that needs to be installed in and around the building for the GHP system, often this is an all-in-one heat pump unit but can include separate compressors, chillers, blowers. Cost for residential versions of these units is currently much higher than their air source relatives due to a small, highly specialized market. On the commercial side, larger systems are built with components common to both markets and cost per ton is much lower. 4. The cost of drilling and installing the ground loop is the most variable element of the cost of any project, and will vary based on geology, region, and specific location. In general, vertical borehole loops will be more expensive, which is part of why GHPs are not commonly seen as a solution for urban environments. 5. Factors in installing or altering ductwork as well as removing older heating and cooling technologies. Will vary significantly based on the current state of the building but will also be necessary for any HVAC modernization project on that same building. 6. 30% base ITC credit for commercial installations (Section 48 ITC) and 30% residential clean energy credit (25D) for residential installations. Source: Data shared by manufactures and installers in geothermal heat pump industry; expert interviews.

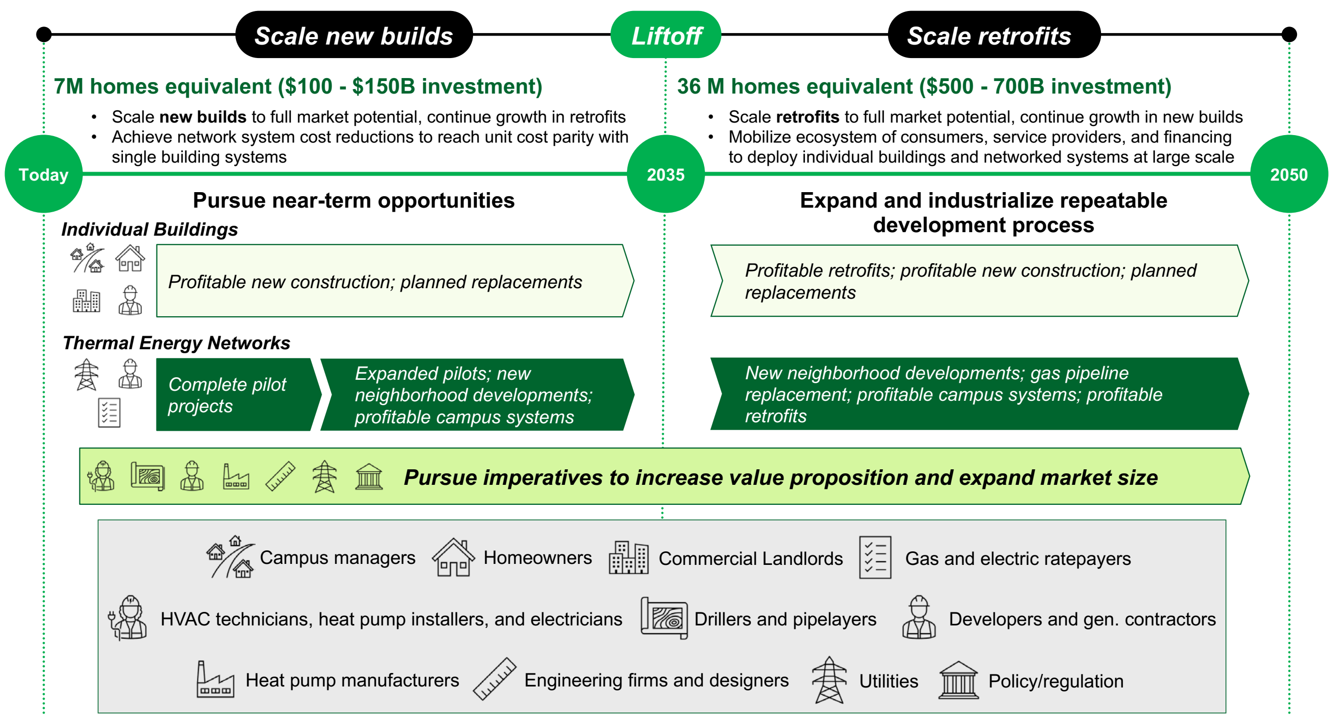
Tax incentives are key to both current and future geothermal heating and cooling adoption. The higher upfront cost relative to lower-capital cost alternatives limit adoption of geothermal heating and cooling. The federal tax incentives introduced or extended in the Inflation Reduction Act (IRA) have dramatically expanded the opportunities for GHPs and TENs for both commercial and residential customers. **Residential GHPs are covered by the residential clean energy credit (25D), and commercial GHPs are covered by the Investment Tax Credit (48 or 48E), which both cover 30 percent of total cost of installation with no upper limit.** Residential ASHPs are instead covered by the energy efficient home improvement credit (EEHIC, 25C), which has a limit of $2,000 per year for ASHPs. Additionally, both ASHPs and GHPs are eligible for the Energy Efficient Commercial Buildings Deduction (179D), which is awarded contingent on meeting efficiency standards. This combination of renewable energy and efficiency credits can make geothermal heating and cooling the option with the lowest upfront cost for consumers in specific installation types.

Pathway to Commercial Scale

Tens of millions of homes and businesses could install GHPs by 2050 with a positive lifetime payback (Figure 24). The 2050 "market" potential, defined as installations with a positive net present value over 10 years, is the equivalent of 21 million homes (52 million tons) for residential installations and 37 million tons for commercial installations. The 2050 "expected installation" potential, defined as installations assuming an empirically-derived percentage of installations at different payback periods and meant to represent current customer behavior, is the equivalent of 9 million homes (23 million tons) for residential installations and 6 million tons for commercial installations. **Without concerted interventions to improve the value proposition and expand the market geothermal heating and cooling will fail to meet its full potential.**

The geothermal heating and cooling industry can stay on track to reach its full market potential in 2050 with a steady industry annual growth rate of ~10 percent. This growth rate is achievable through 2035 by meeting the expected growth in retrofit installations and focusing on increasing the growth of installed systems in new builds, which have lower barriers for installations and will help make initial progress on imperatives to scale. The growth rate is achievable after 2035 by maintaining continued growth of new builds and focusing on increasing the growth of installed systems in retrofits.

Geothermal heating and cooling can reach Liftoff in 2035 by focusing on scaling near-term opportunities for installations of GHPs in the equivalent of 7 million homes, a $100-150 billion investment opportunity (ES Figure 6). The industry can reach commercial scale in 2050 by next expanding and industrializing a repeatable development process that includes retrofits, building systems in the equivalent of 36 million homes with a $500-700 billion investment opportunity.



ES Figure 6: Pathway to Liftoff and commercial scale for Geothermal Heating and Cooling. For stakeholder roles, see ES Figure 3.

Notes: Investment estimates calculated using average system costs from ES Figure 5, removing weatherization and retrofit costs for new builds.

Achieving Liftoff by 2035 implies 3x growth of current U.S. GHP capacity, which has the potential to significantly reduce summer and winter peak demand as well as overall grid system cost. **At Liftoff, summer demand peak could be reduced by 12 GW, winter peak demand could be reduced by over 40 GW, and annual grid system cost could be reduced by $4 billion compared to potential growth.**

Achieving Liftoff and commercial scale will rely on achieving 5 major imperatives that increase the value proposition (by reducing costs or increasing benefits) and expand the market size of GHPs. A number of potential solutions can unlock each imperative:

Imperative	Potential Solutions
Scale and train workforce	▸ Funding for training programs and apprenticeships in drilling and HVAC installation ▸ Develop and enhance regional train-to-hire pathways
Develop and standardize market-ready products and protocols	▸ Demonstrations in a variety of environments, including urban and suburban communities, potentially incentivized by state-level utility pilot mandates ▸ Provide information on best practices and industry standards (e.g., C448), enabled by technical assistance (e.g. pilots & demonstration projects), capital, and loan guarantees from federal and state agencies
Develop ratemaking or other frameworks to incorporate benefits and refine planning	▸ Evaluate opportunity through GHP benefits to grid, including system-wide/peak load savings and resilience, and advance rate structure modifications & utility program incentives to compensate ratepayers for adopting GHPs ▸ Cost sharing between electric and gas utilities on service upgrades and avoided costs
Clarify and standardize regulations	▸ Integrated system planning requirements for utilities ▸ Updated best practices for local and state regulation, including streamlined permitting and guidelines for drilling deeper boreholes
Realize network effects	▸ Uniform or standardized TENs business models developed from pilot program learnings ▸ Integration of efforts to enable prompt installation (by reducing GHP time-to-delivery to near parity with alternative heating & cooling technologies) and drive GHP adoption

ACRONYMS AND KEY TERMS

§179D	Energy Efficient Commercial Buildings Deduction
§25C	Energy Efficient Home Improvement Credit (EEHIC)
§25D	Residential Clean Energy Credit (RCEC)
§48	Investment Tax Credit (ITC)
AHJ	Authorities Having Jurisdiction
ASHP	Air-Source Heat Pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BDC	Building Decarb Coalition
BIL	Bipartisan Infrastructure Law
BLS	Bureau of Labor Statistics
BTO	Building Technologies Office
BTU	British Thermal Units
C448	ANSI/CSA/IGSHPA C448 Design and Installation and Standard for Ground Source Heat Pumps
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditures
ccASHP	Cold Climate Air Source Heat Pump
COP	Coefficient of Performance
DOE	U.S. Department of Energy
DPA	Defense Production Act
EEHIC	Energy Efficient Home Improvement Credit, see §25C
EERE	DOE Office of Energy Efficiency and Renewable Energy
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ES	Executive Summary
FERC	Federal Energy Regulatory Commission
FOAK	First-of-a-kind
GHG	Greenhouse Gas
GHP	Geothermal Heat Pump
GTO	Geothermal Technologies Office
GW	Gigawatt, 1×10^9 W
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
HVAC	Heating, Ventilation, and Air Conditioning
IGSHPA	International Ground Source Heat Pump Association
IRA	Inflation Reduction Act
IRA	Inflation Reduction Act
IRC	Internal Revenue Code
IRS	Internal Revenue Service
ITC	Investment Tax Credit (Section 48)
kW	Kilowatt, 1×10^3 W
kW_{th}	kilowatt-hour thermal
LIHTC	Low-Income Housing Tax Credit (Section 42)
LPO	DOE Loan Programs Office
MW	Megawatt, 1×10^6 W
NBER	National Bureau of Economic Research
NERC	North American Electric Reliability Corporation
NOAK	Nth-of-a-kind
NREL	National Renewable Energy Laboratory
OCED	DOE Office of Clean Energy Demonstrations
OEWS	Occupational Employment and Wage Statistics
ORNL	Oak Ridge National Laboratory
PBP	Payback Period
PNNL	Pacific Northwest National Laboratory
RCEC	Residential Clean Energy Credit, see 25D
RECS	Residential Energy Consumption Survey
RT	Refrigeration Tons
SOI	IRS Statistics of Income
TEN	Thermal Energy Network
Tons	See RT, Refrigeration Tons
TRL	Technology Readiness Level
TW	Terawatt, 1×10^{12} W
UNGC	Utility Networked Geothermal Collaborative
UTEN	Utility Thermal Energy Network

Conversions:

1 RT = 1 ton = 3.517 kW_{th} = 12,000 BTU/hr

Chapter 1: Introduction and Objectives

KEY TAKEAWAYS:

- **Geothermal heating and cooling technologies can simultaneously help achieve energy security, energy efficiency, customer resilience, and energy affordability goals at scale and help manage emerging load and peak demand growth issues.**
- Ambitious building decarbonization goals are critical for achieving economy-wide targets set by the United States. Geothermal heating and cooling contributes to three key levers for building decarbonization: energy efficiency, efficient electrification, and grid edge resource management.
- The efficient electrification of buildings is contributing to projections that suggest the U.S. power grid is entering a new era of potentially unprecedented growth, and peak power demand may also be entering a new era of growth in both summer and winter.
- Geothermal heat pumps (GHPs) operate similarly to air-source heat pumps (ASHPs)—using a refrigeration cycle to move heat for heating or cooling—but use the ground as a source and sink of heat, as opposed to the outdoor air. By connecting buildings via piped fluid at ambient temperatures, Thermal Energy Networks (TENs) can leverage the benefits of GHPs.
- Geothermal heating and cooling systems have a multi-pronged and unique value proposition among building decarbonization technologies, including the highest efficiency of all heat pump options in most states, large grid benefits and savings associated with deployment, broad geographic availability, long lifespans, associated local high-quality employment, and high resiliency. Additionally, TENs provide opportunities for bundled financing, advantages for gas utilities that deploy them, and reduce customers' exposure to volatile heating oil and natural gas prices.

Motivation

Liftoff report motivation and objectives

Geothermal heating and cooling technologies can simultaneously help achieve energy security, carbon emissions, and energy affordability goals at scale and help manage emerging load and peak demand growth issues. For this reason, the ability of this industry to reach commercial scale is of strategic importance. This report focuses on this currently small subsection of efficient building electrification with the potential for large growth and outsized impact.

This report aims to achieve the following goals: 1) to identify the current role of geothermal technology in the building heating and cooling market, and its potential role in decarbonizing the buildings sector; 2) to clarify the value proposition of the technology and characterize the market's current state and potential; 3) to sketch a realistic path to commercialize and create market momentum to scale this high technology readiness level (TRL) technology, and 4) to catalog the barriers to achieving that scale, and their potential solutions.

In determining the common fact base on the pathway to scale in this report, a cross-section of public and private sector stakeholders were engaged for interviews in addition to the technical analysis performed by the authors and contributors. These stakeholders included representation from utilities, developers, manufacturers, NGOs and industry groups, state governments, trade unions, and investors.

Building sector transformation

Buildings play a central role in society, and the building stock changes with unique dynamics. Americans spend 90 percent of their time in buildings[2] and spend roughly $375 billion annually on building energy costs.[3,4] There are about 6 million commercial buildings (96 billion square feet, 2018 estimate)[5,6] and 124 million residential units in the United States (2020 estimate), and estimates suggest that by 2050, 40 million additional homes and 60 billion square feet of additional commercial floor space may be constructed.[7]

Accounting for building lifetimes, 75 percent of homes and 51 percent of commercial square feet projected to be in use by 2050 have already been constructed.[8] In 2023, the United States joined the United Nations Buildings Breakthrough with the goal of normalizing near-zero emission and resilient buildings by 2030.[9]

The U.S. Department of Energy (DOE) has developed a multipronged and holistic set of strategies to achieve a transformation of the buildings sector, including through the Affordable Home Energy Shot[10] and the National Blueprint for the Buildings Sector.[11] The Affordable Home Energy Shot aims to accelerate innovative breakthroughs and reduce costs to decarbonize our nation's residential buildings. To achieve the goals laid out, the DOE is focused on building innovations in three areas: building upgrades, efficient electrification, and smart controls. The National Blueprint for the Buildings Sector sets a vision for the buildings sector with four strategic objectives: increasing building energy efficiency, accelerating on-site emissions reductions, transforming the grid edge, and minimizing embodied life cycle emissions. The Blueprint also identifies key technical solutions and presents a call to action.

GHG emissions from the heating and cooling of buildings

GHG emissions from the heating and cooling of buildings account for half of operational buildings sector emissions, and a majority when including water heating**.** Of the combined U.S. residential and commercial buildings sector direct and indirect emissions, 32 percent were for space heating, 11 percent were for water heating, and 18 percent were for air conditioning and ventilation[12] (see Figure 1), for a total of 61 percent. Cumulatively, these categories account for 52 percent of residential building emissions and 67 percent of commercial building emissions.

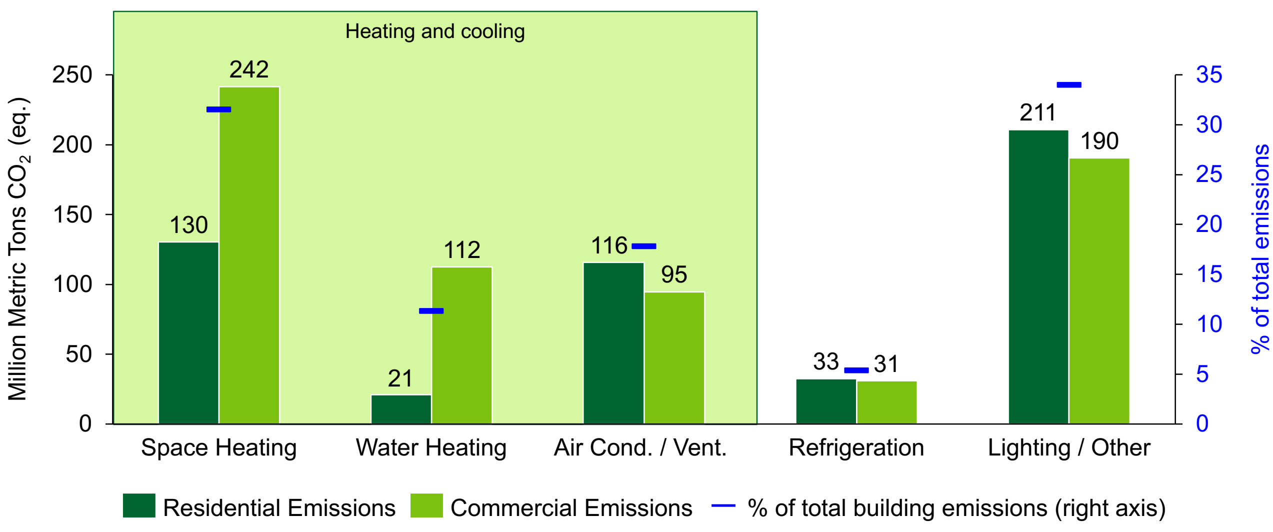


Figure 1: Emissions from buildings sector by end use (million metric tons CO_2 equivalent, % of total)

Notes: Source: Decarbonizing the US Economy by 2050: A National Blueprint for the Buildings Sector, April 2024. [Decarbonizing the U.S. Economy by 2050 (energy.gov)](). Residential includes all residential buildings – single family, multifamily, and manufactured/mobile homes. Commercial includes all commercial buildings – office, education, and other (see source).

GHG emissions from fuel use

The majority (63 percent) of buildings sector site-level GHG emissions are from electricity production and will be reduced with the decarbonization of the power sector. However, **a meaningful portion (37 percent) of buildings site-level sector emissions come from fuel use, and the majority of fuel-based emissions are attributed to heating and cooling** (see Figure 2). On-site fuel combustion accounts for 24 percent of overall buildings emissions (see Figure 3), but fuel use accounts for roughly 50 percent of total emissions from space heating, air conditioning, and water heating, and 75 percent of total emissions from space heating and water heating.

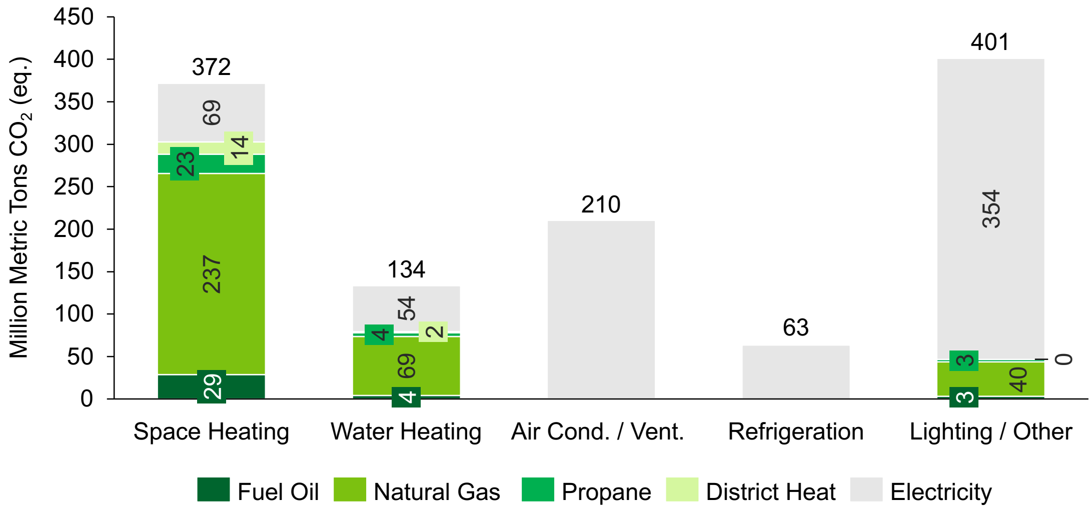


Figure 2: Emissions from buildings sector by energy source and end use (million metric tons CO_2 equivalent)

Notes: Source: Decarbonizing the US Economy by 2050.[13]

Building decarbonization levers

The major building decarbonization levers are energy efficiency and efficient electrification (see Figure 3), which, as described in the section, Introduction to Geothermal Heating and Cooling, are two levers relevant for geothermal heating and cooling. Geothermal heating and cooling also supports grid edge resource management by reducing peak demand and facilitating flexibility, which reduces the cost of electricity infrastructure.

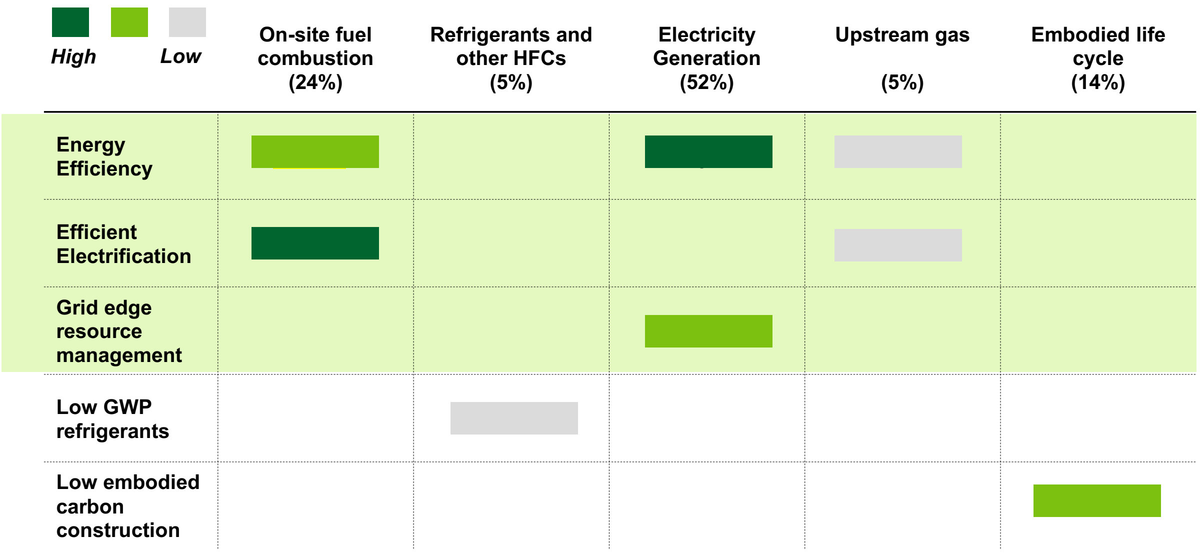


Figure 3: Buildings emissions reduction potential by source for five primary solution types. Values indicated in parentheses (%) indicate percentage of building emissions.

Notes: Adapted from: Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector, April 2024. Decarbonizing the U.S. Economy by 2050 (energy.gov). Data Source: BTO and EPA Publications, incl. energy.gov/eere/articles/decarbonizing-us-economy-2050 and Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022 – Main Text (epa.gov).

Power sector load growth

The efficient electrification of buildings is contributing to projections that suggest the U.S. power grid is entering a new era of potentially unprecedented growth (see Figure 4). Multiple additional factors are also driving this growth, such as the electrification of transportation and industry and increasing electricity demand driven by new manufacturing plants and data centers (particularly to support high performance computing and artificial intelligence applications). As reflected in 2023 Federal Energy Regulatory Commission (FERC) filings, grid planners nearly doubled the five-year load growth forecast, with the nationwide forecast of electricity demand growth increasing from 2.6 percent to 4.7 percent growth.[14] In December 2023, the North American Electric Reliability Corporation (NERC) more than doubled its 9-year electricity demand forecast from the prior year, from ~220 to ~560 GWh of growth.[15,16]

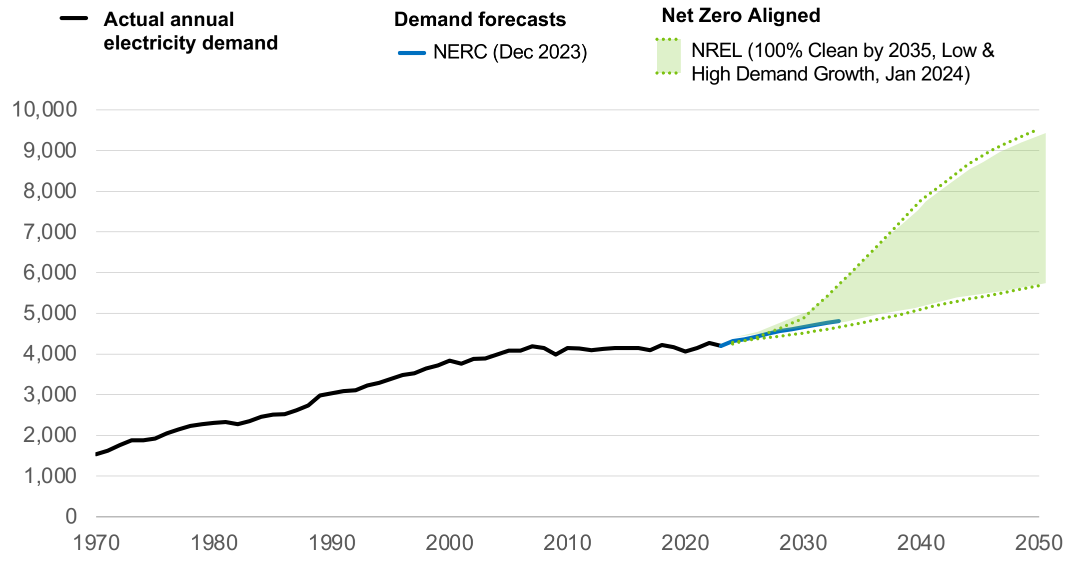


Figure 4: Historical and forecasted annual electricity demand (TWh

Notes: Source: Actual annual and electricity demand from NERC (2023) https://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx. Forecasted annual demand from NREL 100% Clean by 2035: [100% Clean Electricity by 2035 Study | Energy Analysis | NREL]()

Peak power demand may also be entering a new era of growth in both summer and winter (see Figure 5). In some high-electrification modeling scenarios, the projected summer and winter peaks are as much as 150-200 GW higher than the peaks forecasted in NERC electricity demand forecasts. To address this demand growth and peak demand growth, a portfolio approach to meet near-term demand (3-5 years) with commercially available technologies while supporting long-term growth (10+ years) of key technologies to meet demand with low-carbon energy has been identified by the DOE.[17]

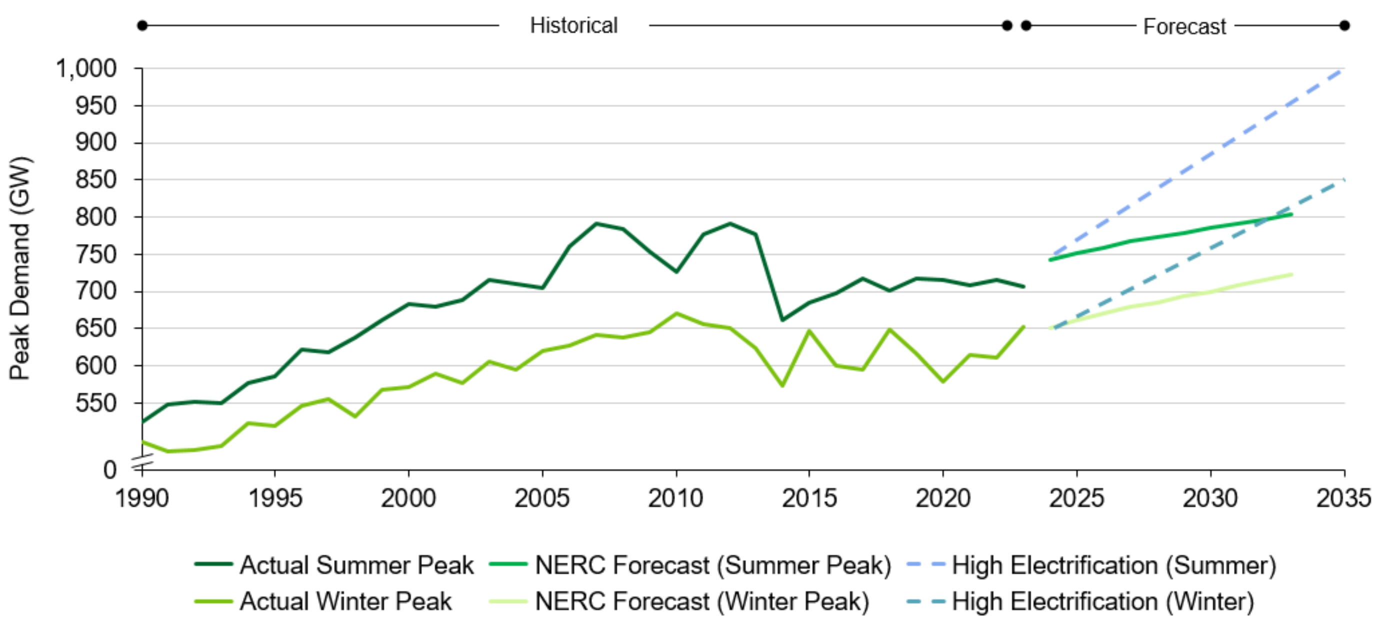


Figure 5: Historical and forecasted seasonal peak demand

Notes: Source: https://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx. Peak demand reported by season as sum of all US regions. Forecast reported as years 1-10 in 2023 forecast. High electrification from EFS scenario in Liu et al. (2023).[18]

Geothermal heating and cooling technologies have the potential to address demand growth and peak demand growth in the power sector. While the value proposition for geothermal heating and cooling is described in further detail in the following sections, it is important to note a study in Maryland found that every ton of geothermal heating and cooling technology deployed can reduce 1 kW of grid demand.[19]

Introduction to Geothermal Heating and Cooling

Geothermal Heating and Cooling Technology Overview and Scope of this Report

Geothermal heating and cooling solutions use the ground as a source or sink of heat and circulating fluids, often connected to heat pump technologies, to maintain temperatures in buildings. They can service single buildings or underpin networked systems operated by single owners, communities, campuses, or utilities. Some geothermal heating systems use high-heat resources deep belowground to transport heat to the surface and distribute to single buildings or networked systems, such as in the city of Boise, ID.[20] Such systems may enjoy the benefits of easier re-use of existing district heating systems originally designed for use with fossil fuel based heating systems. Such systems rely on specific geology that provides heat and fluid flow at economic depths. Other geothermal heating and cooling systems use shallower geothermal resources in conjunction with heat pumps, which is a universal solution applicable in all geologies and climate zones. The shallower, lower temperature systems can additionally benefit from waste heat from industrial and commercial processes (e.g., refrigeration condenser heat, sewer and waste water treatment heat, data center cooling) in addition to heat sources or sinks from the ground at shallow depths.

Because they are applicable in many conditions and use cases, this report focuses on geothermal heat pumps (GHPs) – systems that use heat pumps and the shallow-earth environment, from a few feet below ground to average depths of about 300 feet (full typical range of 50-300 meters)**.** At these depths, ground temperatures are near constant year-round, and the earth absorbs excess heat as a *heat sink* during summer when surface temperatures are hotter and provides additional heat as a *heat source* during winter when surface temperatures are cooler. The key to using this resource is the heat pump, which uses electric power to compress and expand refrigerants and exploit their natural properties to generate heat energy when compressed and absorb heat energy when expanded, transferring heat between refrigerant and air or fluid. Because heat pumps simply move heat energy from a hot side to a cold side, they can achieve far greater efficiencies than electrical resistance heating. In conjunction with the efficient heat transfer with the earth's consistent temperatures, GHPs are highly efficient (described in further detail in the section, Geothermal Heating and Cooling Value Proposition). This type of system is sometimes referred to as a "ground-source heat pump."

GHPs operate similarly to air-source heat pumps (ASHPs)—using a refrigeration cycle to move heat for heating or cooling—but use the ground as a source and sink of heat, as opposed to the outdoor air. The GHP market share is currently just 1 percent of installed residential dwelling unit primary heating systems, with 1.3 million installations, compared to 13 percent for ASHPs, with 15.9 million installations (see Figure 6). While the thermodynamic principles are the same, the ground provides a more constant temperature for heat exchange than outdoor air, increasing the efficiency of GHPs (see the section, Geothermal Heating and Cooling Value Proposition).

Heat pumps can heat or cool depending on the direction of use, and by using the ground as a heat source and sink, GHPs reduce the influence of weather to achieve high efficiency (see Figure 7). Figure 6 demonstrates the cooling mode of both major heat pump categories, in which the heat exchanger releases heat to stabilize the temperature of refrigerants that absorb heat when they are compressed using electricity. Figure 7 demonstrates both modes for GHPs.

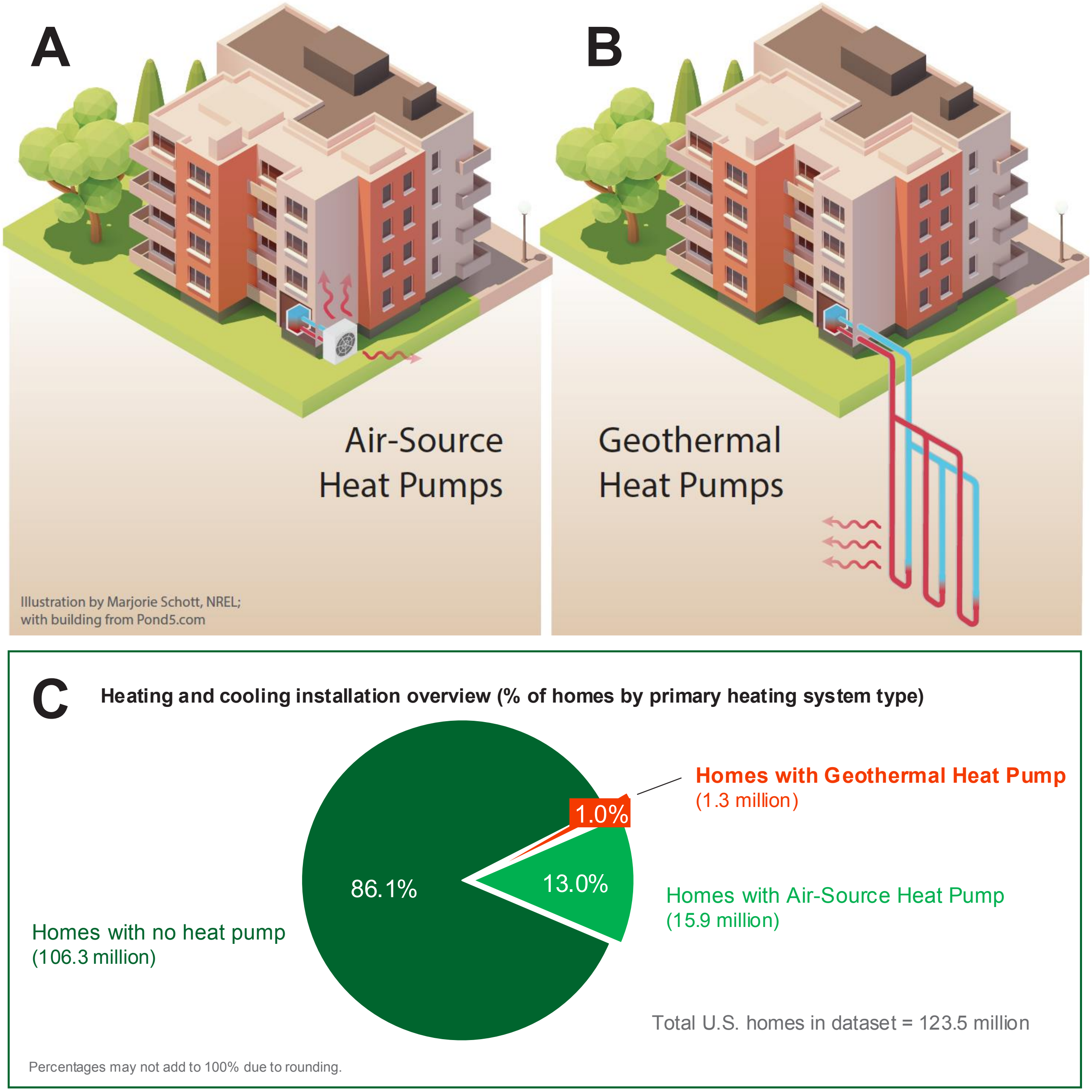
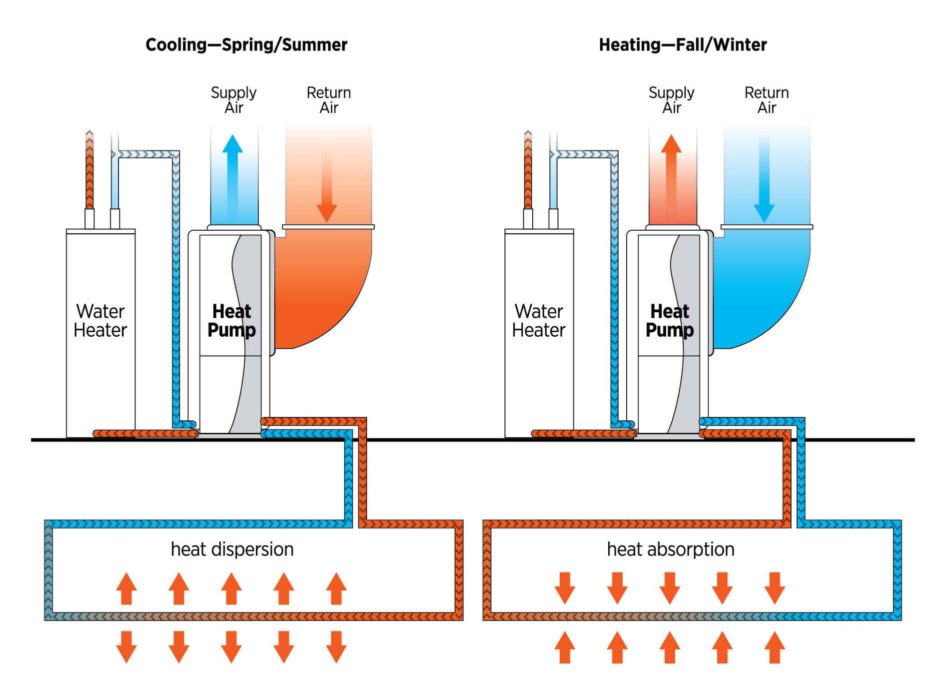


Figure 6: Overview of heat pump technologies and current market share. A) Air-source heat pump overview and explanation of functioning principles for spring/summer cooling mode, B) Geothermal (ground source) heat pump overview and explanation of functioning principles for spring/summer cooling mode, C) Market share of geothermal heat pumps, air-source heat pumps, and all other heating and cooling technology.

Notes: Images adapted with permission from Marjorie Schott, National Renewable Energy Laboratory. Sources: EIA RECS 2020; L. Davis (2023) NBER Working Paper No. w31344; Atlas Buildings Hub (2023). Dataset represents all occupied dwelling units in the United States; excludes vacant units and vacation homes.



Heat pump principles:

- Pull heat from a source and deliver it using a carrier fluid instead of generating heat like a furnace or heater
- Heat and cool depending on direction of use

Geothermal heat pump principles:

- Employ buried pipes to use the ground as a source or sink for heat
- Stable subsurface temperatures remove influence of weather

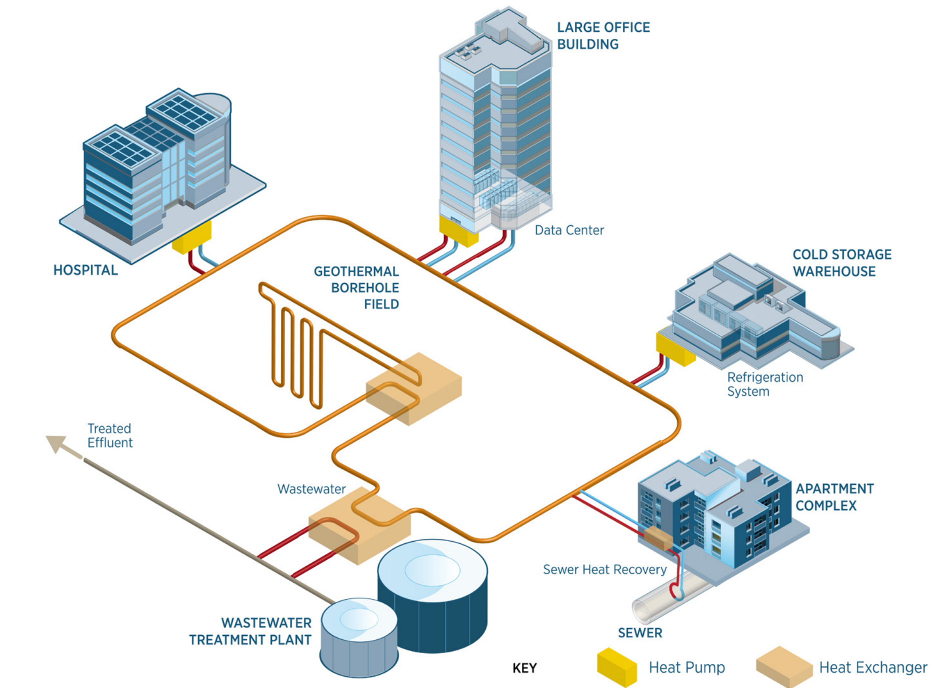
Figure 7: Geothermal heat pump (GHP) principles

Notes: Source: DOE *GeoVision (2019)*. Graphic adapted with permission by NREL from WaterFurnace**.**

By connecting buildings via piped fluid at ambient temperatures, Thermal Energy Networks[iii] (TENs) can leverage the benefits of GHPs. TENs employ shared geothermal boreholes and heat exchangers that are connected to a shared network of piped fluid. GHPs boost or lower the working fluid to the operational temperature at the building level for heating or cooling. Different heating and cooling needs within the network can be met at the same time and therefore smoothed in the networked systems. For example, a hospital may require cooling even in winter months for medical storage, whereas schools and apartments require heating. This "give and take" can ultimately lead to even higher efficiency. Furthermore, **by bundling the infrastructure and capital needs to construct TENs, utilities can increasingly participate in their construction.[21]**

TENs are the latest in an evolving set of technologies used for district heating and cooling and are sometimes referred to as "fifth-generation" district heating and cooling systems.[22] First- and second-generation district heating systems transport steam and pressurized fluids, often heated by fossil fuels, to a network of buildings. These systems can typically only be used for heating.[23] Third- and fourth-generation district heating systems transport heated fluids to a network of buildings. These systems can also typically only be used for heating, but heat pumps can be used to electrify the heating only. Depending on the status of the piping infrastructure in a retrofit of a district heating system, third- and fourth- generation approaches may be a more economical pathway to decarbonization at the community level than a TEN because the heating can be electrified at a single source. One benefit of TENs and fifth-generation systems is that they can be used for both heating and cooling, and therefore can achieve GHG emissions reduction levels and economic efficiencies that heating-only systems may not achieve in areas where cooling is necessary.

iii Thermal Energy Networks can refer to a broad category that include multiple generations of district heating and cooling. In this report, the term refers to "fifth-generation" district heating only.



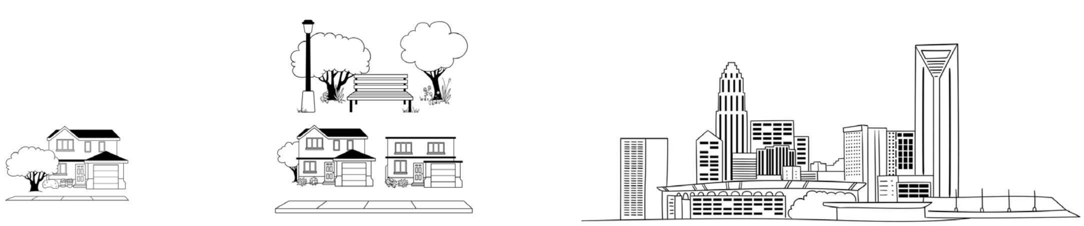
TENs principles:

- Couple heating and cooling loads across different applications via piped fluid, allowing for systems to use one another as a sink or source for heat
- Geothermal heat pumps in use for heating and cooling distribution within each building and connected to the shared loop
- Utilize or store heating or cooling potential that would otherwise be wasted
- Geothermal ground loops can be used as a versatile source or sink of heat, and borehole storage can be used to store up excess heating and cooling between seasons

Figure 8: Thermal Energy Networks (TENs) principles

Notes: TENs, as discussed in this report, refer to systems in which a borehole field is used as a heat source and/or sink for a larger interconnected set of GHPs in a complex of buildings, generally connected by an "ambient temperature loop", insulated pipes filled with water being used as a heat transfer medium. Source: Graphic adapted with permission by NREL from Marjorie Schott.

Geothermal heating and cooling can be employed at multiple scales in the built environment, from single buildings to city-wide (Figure 9). Single building systems can include homes, single commercial buildings, and interconnected HVAC solutions connected to GHPs – a category especially relevant for cooling of commercial spaces that generate heat in their function, such as data centers. Due to the growing power demand from increasing construction of data centers, this is a use case that has received attention and funding from the DOE.[24] Networked systems can include campus-scale systems that are present in universities,[25] community-scale systems such as the Eversource pilot in Framingham, Massachusetts,[26] and eventually city-wide constructions as networks grow. The current market and stock of these different types of systems are described in detail in Chapter 2: Current State – Technologies & Markets.



	Single Building	Campus / Community	City
Ownership Model:	Home or business owner (one time upfront or fee-based lease)	Developer / Landowner (Potential growth in utility ownership)	Utility (Potentially also City / Local government)
Key benefits:	Resilient heating and cooling; lower electricity use; decarbonization	Economies of scale; high performance during peak load	Diverse, mixed-use thermal assets increase efficiency; large scale decarbonization of heating and cooling for buildings; lower grid demand for city; bundled financing and rate-basing

Figure 9: Geothermal heating and cooling systems at different scales from single-family home to city-scale district heating and cooling systems.

Geothermal heating and cooling solutions may be deployed during retrofits or new construction, with differentiated requirements and costs. In general, the additional activities required to retrofit buildings are more expensive and complicated than the integrated planning possible when including geothermal heating and cooling in a new construction. However, as mentioned, the majority of buildings that will be in use in 2050 have already been constructed, so no impactful approach to deploying this technology should focus only on new builds. To retrofit buildings, there are often requirements for interior work including weatherization, duct work, and upgrades to the electrical panels, all of which may be planned from the beginning in the case of new builds. In both retrofits and new builds, borehole fields must be constructed, which involves significant but temporary disturbance to the building site. Again, this can be more convenient in the case of new builds.

Geothermal heating and cooling value chain

The construction of geothermal heating and cooling systems involves various stakeholders and decisionmakers at every level of the value chain (Figure 10). These stakeholders have distinct roles and responsibilities. The way they collaborate depends on whether construction is for 1) a single building vs. for a TEN, and 2) a new build vs. retrofit. While some actors operate at the national or international level, many only operate as highly localized regional businesses, which can contribute to inconsistencies in supply chain, knowledge, and pricing. Thus, the pathway to scale for GHPs must account for the various complex interactions along the value chain depending on installation type.

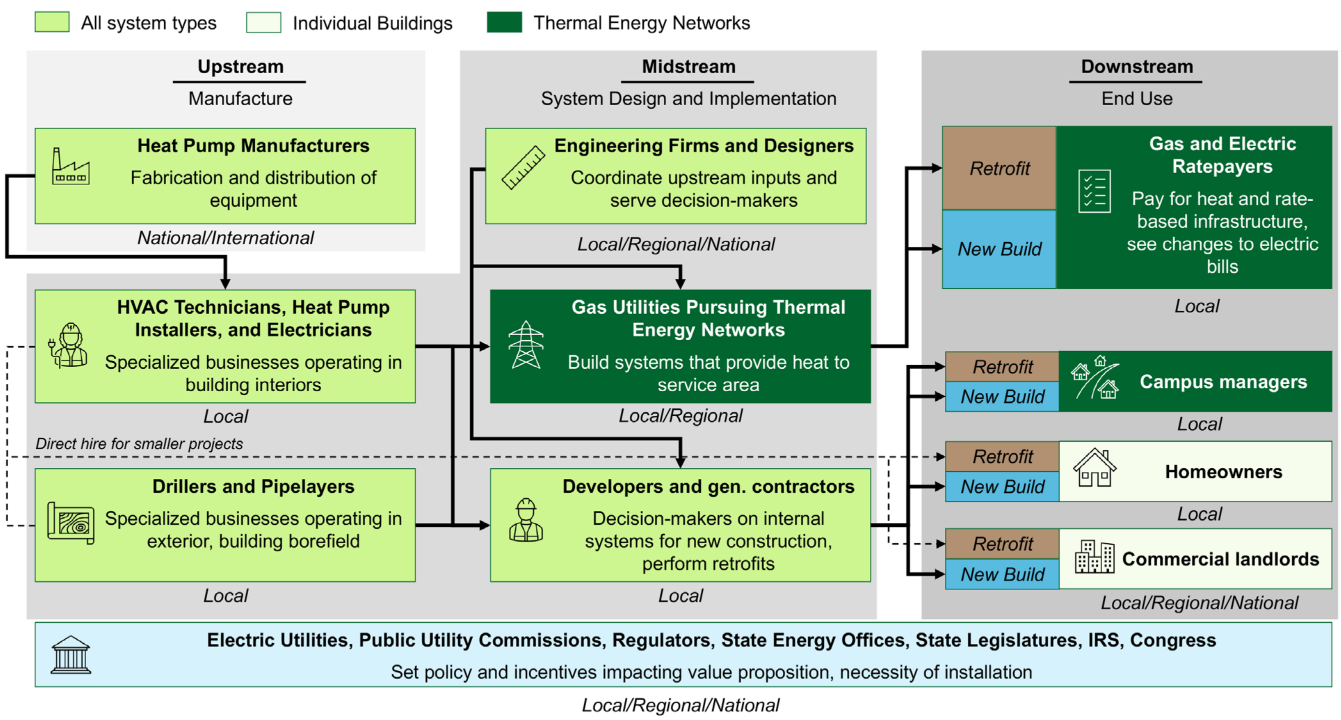


Figure 10: Geothermal heating and cooling value chain

Geothermal Heating and Cooling Value Proposition

Geothermal heating and cooling systems have a multi-pronged and unique value proposition among building decarbonization technologies (Figure 11). Each attribute is described in further detail below.

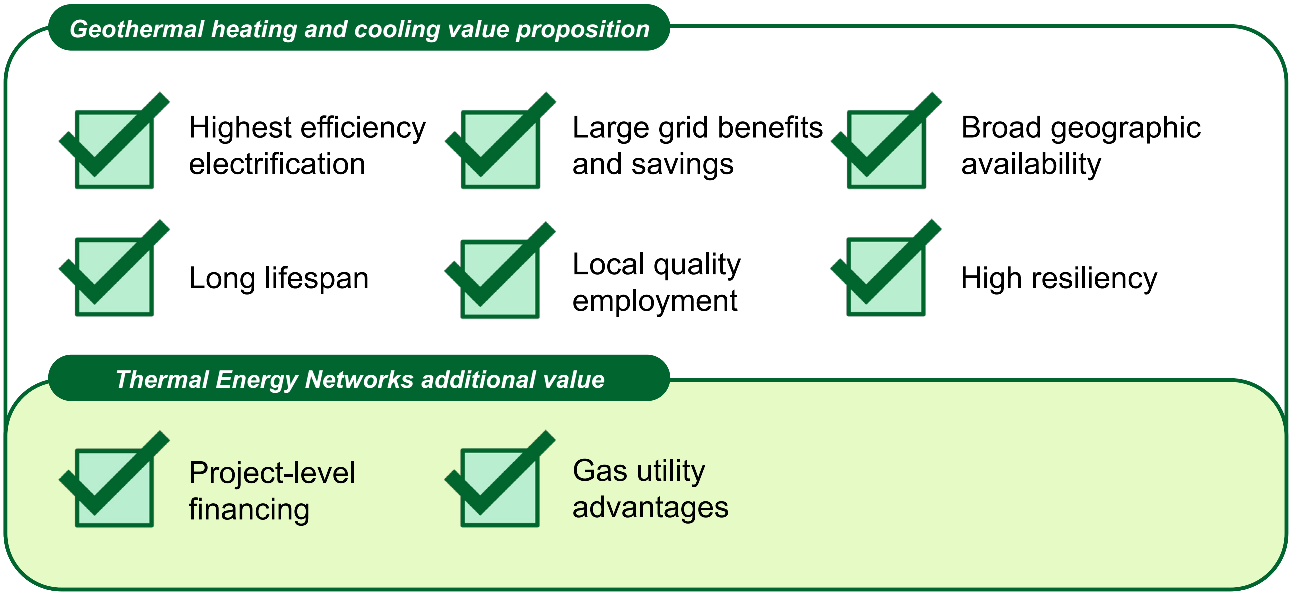


Figure 11: Geothermal heating and cooling value proposition

Highest efficiency electrification

When accounting for weather conditions across the United States, GHPs have the highest Coefficient of Performance (COP)[iv] of all heat pump options in most states. ENERGY STAR® ASHPs generally have lower COPs than both cold-climate ASHPs and GHPs in regions with cold and very cold temperatures (see Figure 37 for a map of climate zones), and GHPs achieve higher COPs than ENERGY STAR ASHPs in almost all regions. The advantage is less pronounced than when compared against cold-climate ASHPs, but there are still notable differences, especially in very cold regions. This high efficiency can lead to higher emissions reductions per unit than other heating and cooling technologies.

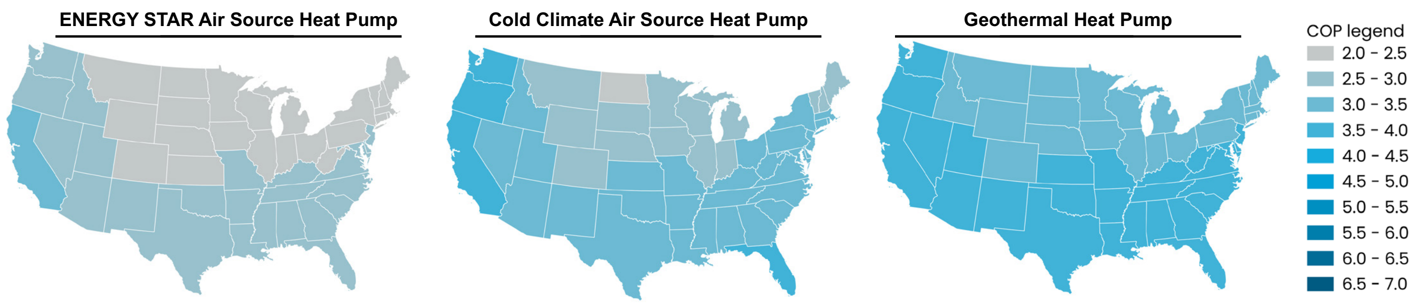


Figure 12: Heat pump winter heating efficiency by geography, expressed as simulated Coefficient of Performance (COP) from ResStock model runs. ENERGY STAR and Geothermal Heat Pump models represent single-speed compressor packages that were chosen as typical examples of models available on the market. The Cold Climate Air Source Heat Pump model represents a variable speed compressor heat pump that maximizes performance and energy efficiency. Future work on the BuildStock package will include similar variable speed models for Geothermal Heat Pumps.

Notes: COP data simulated based on 2018 weather conditions by state and heat pump characteristics. Only residential BuildStock package upgrades are shown. Source: Praprost, Marlena and Amy Allen. 2024. *End-Use Savings Shapes Upgrade Package Documentation: Comprehensive Geothermal Heat Pump Package: Central Hydronic Water-to-Water GHP + Packaged Water-to-Air GHP + Console Water-to-Air GHP*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-89133. https://www.nrel.gov/docs/fy24osti/89133.pdf.

iv A measure of efficiency, equivalent to ratio of useful heating or cooling provided to work (energy) required.

Furthermore, the high efficiency of GHPs means that the reduction in utility energy bills is the highest among all options for heating and cooling electrification.

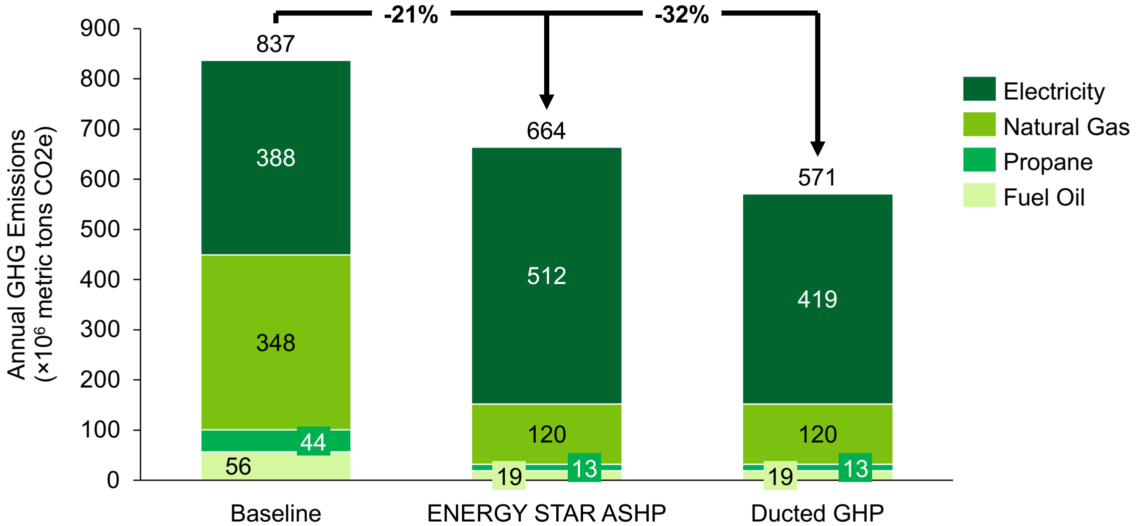


Figure 13: Total emissions reduction from heat pump installation in residential buildings comparing potential swap outs of current heating and cooling systems in the residential building stock with various models of air-source and geothermal heat pumps.

Notes: ENERGY STAR ASHP and Ducted GHP represent single-speed compressor models in the ResStock modeling system. The Cold Climate ASHP is a variable speed compressor model used to maximize efficiency for the model. Dual-speed and variable speed compressor models are currently available in the GHP market, and are planned to be added to ResStock and ComStock in 2025. The Baseline model represents the U.S. commercial building stock in ResStock as it existed in 2018 (for methodology see Wilson et al., 2022) *Sources: ResStock's 2024 Release 2"* Praprost et al. (2024),[27] Wilson et al. (2022).[28]

Large grid benefits and savings

Upgrading to GHPs reduces the peak load on the grid in all climate zones in all seasons except for winter peak load in cold climate zones (Figure 14). This reduction in peak intensity, which is the maximum electric demand for heating or cooling, is higher for GHPs than for ASHPs. Further, for cold climates where winter peak demand could increase, that increase is lower for GHPs than for ASHPs. Cold-climate ASHPs narrow this gap, but GHPs are still more efficient. As noted in Chapters 2 and 3, the decision of which type of heat pump to install will vary by circumstance and depend on a variety of factors, including geography, price and convenience. See Appendix A: Climate Zone Map for climate zone overview.

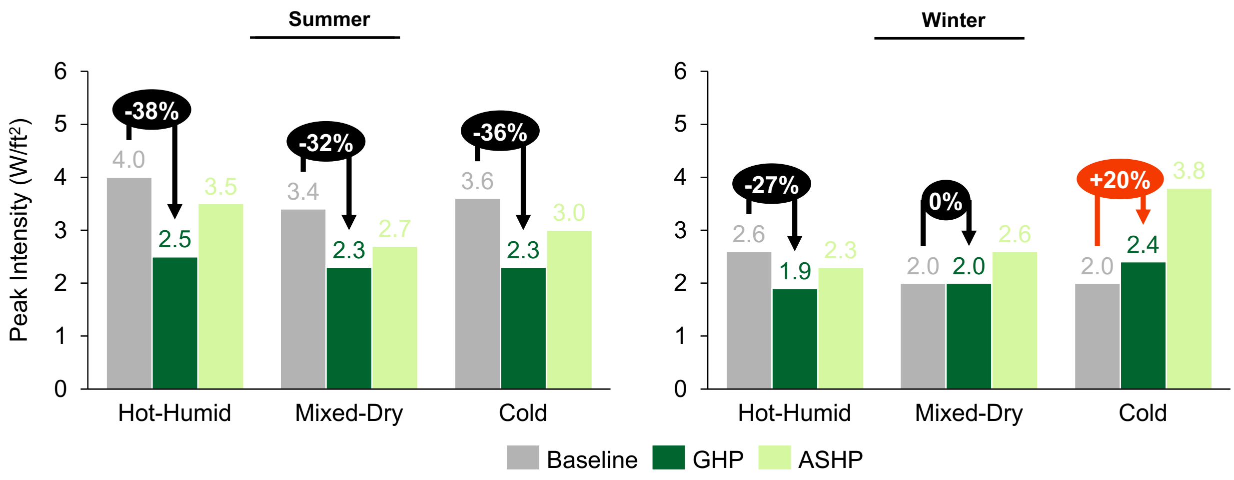


Figure 14: Peak intensity (W/ft²) by season in commercial building stock and selected climate zones (see Figure 37 in Appendix A: Climate Zone Map for climate zone designations)

Notes: Peak intensity represents maximum electric demand for heating or cooling during the respective seasons. Baseline represents “Baseline” ComStock model scenario (see Parker et al., ComStock Documentation); GHP represents “Packaged GHP”; ASHP represents “HP RTU Std Performance”. HP, heat pump; RTU, rooftop unit. See: [Heat Pump RTU | ComStock (nrel.github.io)](). *Sources: Prapost et al. (2024);*[29] Parker et al. (2023).[30]

In scenarios with high levels of electrification, these grid benefits could lead to large benefits in multiple parameters in the aggregate (see Appendix B: Summary of key benefits from widespread GHP deployment). Liu et al. (2023)[31] explore a high GHP deployment scenario (only considering technical potential) vs. an ASHP-only electrification and decarbonization scenario and find that GHP deployment provides large benefits in 2035 and 2050 for: summer peak demand, winter peak demand, cumulative system cost savings, annual customer payment savings, annual generation, required capacity, transmission buildout, and transmission costs.

Broad geographic availability, long lifespan, local high-quality employment, and high resiliency

GHPs have high value and may be the best choice for heating and cooling in a number of geographies, particularly colder regions that also experience significant summer heat. While the relative advantages of GHPs are strongest in cold and very cold regions, their high-efficiency performance in all states (Figure 12) indicates high value in a broad geographical range. Indeed, deployment projections (see Chapter 3) indicate potential economic installation in a significant percentage of buildings in most states.

GHPs and TENs have long lifespans – outside components such as ground loops can last 100 years or more, and GHP compressors are shielded from weather and therefore comparatively long-lived[32] – and systems often last longer than the original capital planning intends. These long lifetimes are often cited in the decision-making for campus systems at institutions like universities and hospitals, which plan for longer periods than a typical commercial development. Because of the reductions in primary energy bills, the decision to invest in a GHP or TEN is more appealing when considered on longer timeframes, which is possible due to the long lifespans of the systems.

GHP installations create local and regional jobs because expenditures flow mainly to midstream and upstream stakeholders in the GHP value chain, which are predominantly local and regional workers and small businesses. In deployment scenarios, GHP expenditures have broad geographic coverage of the United States,[33] consistent with the broad geographic applicability of GHPs.

Because of the underground heat exchange, GHP functionality is isolated from weather changes and generally more resilient to extreme weather. The consistent temperatures of the subsurface mean that extreme cold or heat will not affect the performance of GHPs, and the underground design of ground heat exchangers mean that GHPs can be expected to fare well in storms and other extreme weather events.

Additional value from TENs

TENs, which connect GHPs in networked systems, have a subset of specific benefits and advantages.

Because the construction of a TEN can involve multiple buildings and systems, project-level financing can serve many customers at once who may not have been able to pursue a single-building system. This business model matches well with that of utilities, which can rate base new infrastructure and roll cost into a monthly service fee for users.

Furthermore, gas utilities that intend to decarbonize or are facing low-carbon fuel mandates can consider TENs a potential low-carbon option for new infrastructure when gas pipelines reach end of life. Utilities can leverage their rights of way, access to capital, skilled workforce, and customer relationships to successfully deploy TENs within their existing business model. TENs are carbon free because they leverage efficient electrification and waste heat for heating and cooling. They can be especially appealing when considering the relative costs of the marginal infrastructure in the case where TENs are deployed instead of replacing existing gas pipelines, which in many cases can be comparable (see Chapter 4, Challenge 3).

When deployed, TENs also have significant benefits to local communities. Deployments of TENs in low-income communities reduces the primary energy bills and by being more likely to be deployed in these communities than individual building GHPs because of their bundled financing potential. Despite existing incentive programs, weatherization and modernization of buildings, which have major benefits to these including job creation, have nonetheless been shown to be lacking in single-building electrification.[35] TENs also address priority 2 through the potential replacement of gas pipelines, which can help avoid natural gas leaks, with benefits to air quality and urban tree cover.[36] The energy burden implications of reductions in primary energy bills for projects can be assessed using corresponding mapping tools.[37] However, TENs that are deployed by utilities in these communities also have the potential to gentrify communities and displace residents, and local organizations are beginning to develop community engagement protocols to ensure the benefits serve those for whom they were intended.[38]

Chapter 2: Current State – Technologies & Markets

KEY TAKEAWAYS

- GHP installations in the United States today are estimated at ~114,000 units per year (as of August 2024).
- Net costs of U.S. residential GHP installations vary by region, with the lowest net costs[39] in the Northeast and South ($7,200–7,300/ton) and highest net costs in the West ($11,600/ton). These costs are dependent on federal tax incentives and are still generally the highest-first-cost option for anyone considering either a new HVAC system or a retrofit.
- Larger commercial installations can potentially utilize incentives to be cost competitive with other HVAC options, through a combination of the Investment Tax Credit and other options.
- Regional differences in GHP installation costs are driven by drilling and labor costs, which vary based on the availability and experience of local drilling companies and installers, as well as variations in both local regulation and geological subsurface characteristics.
- Currently, TENs are primarily installed on single-owner facilities like medical centers, military bases, and college campuses. Utilities (particularly gas) are executing pilot projects, but the long-term implementation of TENs as a replacement for the natural gas business model relies on both state policy and proof of the financial viability of the pilot projects.

Current state of GHP installations in the United States

Geothermal heat pump installations are a small but meaningful segment of the U.S. HVAC market. Historical installations and estimated in-service units are shown in Figure 15, highlighting a market that grows steadily but is not yet fulfilling its full potential as a decarbonization and energy efficiency technology. As of August 2024, installations are estimated at a rate of 114,000 units per year, as compared to 3.6 M units of ASHPs per year[40] and 3 M oil and gas furnaces.[41]

Annual installations estimated by the best estimate analysis shown in Figure 15 suggest that the current level of GHP installations as of tax year 2023 is on the order of 114,000 equivalent household units per year, with net additions around 85,000 units per year after accounting for retirements. Uncertainty around the number of installed and operational GHPs in the United States is considerable,[42] and more comprehensive surveys of GHP manufacturers reporting heat pump units shipped by unit type and application will give better clarity and confidence to current deployment trajectories.

While exact data is limited, an acceleration in the growth of GHP installations can already be seen in the years since the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) incentives were passed (Figure 1). Analysis of the effects of these policies will take time and more robust data collection, but the little data we have and anecdotal data from stakeholders indicates that these policies have catalyzed growth. Predictions for TENs are more difficult, but commitments to net-zero in many states have led gas utilities to look for alternative business models, and pilot projects being built by utilities are poised to show the potential of these projects moving forward.

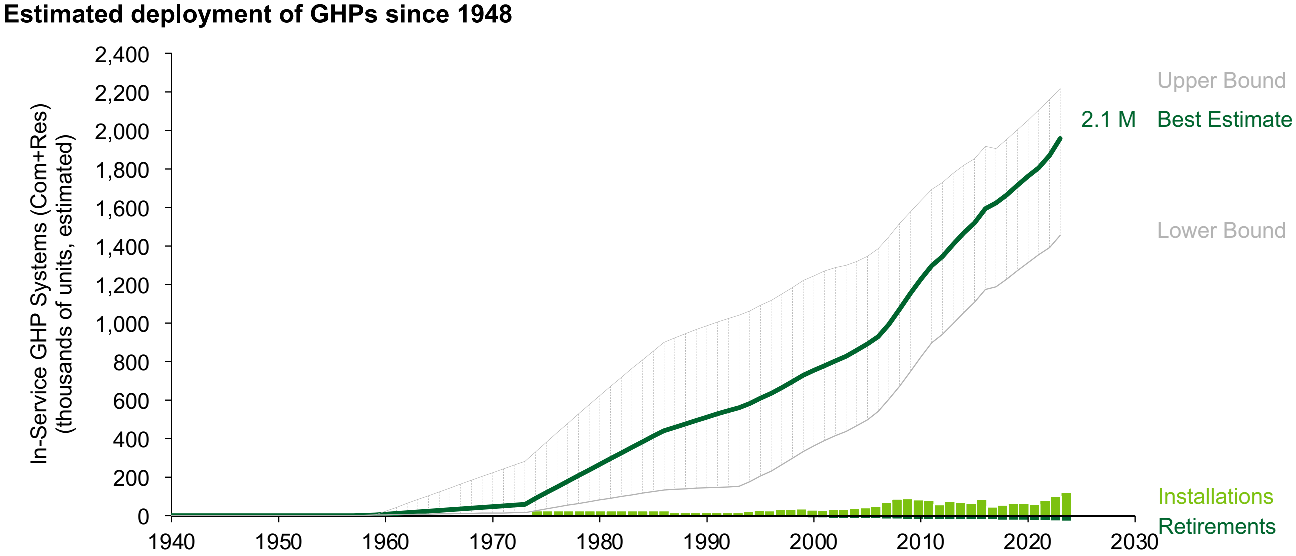


Figure 15: Current GHP capacity stands at 2 million GHP units in service with annual additions exceeding 100,000 units.

Notes: Data gathered from tax returns, trade publications, and manufacturers surveys available for years 1994 to present. Data were adjusted to account for an assumed 3.5:1 ratio of residential:commercial units, a range of possible deployment trajectories during years 1993 and earlier, and a range of failure rate assumptions. Bar chart shows the gross installations & retirements for the Best Estimate scenario, which adopted a Weibull failure probability model fitted to the survival curve of centrifugal chillers (2019 ASHRAE Handbook—HVAC Applications – Fig. 38-1, median service life ~32 years). Installations for 2023 are based on preliminary tax return information, adjusted to account for late filings."

Sources of original or collected data include: IRS Statistics of Income, Pub. 4801 (2008-2021); Holihan (1998) *Analysis of Geothermal Heat Pump Manufacturers Survey Data*; EIA (1997, 2003, 2009) *Geothermal Heat Pump Manufacturing Activities*; EIA (2020) RECS; ENERGY STAR Shipment Data (2003-2015); BRG Building Solutions (2022) *The North American Heating & Cooling Product Markets*, *2022 Edition*; Malhotra et al. (2023) 14th IEA Heat Pump Conference; Tanguay (2017); Liu et al. (2019) "GeoVision Analysis Supporting Task Force Report: Thermal Applications—Geothermal Heat Pumps". ORNL/TM-2019/502; Navigant Research (2013); Lund and Boyd (2016).

Estimated growth of installed GHPs, shown in Figure 15 indicates that the installed U.S. stock of GHPs is growing by 4.6 percent a year. This is less than half the growth rate of the GHP market in Europe (estimated at +12 percent per annum for 2023).[43] We believe that **substantial room exists for the U.S. growth rate of GHP deployment to rise before it might run into further logistical limits** in heating & cooling units needing replacement and new builds. While Europe's gas and power markets and applicable consumer & commercial incentives are substantially different than those of the United States, it seems reasonable that with the right interventions the growth of the U.S. market could approach that of Europe.

Thermal Energy Networks (TENs) that include geothermal heating and cooling are an even smaller segment of the U.S. HVAC market, with projects mostly on either college campuses or military installations. State and local utility policy have funded pilot plants that have generated deeper interest and momentum for the technology. Most notable is Eversource's Framingham pilot project, which is the first district geothermal system backed by a natural gas utility.[44] Other states like New York, Illinois, and Colorado are following suit, with legislation mandating the funding of pilot projects.[45]

Statewide/national policy dynamics and impact on adoption

Multiple states and local governments have implemented renewable portfolio standards (RPS), issued requirements to reduce the utilization of fossil fuels for heating & power generation, and/or mandated a phase-out of newly installed natural gas or oil-based heating systems.[46]

Unlocking geothermal heating and cooling systems on a mass deployment scale for residential and commercial buildings would allow for property owners and utilities to comply with policies and achieve economic benefits alongside realizing long-term environmental benefits. Gas utilities in these states are considering providing geothermal heating and cooling as a potential pivot, where they deliver "heat" as a service, rather than gas.

For both TENs and GHPs, drilling is an essential step of installation, where the ground loop or borehole field is installed. This makes drillers and drilling a key workforce and industry for geothermal heating and cooling. In conversations with developers and installers, drilling was repeatedly indicated as a bottleneck for projects. Drilling as an industry is dominated by residential water well and commercial oil and gas drilling, making it difficult for some installers to source drillers. While there is some transferability from these other drilling industries, businesses in these industries are in high demand and cannot necessarily be easily sourced or retrained in areas where new buildout of geothermal heating and cooling is demanded.

Despite the clear benefits to grid infrastructure from geothermal heating and cooling deployment, multiple mechanisms and tradeoffs exist in capturing the value to the grid for geothermal projects and there is not one clear solution to capture that value. Utilities, state and local governments, and a broad variety of other stakeholders have demonstrated clear interest and intention by funding pilots and studies to explore the feasibility of TENs but the business case for these projects is still unproven, and much of the interest is driven by decarbonization policies. Recently, the Brattle Group produced an exploratory study showing possible changes to the utility rate structure and incentives that could improve alignment of customer behavior with peak load reduction goals, and as well as treatment of what the marginal worth of a kW avoided is (depends on grid capacity constraints at particular location).[47] Their study indicated that power system benefits can best accrue to geothermal projects by modification of two of four cost components of typical residential electricity bills in the NYISO region: energy, generation capacity, delivery, and GHG, to better align cost drivers and ratepayer incentives. Specifically, they suggested that because the primary cost driver of generation capacity and delivery is peak demand rather than volume (as is the case for the other two cost components), a purely volume-based rate structure for residential electric customers means that high load factor customers are disproportionately burdened and that peak reduction is undervalued. In this NY case, the Brattle Group's suggested workaround is to introduce a peak demand element into generation capacity and delivery charges to appropriately compensate customers who switch to geothermal heating & cooling systems for the attendant reduction in peak demand. Possible measures suggested included a new utility program for peak reduction or load shaping, incremental modifications to existing energy efficiency program(s), and improvements in electricity rate design. However, modifications to rate structures and utility billing & savings programs are still in their infancy or in early stage testing.

Thermal Energy Networks

Current TENs installations are largely limited to pilot projects, college and military campuses, and cities with readily available near-surface geothermal features. TENs, despite their potential for maximizing efficiency of geothermal heating and cooling (as well as utilizing myriad sources of waste heat), are even less common than single-building GHPs. While there is strong interest in the technology, the high capital cost and low cost of alternatives mean that TENs market penetration remains limited. In Europe, district heating overall is much more common and many large cities have areas that are at least partially heated in this fashion. It's important to note that most of these European systems are heating only and from an earlier generation of district heating technology, whereas the currently proposed TENs utilize an ambient temperature loop to provide both heating and cooling. Figure 16 displays a map of currently installed projects in the United States that fit these criteria, with the caveat that some of these projects depicted in the figure may only constitute two interconnected buildings. Many of these projects are on college campuses and military installations. It seems likely that single-owner campuses (military, collegiate, or otherwise) will continue to be an area of growth for TENs for all the reasons discussed above.

Flagship projects on campuses are the result of the unique position of campus owners and operators. These facilities represent organizations that generally have full ownership of and authority over the location of their campus, and plan to occupy this land for at least 50 years. Therefore, the large upfront investment can be considered over this much longer project lifespan. Many college campuses also will have climate and green energy pledges that TENs can effectively contribute to.[48] Military bases also have a mission for energy independence and resiliency[49], and the significantly lower energy use required for geothermal heating and cooling can be very appealing when viewed through this lens. TENs fit very well on a microgrid system with onsite renewable energy generation due to the flexibility of time of operation and ease of integrating heat storage into the system.

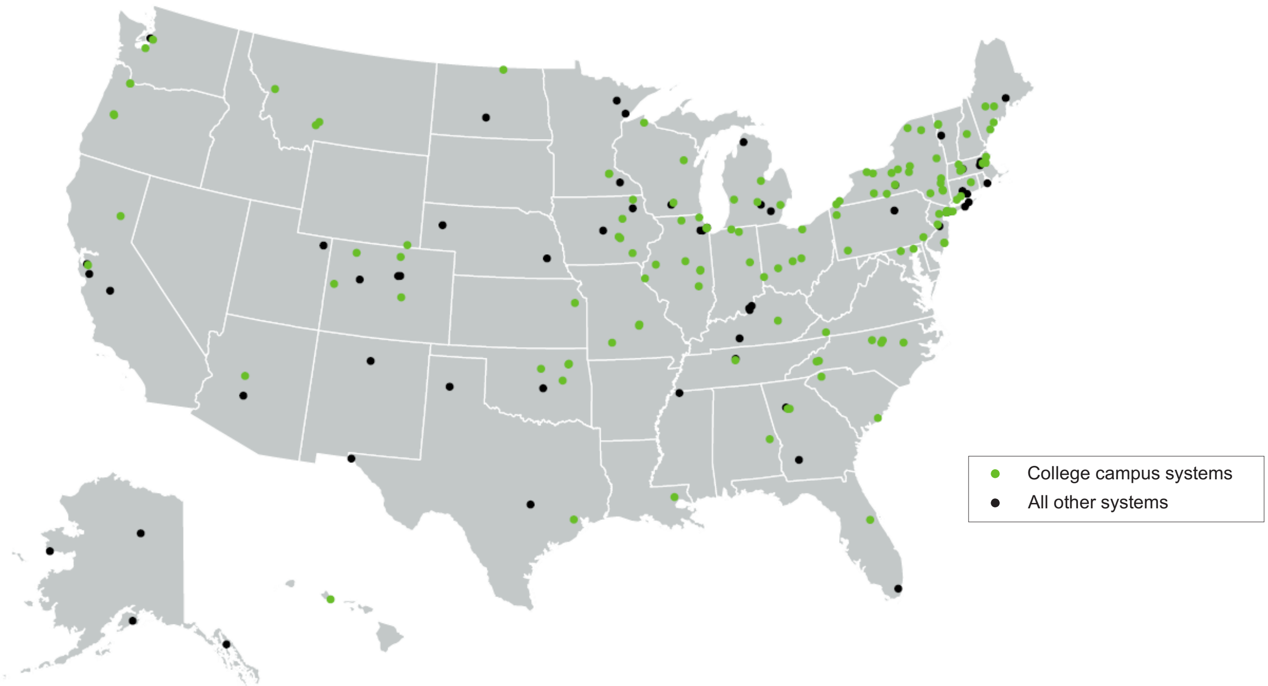


Figure 16: College Campus, TENs Projects, and Large Single-Building Systems collected from public datasets.

Notes: The National Renewable Energy Laboratory and DOE recently released their GHP Yearbook: [Geothermal Heat Pump Case Studies | Department of Energy](), which contains 19 case studies of private-sector (non-DOE-financed) projects. These projects are included in Figure 16 above. Sources: Stan Cross, David J. Eagan, and Paul Tolme; foreword by Robert J. Koester Feb 01, 2011 Going Underground on Campus - EcoLeaders | National Wildlife Federation (nwf.org); various news clippings, press releases, developer and college websites; DOE Community Geothermal FOA sites; DOE internal databases (H. Hughes, GTO).

State and utility policy has recently spurred an increase in the number of TENs pilots being both considered and built by utilities. These policies are often linked to state decarbonization goals that set targets to limit and/or eliminate gas and oil heating.[50] Gas utilities have responded by looking for potential alternative models, of which TENs have been identified as a compelling option.[51] The high cost of these pilots (Figure 21) means they currently need to be funded outside of the ratemaking process. **However, with anticipated learning curves and proven demonstrations, in the future it may be reasonable to imagine a gas utility transitioning to a "heat utility" model if it makes the decision to deprecate its gas supply.**

Current Cost of GHPs and TENs

The cost of GHPs in single buildings is high, particularly for residential installations. Much but not all of this cost is attributable to the ground loop. Figure 17 breaks down simplified median estimates of the net costs for residential and commercial GHP installations.

In almost all cases, the highest cost of the installation is the ground loop. Safely drilling or digging the ground loop requires expertise and equipment that can be in high demand for other purposes, such as water, gas, and sewage infrastructure.

Heat pumps and other internal HVAC equipment prices are higher for residential GHPs than for ASHPs. The market for GHPs is much smaller than for ASHPs, and the result is that the cost of equipment is much higher for GHP specific equipment despite the fact that the mechanical function and operation of this equipment is almost identical between the two technologies, with the primary difference being the heat exchanger (either the air exchanger or the ground loop). This internal component cost gap in residential installations can be confused with the cost of the ground loop installation, both of which can be significant. In commercial installations, this cost gap is not present, as commercial HVAC installations often use identical internal components for heat pump-based systems, regardless of type, and simply configure them to suit the installation and source/sink. Recent growth of domestic companies such as Dandelion Energy indicate growing domestic interest in geothermal heat pump manufacturing.[52] Additionally, funding authorized under the Defense Production Act (DPA) have been authorized to boost the domestic manufacturing capacity of all heat pumps, GHPs included.[53]

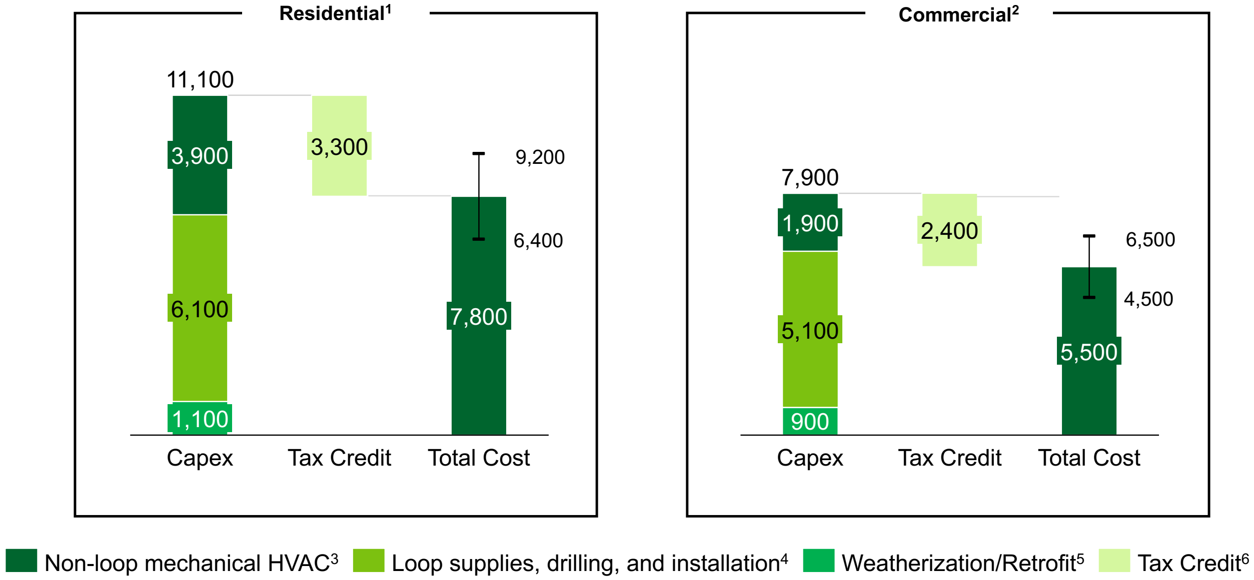


Figure 17: Median national cost estimate for single-building geothermal heat pumps ($/ton).

Values for cost were selected to be an illustrative and simplified median estimate aligning broadly with costs of actual projects as well as data and estimates provided by industry. Median values only shown for Capex and Tax Credit, error reflected in error bar in Total Cost bar. These data are median and meant to show a "typical" costing scenario. Notes on specific values below highlight areas where cost can greatly increase or decrease based on specific situations related to a project, but in general significant differences based on size and age of the building, regional cost of specialized labor, and the relevant geology and local governance of subsurface work will dictate the cost of any project. Notes: 1. Residential defined as single-family unattached homes with one HVAC system 2. Commercial defined as any building owned and operated by one or more commercial entities. 3. This includes all mechanical equipment that needs to be installed in and around the building for the GHP system; this is often an all-in-one heat pump unit but can include separate compressors, chillers, blowers. Cost for residential versions of these units is currently much higher than their air-source relatives due to a small, highly specialized market. On the commercial side, larger systems are built with components common to both markets and cost per ton is much lower. 4. The cost of drilling and installing the ground loop. This is the most variable element of the cost of any project, and will vary based on geology, region, and specific location. In general, vertical borehole loops will be more expensive, which is part of why GHPs are not commonly seen as a solution for urban environments. 5. Factors in installing or altering ductwork as well as removing older heating and cooling technologies. Will vary significantly based on the current state of the building but will also be necessary for any HVAC modernization project on that same building. 6. 30% unboosted ITC credit for commercial installations (Section 48 ITC) and 30% residential clean energy credit (25D) for residential installations . Source: Industry data; expert interviews.

Tax incentives are a key driver to both current and future geothermal heating and cooling adoption. The high upfront cost and reality of affordable alternatives limit adoption of geothermal heating and cooling even more than other energy efficiency options. The changes in tax incentives introduced IRA have adjusted and added to tax credits that have dramatically expanded the possibilities for commercial and residential customers to upgrade their heating and cooling systems.

Particularly important to economics of GHP projects are the Investment Tax Credit (ITC) and Residential Clean Energy Credit (25D). These credits are specifically for businesses or homeowners investing in renewable energy projects, which as defined in statute and the Internal Revenue Code (IRC) includes geothermal heat pump technologies. For homeowners this credit is generally larger than the equivalent energy efficiency credit that most new HVAC installations might be eligible for, helping bridge the cost gap for GHPs. The business credit can be similarly impactful. Businesses considering implementing a larger HVAC system for a facility could take a percentage credit (generally 30 percent of the total system cost for geothermal heating and cooling) on the HVAC portion of their new build or refurbishment if they decide to use a geothermal-based system, which is not possible with other energy efficiency credits. Further discussion of the impacts of this credit on the financial favorability of projects is included in the case study later in this section.

The ITC is seen as a necessity for utilities looking to integrate geothermal heating and cooling systems into their business models. As shown in case studies and cost estimates, the ITC is almost always the most valuable credit to any commercial installation. As utilities consider implementing TENs in neighborhoods, the most likely business model involves the utilities owning and operating the ambient temperature loop and borehole field, which then hook up to GHPs inside homeowners' residences. Under the notice of proposed rulemaking, systems under this split or third-party ownership situation wherein different parts of the GHP system have different owners are not eligible for the credit. Several public comments from GHP stakeholders identified this as a key barrier to further deployment that they hoped would be revisited in the final rule.

Table 1: Tax credits relevant to GHPs

Tax Credit	Description	Adders	Relevant Stakeholder	Notes
Residential Clean Energy Credit (Section 25D)[54]	Provides homeowners with a tax credit for installing a GHP. This credit covers a percentage of the entire installation cost in a given year, which can include necessary enabling upgrades such as the addition of ductwork and panel upgrades.	▸ 30% when your GHP is placed in service after Dec. 31, 2021 and before Jan. 1, 2033. ▸ 26% when your GHP is placed in service after Dec. 31, 2032 and before Jan. 1, 2034. ▸ 22% when your GHP is placed in service after Dec. 31, 2033 and before Jan. 1, 2035.	Homeowners	This 30% credit is not available for other HVAC installations, such as ASHPs (ASHPs are eligible for the energy efficiency credit, which is capped at $2000[55]). Must be ENERGY STAR-certified, though this is essentially universally true for GHPs available in the U.S. consumer market.
Investment Tax Credit (ITC, Section 48)[56,57]	Provides a tax credit for investment in renewable energy projects. Fuel cell, solar, geothermal, small wind, energy storage, biogas, microgrid controllers, and combined heat and power properties. This 30% credit applies to the total system cost, including equipment, installation and necessary upgrades.	▸ 6% of qualified investment (basis of energy property). For geothermal heat property, the base investment tax credit is 6% for the first 10 years, scaling down to 5.2% in 2033 and 4.4% in 2034. ▸ Multiplied 5x for projects meeting prevailing wage and registered apprenticeship requirements. ▸ An additional (up to) 10% is available for projects meeting certain domestic content requirements for steel, iron and manufactured components. ▸ Another (up to) 10% bonus is available for projects located in energy communities.	Developers, utilities, anyone involved with building and operating commercial geothermal equipment.	Generally cited as 30%, under the assumption that a given project meets the prevailing wage and apprenticeship requirements. In discussions with stakeholders, it was generally agreed that the additional 10% credit for domestic content is not a given for geothermal heat pump installations but should be feasible when purchasing domestically manufactured heat pumps.

Tax Credit	Description	Adders	Relevant Stakeholder	Notes
Energy Efficient Commercial Buildings Deduction (179D)[58]	Provides a deduction for energy improvements made on new and refurbished property based on meeting certain standards.[59] The deduction is provided per square foot and can be made on the cost of lighting, HVAC, and building envelope improvements. Energy savings are measured against the ASHRAE standards from four years before the property is put into service.	▸ Base rate of $0.50 per square foot for a building with 25% energy savings. ▸ An additional $0.02 per square foot for each percentage point of energy savings above 25%. ▸ Up to a maximum of $1.00 per square foot for a building with 50% energy savings. ▸ 5x if local prevailing wages are paid and apprenticeship requirements are met.	Building developers/ owners	The 179D deduction can be claimed in combination with Sec. 48 ITC for commercial properties that meet the requirements of both credits.
Low-Income Housing Tax Credit (LIHTC), Section 42[60]	Allows housing developers to receive a tax credit based on the percentage of a property that is reserved for rent-restricted low-income housing.	▸ 4% of the property's production or renovation cost can be taken annually for ten years; this is multiplied by the percentage of housing reserved for low-income residents. ▸ Credit boosted to 9% in competitively awarded areas. ▸ Subject to recovery if terms of the credit are not met. Credits are often traded on a marketplace by housing developers to monetize the value of the decade-long credit immediately.	Building developers and commercial owners	IRA updates allow this credit to be combined with the ITC credit, with both credits using the original cost of renovation or construction. This is a change, as previously the ITC deduction would reduce the value of the property eligible for LIHTC.

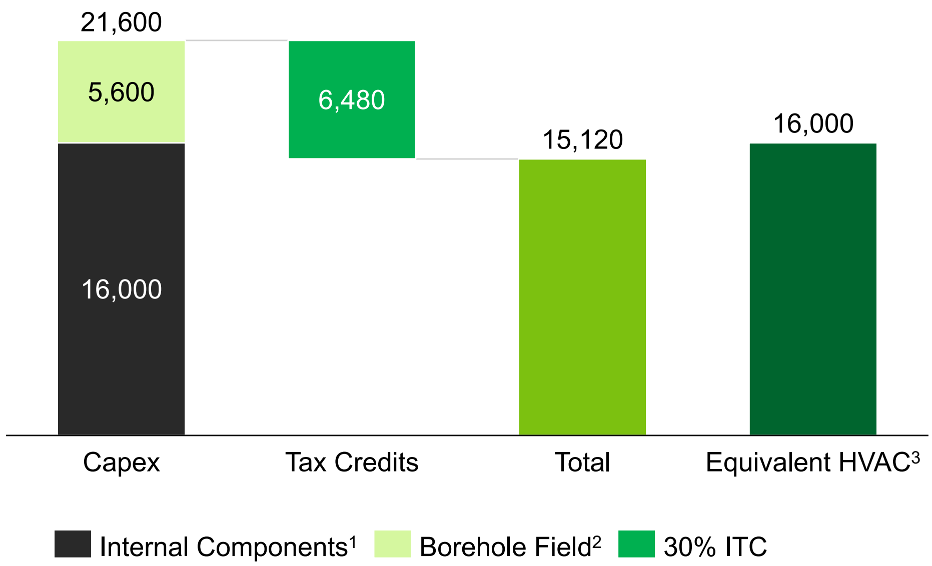


Figure 18: Economics of hypothetical large new mixed-use building in the Northeast ($/ton). Case Study - IRA Tax credits can offset the borehole field cost to make geothermal heat pumps for large buildings the lowest upfront cost.

Notes: Case study examines new mixed-use building with almost a thousand units of housing and approximately 15,000 sq ft of commercial space, with an estimated 2500 tons capacity. Both the proposed project and equivalent HVAC system also provide hot water. Building eligible for 30% national investment tax credit (ITC) from Inflation Reduction Act. 1. Includes ductwork, heat pump, chillers, evaporators, blowers, and hot water heating and storage. 2. Includes 500,000 ft of drilling at an assumed drilling cost of $28/ft. 3. Assumed to be equivalent HVAC system up to modern standards using ASHPs and electric water heating. Source: Anonymized industry data from urban project in the Northeast; expert interviews.

The 30 percent ITC can offset borehole field cost to make geothermal heat pumps the lowest first cost option for large buildings as shown in Figure 18. Geothermal is the only heating and cooling technology eligible for this credit, allowing it to close the gap when the overall cost of the project is high enough. The case study in Figure 18 is of a large mixed-use building containing both residential and commercial space. An industry-standard electrified HVAC system would involve an ASHP, large hot water heaters, ductwork and ventilation equipment, and any number of other pieces of internal equipment necessary to balance heating and cooling loads across the building to maximize efficiency. For any large building, this cost becomes significant, particularly in parts of the country that experience intense weather extremes. The comparable geothermal system would use identical equipment, except instead of an ASHP, the heat pump would be connected to a set of boreholes. The cost of these boreholes is high, but because the overall cost of the project is already high and it allows the entire project to claim at least 30 percent on the ITC credit, the cost of the borehole field can be partially or completely offset, making the GHP installation the lowest-first-cost installation as well as the most energy efficient and best for decarbonization.

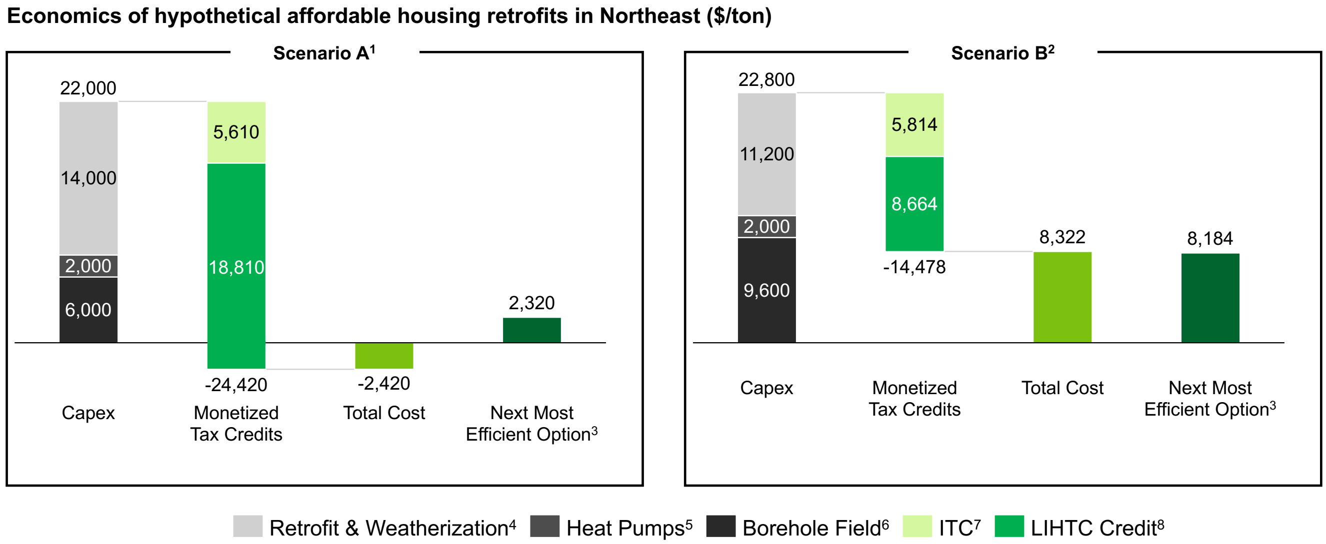


Figure 19: Economics of hypothetical affordable housing retrofits in Northeast ($/ton). Case Study – Effects of hypothetical housing retrofits in Northeast ($/ton). Tax credits can make geothermal heat pumps for affordable housing the lowest-first-cost option.

Notes: Hypothetical projects informed by conversations with developers. Both scenarios are recapitalization of an existing multi-family housing building in Northeast. 1. Scenario A assumes 200 units of affordable housing are retrofitted, replacing steam heating and window AC units with a central geothermal heating and cooling system. Project cost eligible for the 30% ITC tax credit and the 9% LIHTC annual credit (available in certain areas) 2. Scenario B assumes 100 units of affordable housing with the same retrofits, eligible for the 30% ITC tax credit but only the 4% LIHTC credit 3. Assumed to be equivalent to sum of retrofit and heat pump costs without ITC but including same LIHTC monetization to represent a similar air-source heat pump 4. Retrofit includes removal of steam heating, addition of ductwork, and weatherization improvements. The whole-building retrofit costs are assumed to be $7M (A) and $2.8M (B). 5. Heat pumps used are commercially sized and sourced, so cost is assumed to be $2000/ton, lower than what would be expected in a residential market. 6. Borehole field is assumed to be in a suburban area with costs commensurate with that reality, including permitting and environmental impact analysis. The resulting cost is $6000/ton. 7. 30% ITC credit monetized at 85% of full value by sale on a marketplace; this is the lower end of a given range. Assumes no additional boost for domestic content. 8. 10 years of annual LIHTC credit monetized at 95%, this is sold in the first year and again is the lower end of a given range; a developer stated that it isn't uncommon for LIHTC credits to be sold for greater than sticker price at times.

The Low-Income Housing Tax Credit (LIHTC) in addition to the ITC means that affordable housing with GHPs can be the lowest first cost option and even net-profitable in certain cases. The 30 percent ITC and the LIHTC can be simultaneously applied to the original capital cost of an HVAC system for both new builds and retrofits that include geothermal heating and cooling due to adjustments made in the IRA. The LIHTC is more complex than the ITC and requires that some portion of the relevant housing built be reserved for lower-income households. In most areas of the country, the LIHTC is a maximum of 4 percent of the total project capital cost annually for 10 years, which comes to 40 percent. In specific areas where credits are competitively awarded, this percentage is boosted to 9 percent, reaching 90 percent.

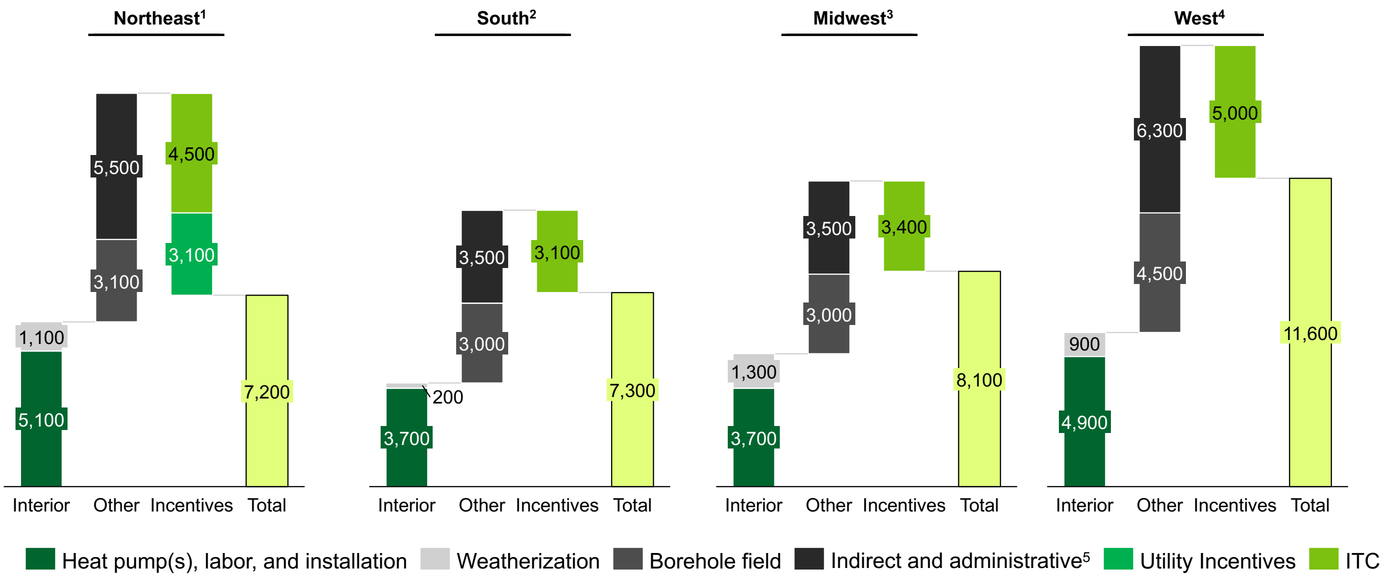


Figure 20: Regional cost estimates for residential geothermal heat pump retrofits ($/ton).

Notes: 1. 17% of square footage in the U.S. residential building stock. Assumes 2,300 sq. ft. home 2. 39% of square footage. Assumes 2,000 sq. ft. home 3. 21% of square footage. Assumes 2,000 sq. ft. home 4. 22% of square footage. Assumes 2,000 sq. ft. home 5. Includes leases, benefits, project management, sales, permitting, and customer financing. Notes: Sums may not add exactly due to rounding. Source: Industry data; expert interviews.

GHP installation costs can vary significantly by region (see Figure 20.) Regional variation in the price of GHP installations is primarily due to differences in the cost of the borehole field, which is dependent on the cost of the relevant skilled labor. Retrofit costs can also vary significantly based on the upgrades necessary. Ductwork and panel upgrades in particular can drive up the cost and time needed for an upgrade significantly. Costs shown in **Figure 20** for the Northeast region are broadly consistent with MassCEC Data on Residential Heat Pump Costs.[61] Note that MassCEC datasets only cover Massachusetts and not the entire United States.

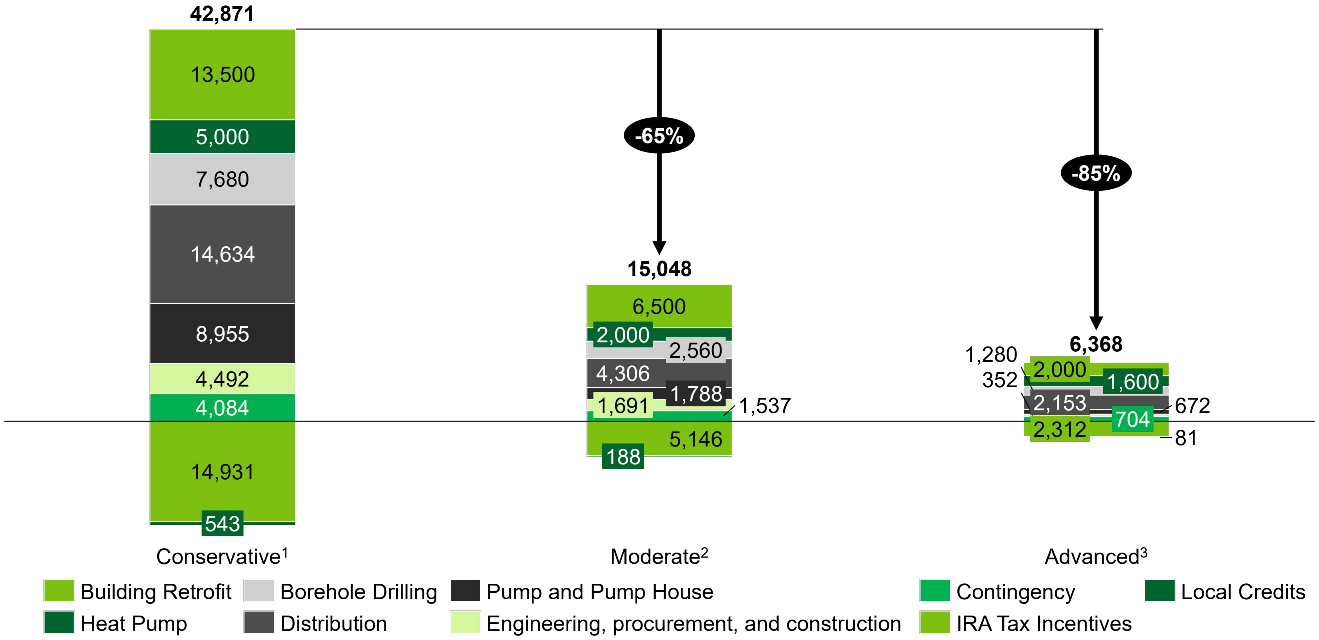


Figure 21: Estimated costs of community-scale TENs ($/ton).

Notes: 1. This Conservative value is based off actual costs from projects, in many cases first of a kind and maximal. 2. Costs here are based on discussions with industry and are meant to represent what the second-of-a-kind project might cost in each area and application. 3. This Nth-of-a-kind estimate further examines the possibilities of deeper cost reduction at each level of installation based on learning curves, and in particular highlights that in cases where retrofits are not needed (new builds or minimal, cost can be driven down.

The cost of TENs can vary widely, but initial estimates from pilot projects show high costs, and even with expected cost reductions TENs are likely to remain expensive. Figure 21 highlights a conservative case primarily based on reported costs from first-of-their-kind installations, such as the Framingham pilot. This cost is expected to reduce rapidly to a more Moderate case, also represented, but even this Moderate case remains costly relative to GHP estimates earlier in this section. The values here derive from a best-case scenario envisioning a second highly similar project that takes advantage of the direct lessons of the previous project. A reasonable goal for these projects is for costs to reach parity with single building GHP installations on a per ton basis, which is represented in the Advanced case.

Workforce

The workforce supporting geothermal heating and cooling is comprised of diverse occupations. While occupational skills are transferable, there may be high competition for labor. Figure 22 summarizes key occupations and their associated training requirements and skill transferability with other technology applications and industries. In many cases the training, talent, and skills required to install GHP equipment are similar to those needed for standard HVAC installation. GHP systems are differentiated from other HVAC systems by the addition of drilling and ground loop installation, which is analogous to or similar to drilling methods required to install water wells or gas pipelines and perform environmental monitoring. The degree of additional retraining required varies across these occupations, however, and this can be highly relevant when looking to grow the industry.

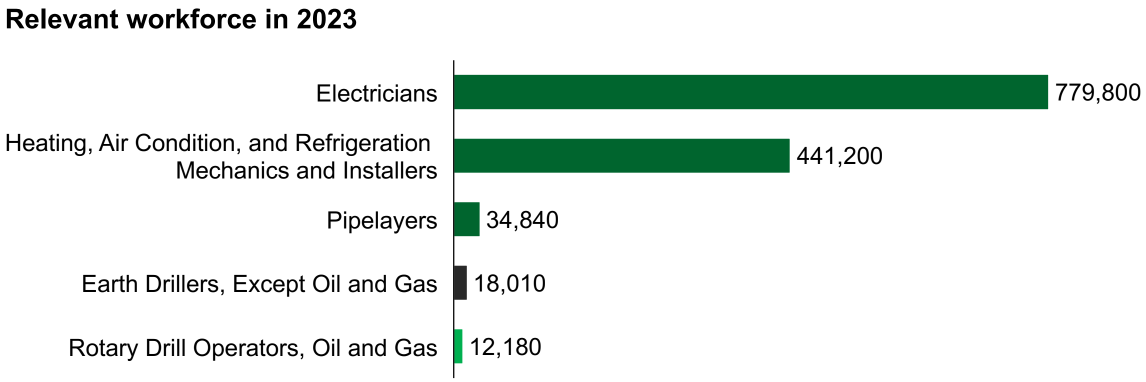
Drillers have the largest training requirements and are in high demand from numerous industries. New drillers require 2 years in an apprentice program, which is often competitive and space limited. Drilling businesses also need to invest in drill rigs, large and expensive machines for which financing will generally be necessary. Both businesses and apprenticeship programs may be wary to expand their workforce in a given market if there are not clear and sustained demand signals.

As discussed previously, the cost of drilling can be driven up significantly by a deficit of available labor and expertise. Figure 23 shows the current composition of the U.S. workforce in GHP-related industries, with a focus on the drilling workforce and its variability over time. The BLS occupation "Earth Drillers, Except Oil and Gas" represents the drilling professionals associated most closely with water well drilling, horizontal directional drilling, and construction.[62] Drillers are already in high enough demand that a mobile workforce has developed. In the northeast, demand is high, and in at least one case drillers have been sourced from Alabama and Oklahoma.[63] Note that the industry-occupation slices shown in Figure 23 do not encompass all relevant classes of workers.[64] The U.S. workforce, including drilling, is currently undergoing a generational shift related to mass retirement of members of the Baby Boomer generation and an emerging dominance of Millennial and Generation Z workers.[65]

High – Low	Drillers	Pipelayers/Loopers	GHP Installers	Electricians
Occupation Description	Responsible for construction of ground loop heat exchanges and protection of surrounding groundwater resources from contamination	Responsible for connection between ground heat exchanger and mechanical equipment through assembly of high-density polyethylene pipes	Responsible for installation and service of ground source heat pump HVAC systems inside building	Responsible for necessary updates and additions to electrical systems inside buildings to accommodate new systems
Required training	2 years with apprenticeship (1-2 years) programs; high capital cost to purchase rigs	General construction degree (at least 2 years) and then specific training (1 year)	2 years community college,	Vocational school and apprenticeship (5-6 years to journeyman)
Retraining Time	N/A, highly generalizable	<1 week for existing gas workers	1-2 months if already journey worker	N/A, highly generalizable
Skill transferability	Drillers for water wells, shallow oil and gas wells, and environmental wells	Easy transfer with minimal training between gas and water pipes because of high density polyethylene pipes	Easy transfer for HVAC and journey workers	Universal

Figure 22: All sectors of the GHP workforce have high transferability; drillers have greatest training duration and their equipment has the highest capital cost.

Other allied occupations, particularly electricians, pipelaying, and HVAC installation, are more fungible or transferable, but are also experiencing skilled labor shortages. GHP installation is a small subset of a larger market, with a substantial labor force overlap with installers cross-trained in other heating & cooling systems (e.g., radiant heating, air conditioning, ASHPs). Broader trades, such as electrical, while impacted by general labor supply issues amongst skilled trades, are only marginally impacted by increased demand in GHP installation given the size of the electrical workforce relative to the GHP-specific workforce (Figure 23). Relative to more industry-specific or more specialized occupations, particularly borehole drilling, installers already trained in other HVAC systems may require only a small amount of additional cross-training to be certified for GHPs. However, despite the relatively small incremental training required to certify HVAC installers for GHP installation, many stakeholders have communicated that such training and certification requirements exist in a patchwork that differs from state to state and locality to locality. Therefore, as described in Chapter 4, standardizing and streamlining training and certification is identified as an imperative for Liftoff. Other more general trades, for example pipelaying, experience similar dynamics, but are slightly more impacted by incremental increases in GHP demand given the smaller size of those workforces compared to electrical.



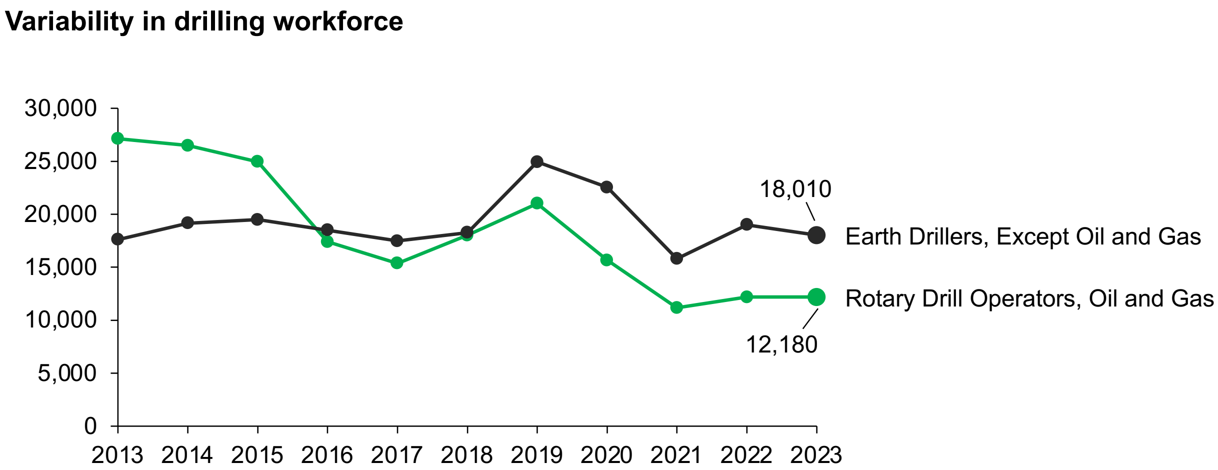


Figure 23: Snapshot of the small existing workforce in geothermal heat pump-related occupations, with bottlenecking in an even smaller drilling workforce that is in high demand and under constant flux. Source: Occupational Employment and Wage Statistics (OEWS) from the Bureau of Labor Statistics. Notes: Detailed occupational employment shown as number of workers in survey year. BLS estimates do not include self-employed workers. For details on BLS's calculation methods see "Base-year employment" under **Calculation : Handbook of Methods: U.S. Bureau of Labor Statistics (bls.gov)**.

Unions are already heavily involved in the HVAC industry, drilling, and pipelaying, taking on a key role in providing the relevant training to workers. Unions run many of the apprenticeship and certification programs relevant to this industry and have collaborated on major projects to provide training and workforce. Unions were among the many stakeholders interviewed for the liftoff report and they showed strong interest in geothermal heating and cooling, particularly in scenarios where jobs and work could be guaranteed for potential trainees. And as discussed in the tax credits section, most of the IRA incentives relevant to geothermal heating and cooling are boosted by apprenticeship and prevailing wage requirements.

Chapter 3: Pathway to Commercial Liftoff and Scale

KEY TAKEAWAYS:

- Geothermal heating and cooling installations recoup upfront costs through reductions in primary energy bills, but not all installations with a positive net present value will be pursued for a variety of reasons. Tens of millions of homes and businesses could install GHPs by 2050 with a positive lifetime payback. However, without concerted interventions to increase the GHP value proposition and expand market size, installation is expected to lag behind GHPs' market and economic potential.
- The geothermal heating and cooling industry can stay on track to reach its full market potential in 2050 with a steady industry annual growth rate of ~10 percent ± 2 percent – achievable through 2035 by maintaining the expected growth in retrofit installations and focusing on increasing the growth of installed systems in new builds, which have lower barriers for installations and will help make initial progress on imperatives to scale.
- The geothermal heating and cooling industry can reach Liftoff in 2035 by focusing on scaling near-term opportunities for installation of GHPs in the equivalent of 7 million homes, a $100-150 billion investment opportunity with the potential for $4 billion in annual grid savings.
- Installation incentives alone, provided at a similar overall level to the annual grid system cost savings, could increase expected installation to levels close to Liftoff by 2035.
- The geothermal heating and cooling industry can reach commercial scale in 2050 by expanding and industrializing a repeatable development process that includes retrofits, building systems in the equivalent of 36 million homes, a $500-700 billion investment opportunity.
- Various stakeholders have important roles to play in pursuing five imperatives to increase the value proposition and expand the market size of geothermal heating and cooling to support the pathway to Liftoff: scale and train workforce; develop and standardize market-ready products and processes; develop frameworks to incorporate benefits and refine planning approaches; clarify and standardize regulations; and realize network effects.

Deployment potential of geothermal heating and cooling solutions

Tens of millions of homes and businesses could install GHPs by 2050 with a positive lifetime payback (Figure 24). The 2050 "economic" potential, defined here as installations with a positive net present value over 30 years, is the equivalent of 48 million homes (119 million tons) for residential installations and the equivalent of 31 million homes (76 million tons) for commercial installations. The 2050 "market" potential, defined here as installations with a positive net present value over 10 years, is the equivalent of 21 million homes (52 million tons) for residential installations and the equivalent of 15 million homes (37 million tons) for commercial installations. The 2050 "expected" installation, representing current customer behavior (defined using an "installation curve that assumes a certain percentage of installations at different payback periods, described in detail in Liu et al., 2019[66]), is the equivalent of 9 million homes (23 million tons) for residential installations and the equivalent of 3 million homes (6 million tons) for commercial installations.

Geothermal heating and cooling installations recoup upfront costs through reductions in primary energy bills, but not all installations with a positive net present value will be pursued for a variety of reasons. Upfront costs may be unacceptable, despite a potential payback period on an acceptable timeframe (e.g., <10 years); cost recovery could take too long to be meaningful to a potential customer or be longer than for some alternatives. The disruption caused by exterior and interior work may be too high to be a viable alternative. The installation time may also be unacceptable — heating and cooling systems are also frequently replaced with immediate need when a previous system fails.

Also, potential customers interested in installing a GHP system may not be able to find local technicians, drillers, engineering firms, or developers with knowledge of GHPs to perform the installation. These barriers and potential solutions are discussed at length in Chapter 4.

The majority of the potential for future GHP installations is in retrofits, with newbuilds representing a much smaller fraction of the annual potential. This holds true across economic, market, and expected installation potential. Newbuild potential is limited by the turnover and growth of the U.S. housing and commercial construction markets. For a breakdown of retrofits versus new build potential, see Figure 40.

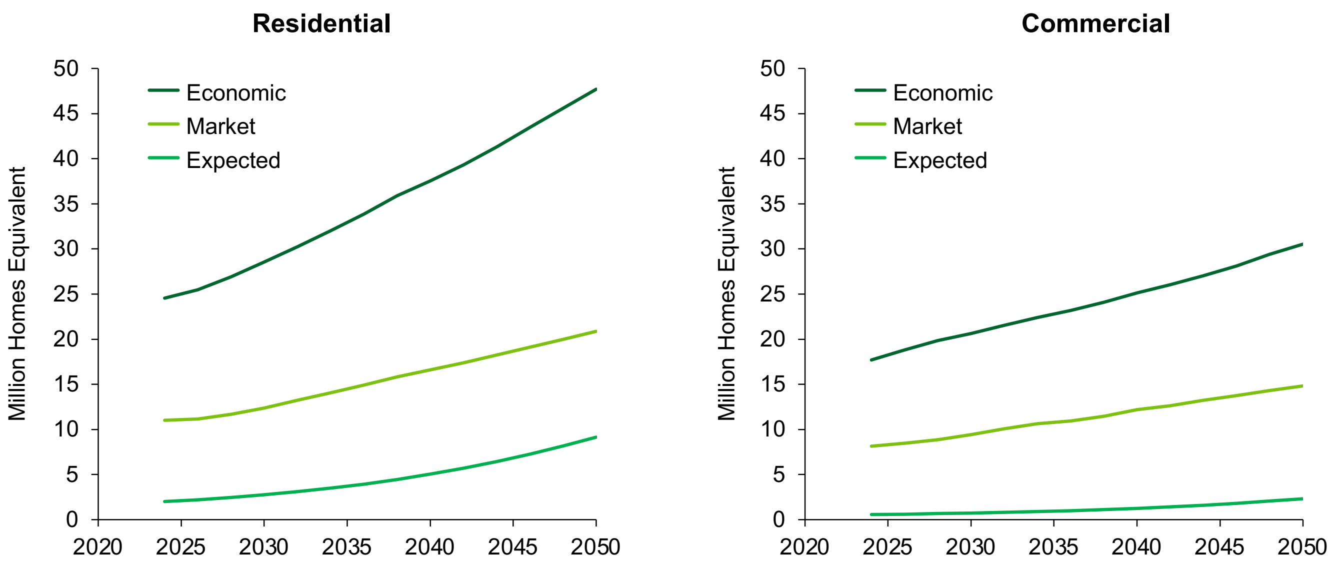


Figure 24: Residential and commercial total installation potential (million homes equivalent).

Notes: Source: dGeo / GeoVision (2019), updated with 2024 analyses[67]. Model results shown assume NREL optimistic market adoption correlation for installed potential described in Liu et al (2019)[68]. Market potential is defined as installations (retrofits and new builds) with positive payback over 10 years assuming a 7% discount rate. Economic potential is defined as installations (retrofits and new builds) with positive payback over 30 years assuming the same discount rate. Modeling assumes a 30% federal investment tax credit extended through 2050, EIA Annual Energy Outlook 2023 Reference Scenario for energy prices, Breakthrough scenario for drilling costs (GHP drilling costs gradually decline from $20/ft to $14/ft through 2050 [in units of $2022]), with both vertical drilling and horizontal allowed. Results are converted from GW thermal to millions of homes assuming an average U.S. household floor space of 1,750 square feet, average U.S. household HVAC system size of 700 square feet/ton, and 28,433 tons / GW thermal.

The market and economic potential for GHP installations are high in almost every U.S. state. By 2035, the economic potential by percentage of building stock is over 27 percent for residential buildings and over 20 percent for commercial buildings in the majority of states and is over 50 percent for residential and commercial buildings in 5 states (Figure 25). The market potential by percentage of building stock is over 12 percent for residential buildings and over 5 percent for commercial buildings in the majority of states, and over 20 percent for residential buildings in 5 states and over 20 percent for commercial buildings in 10 states (Figure 26). The expected installation potential by percentage of building stock is over 3 percent for residential buildings and over 1 percent for commercial buildings in the majority of states, and over 5 percent for residential buildings and over 2 percent for commercial buildings in 10 states (Figure 27).

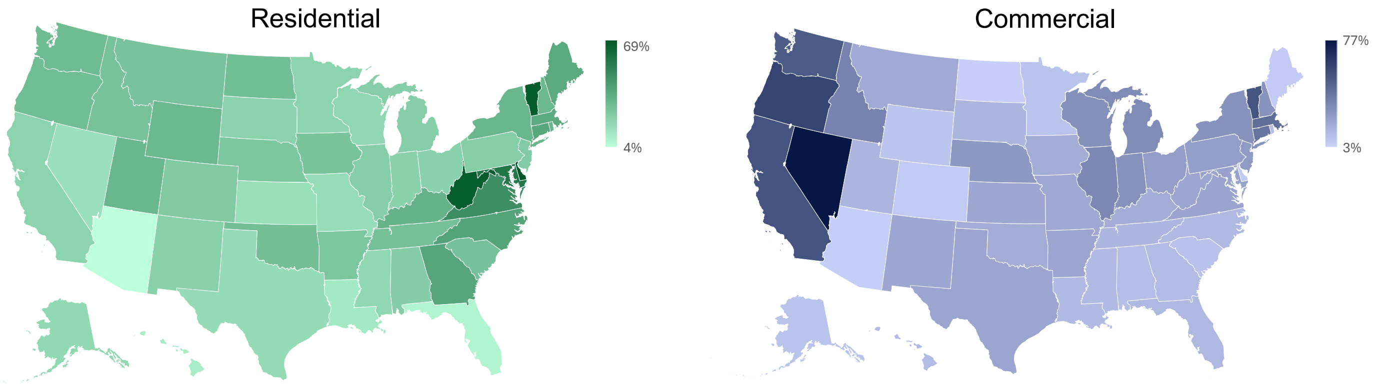


Figure 25: 2035 residential and commercial economic potential (% building stock by state)

Notes: Sources and modeling assumptions the same as Figure 24.

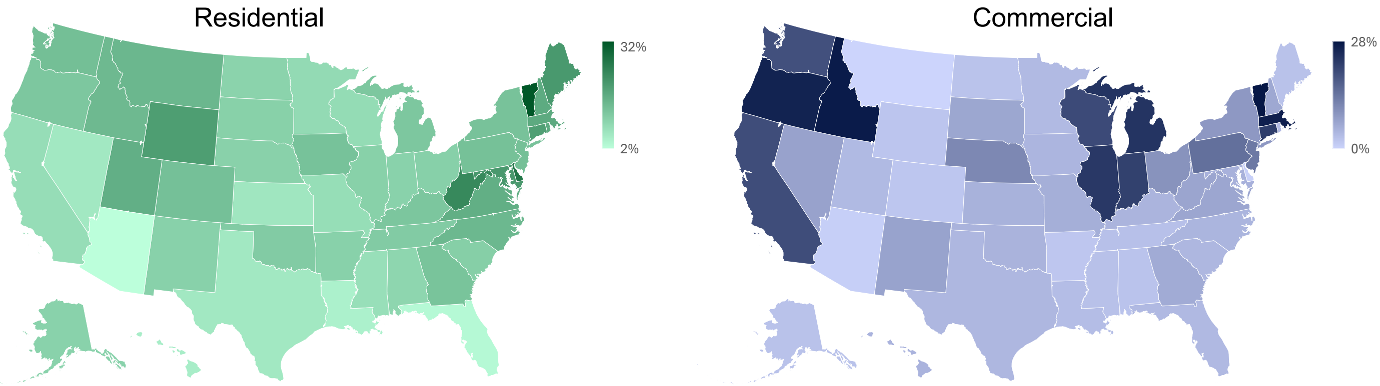


Figure 26: 2035 residential and commercial market potential (% building stock by state)

Notes: Sources and modeling assumptions the same as Figure 24.

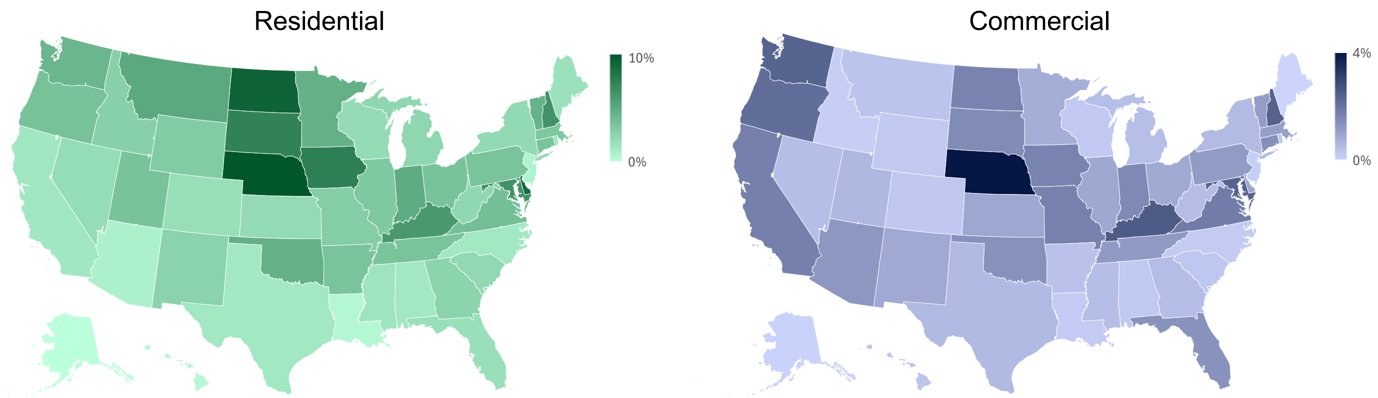


Figure 27: 2035 residential and commercial expected installation (% building stock by state)

Notes: Sources and modeling assumptions the same as Figure 24.

The gulf between estimates of expected installations and market and economic potential suggests that without concerted interventions to increase the GHP value proposition and expand market size, installation will lag behind GHPs' market and economic potential. To realize the climate, societal, and consumer benefits of GHPs, the industry will need to grow beyond the current installation rates to reach Liftoff and full potential commercial scale.

Pathway to Liftoff and commercial scale

The geothermal heating and cooling industry can stay on track to reach its full market potential in 2050 with a steady industry annual growth rate of ~10 percent ± 2 percent (see Figure 28)**.** This growth rate is achievable through 2035 by maintaining the expected growth in retrofit installations and focusing on increasing the growth of installed systems in new builds, which have lower barriers for installations and will help make initial progress on imperatives to scale. The growth rate is achievable after 2035 by maintaining continued growth of installed systems in retrofits (see Appendix C: Geothermal Heating and Cooling Industrial Growth Trajectory and Liftoff Details). The current industry-wide annual growth rate in the United States is roughly 5 percent[69], but the recent growth rate in the European Union is closer to 10 percent[70], which implies this goal is reasonable.

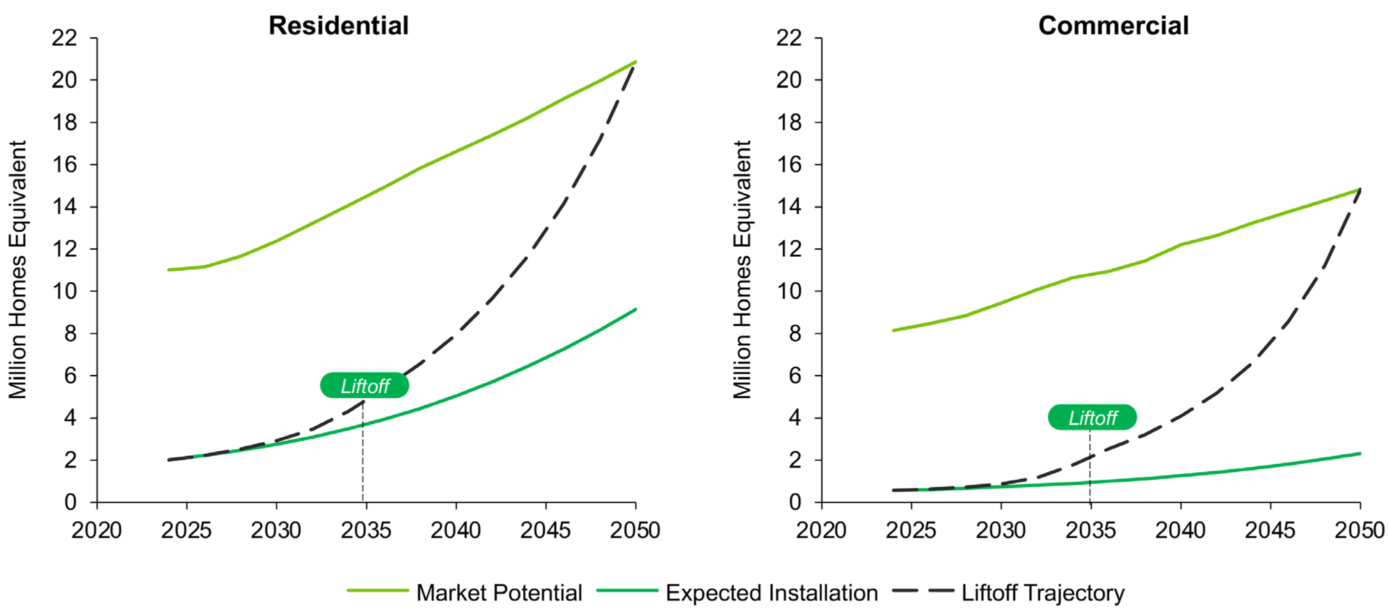


Figure 28: Industry growth trajectory to Liftoff (2035) and commercial scale (2050). See Figure 41 for breakdown between new builds and retrofits.

Notes: Modeling and assumptions equivalent to Figure 24. Liftoff trajectory calculated by assuming steady growth from expected installations to market potential for new builds by 2035, after which new builds remain on market potential trajectory. Retrofits remain on expected installation trajectory until 2035, after which they grow at a steady rate to market potential. In aggregate, industry annual growth rate remains consistent at 10% ± 2% for the period in question. Full breakdown by new builds and retrofits shown in Figure 41.

The geothermal heating and cooling industry can reach Liftoff in 2035 by focusing on scaling near-term opportunities for installation of GHPs in the equivalent of 7 million homes, a $100-150 billion investment opportunity (Figure 29). Individual-building GHP systems are executed mainly by campus managers, homeowners, commercial landlords, and developers (for a review of the geothermal heating and cooling value chain and the ecosystem interactions necessary, see Figure 10), who can focus first on profitable new constructions and planned replacements with necessary lead time to execute profitable retrofits. TENs are executed by utilities and developers, often in partnership with and with consent of gas and electric ratepayers. These stakeholders can focus first on completing pilot projects, both utility-run (e.g., Framingham, MA[71]) and developer-run (e.g., Whisper Valley[72]), and then on expanding those pilots, building systems in new neighborhood developments as an alternative to other networked heating infrastructure, and continuing to build campus systems. **It is important that costs for TENs continue to fall during this period and ultimately reach per-unit parity with costs for individual systems in order for liftoff to be achieved.**

The geothermal heating and cooling industry can reach commercial scale in 2050 by next expanding and industrializing a repeatable development process that includes retrofits, building systems in the equivalent of 36 million homes, a $500-700 billion investment opportunity (Figure 29). To do so will require mobilizing an ecosystem of consumers, service providers, and financing that enable deployment of both individual-building GHPs and TENs at large scale. In this period, individual building systems can continue to pursue profitable new construction, planned replacements, and profitable retrofits at larger scale. During this period TENs may focus further on new neighborhood developments, campus systems, and may also refine a use case around end-of-life replacement of gas pipelines (see Chapter 4, Challenge 3) for profitable retrofits. At this scale, roughly 15 percent of all buildings in the United States would have a GHP system, and 25 percent of new or retrofitted systems will have a GHP by 2050.

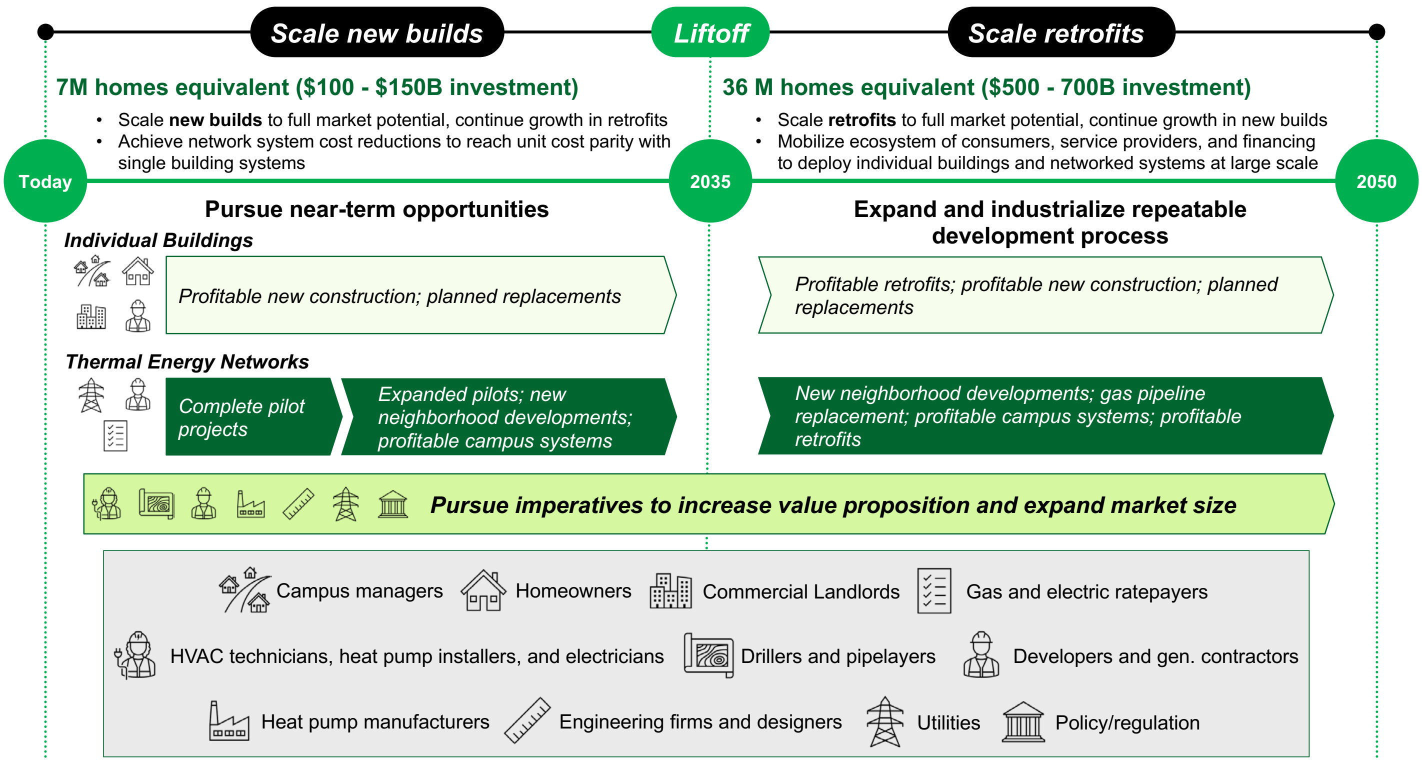


Figure 29: Pathway to Liftoff and commercial scale for Geothermal Heating and Cooling. For stakeholder roles, see Figure 10.

Notes: Investment estimates calculated using average system costs from Figure 17, removing weatherization and retrofit costs for new builds.

Various stakeholders have important roles to play in pursuing imperatives to increase the value proposition and expand the market size of geothermal heating and cooling to support the pathway to Liftoff (Figure 30). The formulation of these five imperatives represents a distillation of the interviews conducted for this report, and a detailed discussion of the specific solutions to achieve these goals is presented in Chapter 4.

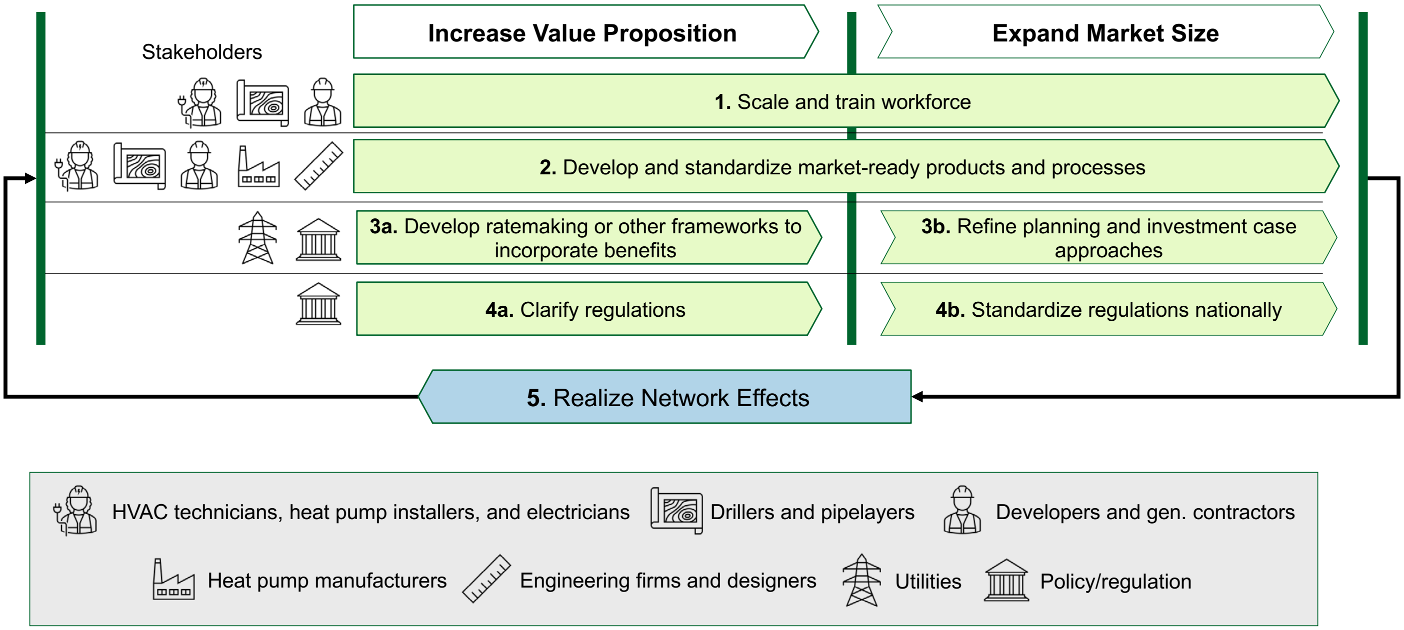


Figure 30: Imperatives for geothermal heating and cooling Liftoff

These five imperatives are:

1. **Scale and train workforce:** The workforce involved in building geothermal heating and cooling systems, including HVAC technicians, heat pump installers, electricians, drillers, pipelayers, developers, and general contractors, must reach sufficient scale for the industry to achieve the growth described in its pathway to Liftoff and scale. A readily available and trained workforce will lower costs and expand access.

2. **Develop and standardize market-ready products and processes:** The workforce described in imperative 1, alongside the manufacturers of GHPs and the engineering firms and designers, will need to develop products and processes that approach commoditization in order to standardize the customer experience of installing these systems across the country. This will serve to lower costs and expand access. This imperative includes adoption of consistent standards and codes governing GHPs and TENs systems across the country.

3. **A) Develop ratemaking or other frameworks to incorporate benefits; B) Refine planning and investment case approaches:** Utilities and the regulators that govern them will need to find mechanisms to recover the benefits of deploying geothermal heating and cooling systems at scale in order to increase their value proposition (by increasing profitability through cost recovery) and expand their market size (by standardizing the way in which these systems are included in the utility planning process).

4. **A) Clarify regulations; B) Standardize regulations nationally:** Some regulations that geothermal heating and cooling systems are subjected to remain unclear and can be clarified to ease planning. Further, implementation of non-standardized regulations across the country can become an impediment to achieving required network effects and benefits of business model replicability.

5. **Realize network effects:** For all stakeholders, network effects that come from increasing scale will remove barriers for marginal installations of a geothermal heating and cooling system. For instance, in the case of a TEN servicing a specific neighborhood, connecting the next building is lower cost than connecting the first segment.

Implications of achieving Liftoff

Achieving Liftoff by 2035 implies 3x growth of current U.S. GHP capacity (Figure 31). Expected installation of GHPs alone would reach a doubling of GHP capacity by 2035 (to ~4 million homes equivalent). Liftoff represents an additional 100 percent increase above current capacity, equivalent to ~6 million tons, or ~2 million homes, and would provide significant benefits to the grid in 2035.

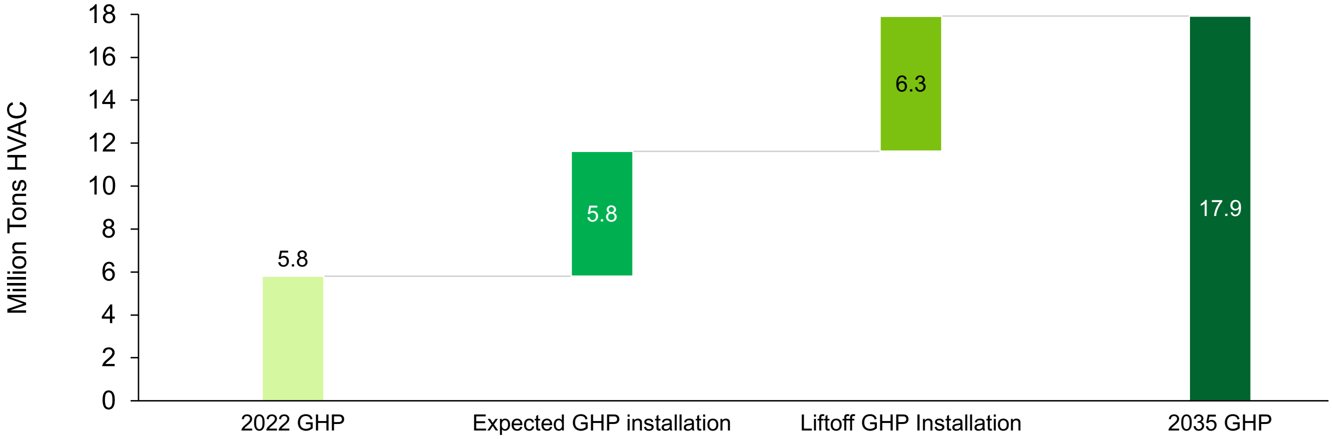


Figure 31: 2022-2035 Geothermal Heat Pump (GHP) growth potential

Notes: Source: dGeo / GeoVision (2019), updated with 2024 analyses[73] Expected GHP installation reported as Installed Capacity in NREL scenarios. Liftoff GHP installation calculated as in Figure 28.

Reaching geothermal heating and cooling Liftoff by 2035 has the potential to significantly reduce both summer and winter peak demand. In high-electrification decarbonization scenarios without the expansion of geothermal heating and cooling, both summer and winter demand could grow significantly (Figure 32). In summer, geothermal heating and cooling liftoff could reduce peak demand by 12 GW. In winter, where peak demand may grow in high-electrification scenarios because of the switch from fuel to electric heating, geothermal heating and cooling liftoff could reduce peak demand even further – by over 40 GW.

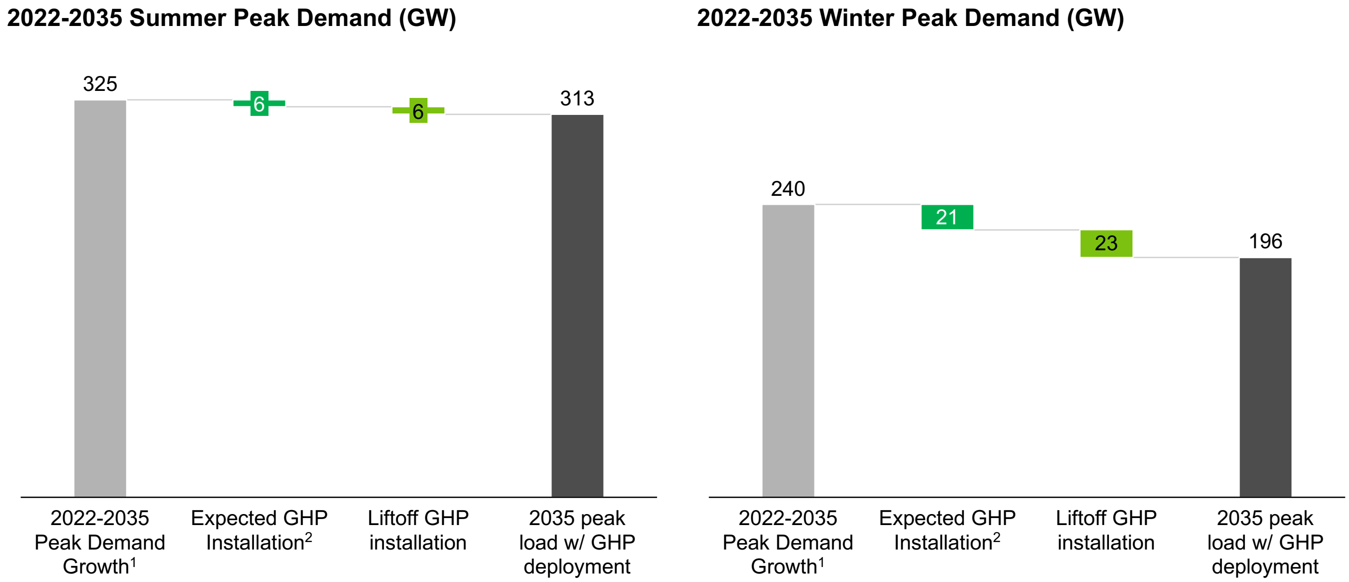


Figure 32: Reduction potential of Summer (left) and Winter (right) peak demand (GW) between 2022 and 2035 under a highly-electrified future scenario.

Notes: 1. Potential peak demand growth from high-electrification scenario (EFS) in Liu et al. (2023) 2. GHP impact on peak demand calculated as the GW reduction in peak demand per ton deployment of GHPs in EFS scenario in Liu et al. (2023) in 2035, scaled to implied level of deployment at expected installation and Liftoff

The potential impact of mass-deployed GHPs on peak demand is approximately 6 times more in winter than in summer (~18 percent vs. ~4 percent), which is important because many summer peaking utilities are expecting to become dual peaking around the early to mid 2030s due to climate change and electrification growth. Furthermore, winter peaks may eventually exceed summer peak demand and in some cases will require capital infrastructure investments. **GHPs can be an alternative to these investments or part of a portfolio of solutions**.

Geothermal heating and cooling Liftoff can also significantly reduce overall grid system costs through reductions in capacity, transmission, and other grid maintenance needs associated with peak demand. Reaching Liftoff by 2035 could lead to a roughly $4 billion annual savings in grid system cost, providing savings of roughly 2 percent (Figure 33).

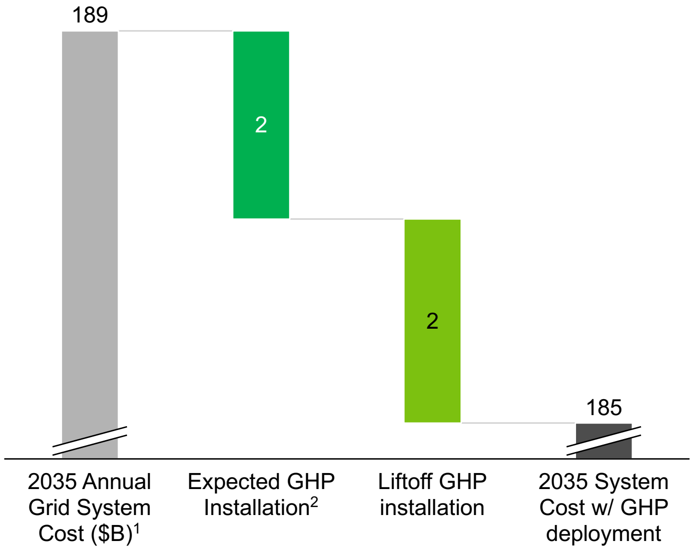


Figure 33: 2022-2035 Annual grid system cost reduction potential

Notes: 1. Annual Grid System Cost from 2035 for high electrification (EFS) scenario in Liu et al. (2023) 2. GHP impact on grid system cost calculated as the $B reduction per ton deployment in GHP in EFS scenario in Liu et al. (2023) in 2035, scaled to implied level of deployment at expected installation and Liftoff.

Potential effect of system cost savings redistribution on expected deployment

Annual grid system costs savings provide a potential pool of capital to fund incentives for GHP deployment. While the exact mechanism and level of subsidy would be a legal, economic, and policy decision, some mechanism of value capture and distribution would enable larger scale deployment of GHP systems.

By providing roughly $2B in annual incentives to residential installations by 2035 (~1/2 the total value of annual grid savings from achieving liftoff in that year), an additional 2.2 million homes equivalent would be expected to install GHP systems (Figure 34**).** At roughly full cost recovery of the expected savings – $4B annually in annual incentives provided – the expected installation for residential systems would increase by the equivalent of 3.3 million homes. Further, incentives in this analysis are provided to all systems; incentives targeted only to those systems less likely to deploy would result in an even greater increase in expected installations. Given Liftoff in 2035 represents the equivalent of roughly 3 million homes more than the expected installation for that year without any incentives, **recovery and re-use of the savings generated to the grid are on the same magnitude as the total amount of incentives necessary to achieve Liftoff.**

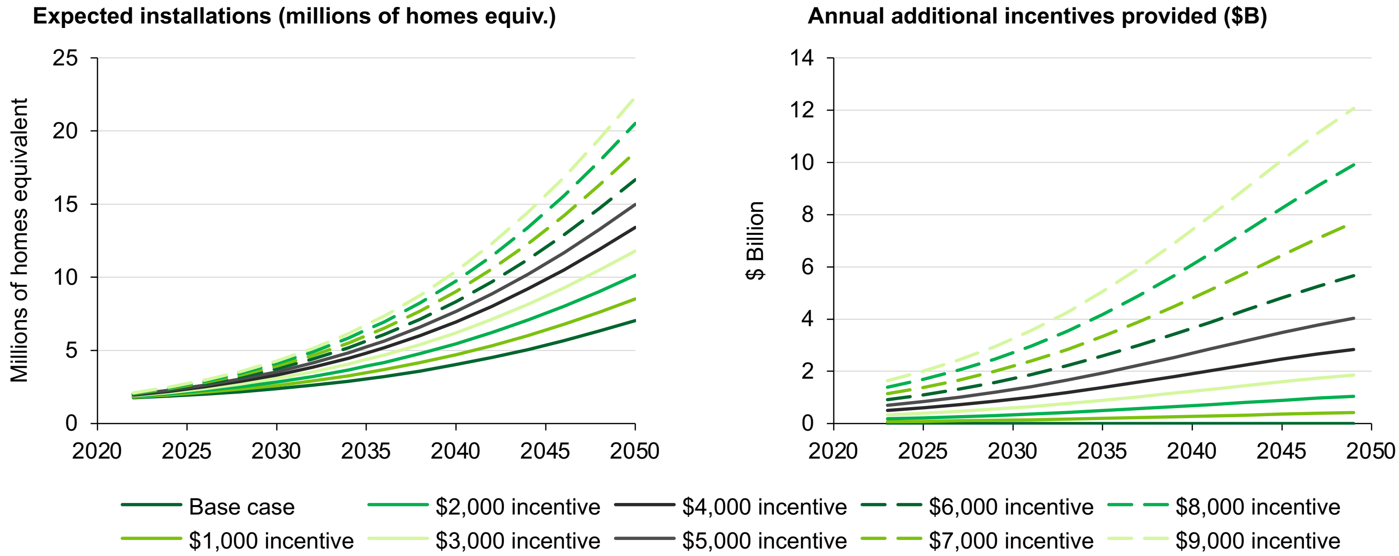


Figure 34: Expected installations (millions of homes equivalent) and total annual incentives ($ Billion) at different levels of installation incentives for residential GHP retrofits only.

Notes: Modeling performed using same tools and assumptions as Figure 24 and others, with incentives offered for individual installations at varying levels in addition to the existing incentives in the analysis (30% ITC and state incentives). Slight variation in base case from updates to GHP cost correlation for high tonnage systems, and from considering only retrofits. Model assumes incentives available to all agents at levels indicated, and annual additional incentives provided calculated based on the number of systems that are expected to install in that year. Note, this analysis is performed by offering a flat incentive to all homes. The incentives shown are in addition to federal ITC and state incentives. Incentives targeted only to agents less likely to deploy would further increase total installations. Net present value calculated at a 7% discount rate.

Chapter 4: Challenges to Commercialization and Potential Solutions

KEY TAKEAWAYS:

- Scaling and training a nationwide GHP workforce (including drilling, trades, and designers) is key to overcoming a number of barriers to mass commercialization of GHPs and TENs systems
- Standardization of local & state regulatory frameworks and local, state, national, & international technical standards is key to consolidating lessons from early demonstrations (pilot projects)
- Rate schedule innovations and utility savings programs that align energy savings incentives with management of future demand and peak reduction supports and helps compensates consumers who adopt GHP systems
- Network effects derive from the ability for local companies and workers to support prompt installation and reduce GHP time-to-delivery to near parity with alternative heating & cooling technologies
- Additional demonstration projects help provide market confidence and accumulate learnings that drive Nth-of-a-kind (NOAK) project costs down to self-sustaining, broadly-competitive levels

Liu (2010) [74] assessed barriers preventing rapid growth of GHP installations in the United States as "a high initial cost to consumers, a lack of knowledge and/or trust in GHP system benefits, limited design and installation infrastructure for GHP systems, and a lack of new technologies and techniques". These barriers remain, in addition to a new workforce barrier that has emerged in recent years as generational changes in the American labor force take place.[lix] Given this, there are five major imperatives for commercial liftoff of GHP systems:

1. Scale and train workforce
2. Develop and standardize market-ready products and protocols
3. Develop ratemaking or other frameworks to incorporate benefits and refine planning
4. Clarify and standardize regulations
5. Realize network effects

Table 2: Deliberate action from the private and public sector help meet imperatives to unlock scale

Imperative	Potential Solutions
Scale and train workforce	‣ Funding for training programs and apprenticeships in drilling and HVAC installation ‣ Develop and enhance regional train-to-hire pathways
Develop and standardize market-ready products and protocols	‣ Demonstrations in a variety of environments, including urban and suburban communities, potentially incentivized by state-level utility pilot mandates ‣ Provide information on best practices and industry standards (e.g., C448), enabled by technical assistance (e.g. pilots & demonstration projects), capital, and loan guarantees from federal and state agencies
Develop ratemaking or other frameworks to incorporate benefits and refine planning	‣ Evaluate GHP benefits to grid, including system-wide/peak load savings and resilience, and advance rate structure modifications & utility program incentives to compensate ratepayers for adopting GHPs ‣ Cost sharing between electric and gas utilities on service upgrades and avoided costs
Clarify and standardize regulations	‣ Integrated system planning requirements for utilities ‣ Updated best practices for local and state regulation, including streamlined permitting and guidelines for drilling deeper boreholes (e.g., C448)
Realize network effects	‣ Uniform or standardized TENs business models developed from pilot program learnings ‣ Integration of efforts to enable prompt installation (by reducing GHP time-to-delivery to near parity with alternative heating & cooling technologies) and drive GHP adoption momentum

Challenge 1: Scale and Train Workforce

Widespread GHP deployment will likely incentivize local job creation in the drilling and HVAC sectors across the United States.[75] Conversely, **rapid and sustainable growth of the GHP workforce is a necessary enabler for widespread GHP adoption.** In Chapter 2, we discussed the broader challenges to growing the GHP workforce, including cannibalization of other HVAC workers and bottlenecks related to the small and variable water well drilling workforce (Figure 23).

DOE recognizes six barriers to training and scaling the GHP workforce:

- **Complexity of Certification Process:** The certification process for GHP design, installation, and inspection may be complex and require specialized knowledge or jurisdiction-specific licensing, making it difficult for individuals to obtain certification.
- **Certification Cost for Installers:** Certification programs and apprenticeships can be costly to develop and implement, especially for smaller organizations or communities with limited resources.
- **Limited Training Opportunities:** There may be a shortage of training programs and educational resources focused on GHP systems, limiting the number of individuals who can become certified or gain experience through apprenticeships.
- **Lack of Industry Collaboration:** Collaboration between industry stakeholders, certification bodies, and educational institutions may be lacking, hindering the development and implementation of effective certification and apprenticeship programs.
- **Lack of Awareness:** Many individuals and localities may not be aware of the benefits of GHP systems or the importance of certifications and standards, leading to low demand for certification and apprenticeship programs.

- **Consumer Awareness and Education:** There is a need for more awareness and education about GHPs among consumers and contractors.

Activating enablers for the drilling industry to scale may be key to driving down cost and speeding up adoption. Cost, and particularly the cost of drilling, is a key barrier for geothermal heating and cooling adoption. The workforce and the small businesses filling this need during installation grow or shrink in response to market signals, but relatively slowly. This slower response is due to several factors, one already highlighted being the extensive training a drill rig operator needs to undergo. And since the cost of a drill rig is high and the order time for a new one may be significant, there may be a long lead time for a small business looking to expand.

Targeted collaboration to create and further build out apprenticeship programs, enable financing opportunities for small businesses, and guarantee work for trained apprentices will drive down the cost of geothermal heating and cooling and help realize network effects that will enable liftoff for the industry. Federal, state, and local government initiatives could collaborate specifically with training programs serving drillers. Developers and utilities can also engage with Registered Apprenticeship Programs, which ensure job placement for workers and increase retention rates for firms. Additionally, by utilizing apprentices and meeting other requirements, such as paying a prevailing wage, firms can be eligible for various enhanced IRA tax credits.

Including GHP installations in HVAC installer training programs will ensure that GHPs are offered as an option to more and more consumers. HVAC installers are often comfortable installing multiple different types of systems, but the specific additional work required to install a ground loop and hook it up means that without training, an HVAC company may not be able to offer this option to the customer regardless of their interest. Ensuring that HVAC training programs integrate GHP installation by providing them with training equipment and incentives can be a simple way to enable the workforce to allow for scaling of GHP installations.

	Entity Type	Examples
1	Source of Workers	• Existing Journeyman Tradespersons • Apprentices • New Entrants (e.g., temp agencies) • Engineers
2	Certification Body / Training Providers	• Organizations providing Training Materials • Original Equipment Manufacturers
3	Training Venue	• Community Colleges • Trade Schools • Unions
4	Employers offering Good Jobs	• Water well drilling companies • Civil contractors • HVAC companies • HVAC & GHP manufacturers • Energy service companies • Utilities
5	Nonprofits & Government	• Industry associations • Regional interest groups • Municipalities • Accelerators

Train-to-Hire Pipeline

Figure 35: Groups to be brought together to form regional train-to-hire partnerships and GHP workforce pipelines.

DOE's Geothermal Technologies Office is launching the American-Made Challenges **Partnerships to Accelerate Training & Hiring for Geothermal Heat Pumps | HeroX (GHP PATHs) Prize**, which aims to catalyze regional outreach-focused partnerships to improve Geothermal Heat Pump workforce pipeline development. This Prize is designed to foster or improve regional partnerships that create or enhance training-to-hiring worker pipelines for in the GHP workforce and allied industries, by bringing together groups listed in Figure 35. Creating or enhancing regional train-to-hire partnerships can address four of the barriers previously identified: Complexity of Certification Process, Certification Cost for Installers, Limited Training Opportunities, and Lack of Industry Collaboration.

Challenge 2: Develop and standardize market-ready products and protocols

The domestic GHPs and TENs markets are sufficiently small that costs of equipment and installation are elevated due to the need for specialized installation expertise, first-of-a-kind (FOAK) design costs, and specialized products (many of which are currently imported at a premium). By ensuring that information and protocols from these early installations are shared, standardized, and iterated upon, the industry can be equipped to provide for demand of a growing market.

Demonstration Projects Across Different Use Cases and Locations are Key

The U.S. building stock is highly varied and spans a diverse range of climate regions (Figure 37) and subsurface conditions. Local regulations, market conditions, and energy efficiency norms also vary significantly across communities and built environments in the United States. The construction and operation of geothermal heating and cooling systems particularly TENs, in these different areas, will build the industry expertise necessary to lower costs and increase effectiveness across all future implementations. State and federal programs have already begun to make deep investments into these demonstrations, with diversity of application and location as key criteria. For example, the DOE's Community Geothermal Heating and Cooling Design and Deployment Funding Opportunity Announcement (FOA) was an initiative launched in 2022 which supported the design activities of 11 domestic projects which seek to supply at least 25 percent of heating and cooling demand in their community using geothermal systems.[76] These projects spanned urban/ suburban, rural, and remote areas.

EXAMPLE ACTIONS AT DOE:

1. DOE GHP PATHs Prize (launching ~December 2024)
2. DOE Connected Communities 2.0 FOA
3. ORNL GHP Impacts Report
4. NREL dGeo deployment trajectory update (Geothermal Rising Conference 2024)
5. NREL upcoming ComStock/ResStock Report (~FY25)
6. GTO's GRID Impacts FOA
7. GTO's GeoVision 2019
8. GTO's Multi-Year Program Plan 2022-2026
9. DOE Cross-functional Grid Modernization working group
10. ORNL GHEDesigner Enhancements
11. ORNL ReEDS/PLEXOS National GHC capacity expansion modeling and value streams analysis
12. GHP Yearbook (NREL – FY24/25) Geothermal Heat Pump Case Studies | Department of Energy
13. NREL Grocery Store GHP Studies
14. GTO FedGeo Partnerships Technical Assistance Initiative
15. Better Buildings Initiative Better Buildings Solution Center | Better Buildings Initiative (energy.gov)
16. NREL URBANopt Support for Design and Deployment of Community-Scale Geothermal Heat Pump Systems
17. GTO's Community Geothermal FOA
18. DOE's ETIPP program (Cohort 4 most recent)
19. NREL Enhanced Geothermal Heat Pump Modeling in EnergyPlus
20. NREL Geospatial GHP Data Analysis

Economic and Engineering Lessons from Installations

Decisionmakers, developers, customers, and municipalities are faced with a myriad of potential solutions for building decarbonization. **Open, carefully analyzed, and widely shared data to inform decision-making is a key enabler for Liftoff.** The National Renewable Energy Laboratory, in conjunction with the Better Buildings Design and Construction Allies and ASHRAE, has developed the Decarbonizing Building Thermal Systems: A How-to Guide for Heat Pump Systems and Beyond (nrel.gov), which provides a starter kit design guide and decision tree for building owners and operators to determine the best heat pump technology for their application. This guide "focuses on the design of heat pump systems and complements forthcoming guidance on combined heat and power, district energy, ground-source heat pump design, high-temperature heat pumps, and other emerging technologies" and provides technical guidelines for residential and commercial customers.

Furthermore, data from existing GHP projects funded by DOE are made openly available on the Geothermal Data Repository, an OpenEI subsite maintained by NREL through DOE support.

Partnerships coordinated by membership organizations can drive product innovation and market growth. Organizations comprising manufacturers, suppliers, installers, utilities, building owners, regulators, and ratepayer representatives may help deliver public policy mandates and uniform standards across regions and technologies, build positive momentum for demonstration efforts, and streamline the develop and test new products in the market.

The distribution of (inter)nationally accepted technical standards (in addition to regulations) is also a key enabler of Liftoff. The ANSI/CSA/IGSHPA C448 Design and Installation and Standard for Ground Source Heat Pumps is the current acceptable industry standard for GHP systems.[77] The 2022 edition was the first edition of the ANSI/CSA/IGSHPA C448 Series-16 Bi-National American–Canadian Standard (#21036), superseding prior versions dating to 2002 under a different title. The current published version of these standards do not necessarily cover TENs but do approximate key TENs elements. A recent, pending revision (2024) updates C448 to include new materials & equipment standards and new guidelines on design, construction & operation of district energy systems.[78]

Challenge 3: Develop rate structures and programs to compensate GHP benefits, align regulation and planning with established policy, and establish regulated utility TEN business models

Stakeholders repeatedly emphasized the importance of rate design in setting consumer incentives for switching off traditional fuels.[79] Some stakeholders identified a need to develop frameworks to incorporate the utility system benefits of GHP deployment into the rate-setting mechanisms for gas and electric utilities. These include lower contribution to peak demand relative to other electrification options, and the associated reduction in peak generation, transmission, and distribution capacity needs.

Rate Structures and Rebate Programs that Compensate GHP Benefits

Historically, residential utility rates comprise two classes of charges: (i) a volumetric rate (¢/kWh) dependent on usage, and (ii) a fixed charge irrespective of usage, for recovery of capital investments and operating expenses plus financing costs and margin. Industry reports suggest that increasing fixed customer charges reduces incentives to encourage energy conservation; conversely volumetric rate increases disproportionately impact consumers without access to DERs and energy efficiency measures to offset rate rises.[80]

Demand response (DR) and time-variable pricing (TVP) programs help utilities smooth demand on the grid and reduce peak loads from residential and commercial customers and modulate fluctuations in service pricing due to spikes in production costs. Most utilities in the United States offer a DR option to customers, and most utilities offer at least one TVP option for each customer class. [81] While time-of-use (TOU) tariffs (a form of TVP) have been studied for their interplay with electric vehicle (EV) charging in the United States,[82] further research is required into consumer attitudes and behaviors in response to heat pump-specific utility incentives to shift demand off of peak hours,[83] as well as enabling technologies (e.g., hybrid GHP systems that combine primary GHP heating & cooling with supplementary ASHP, electric resistance, or gas boiler backups).[84] Volumetric TOU rates or demand-dependent rates (such as critical peak pricing) can potentially better reflect on-peak savings associated with GHPs (i.e., the GHP efficiency advantage is greatest during seasonal peaks, when energy is the most expensive for utilities to provide). Additionally, rebates associated with utility efficiency programs can compensate for utility system benefits of more efficient technologies upfront. Examples include the Mass Save[85] and ConEd Clean Heat[86] rebates for GHPs. Note that a number of similar state & utility incentives are available for ASHPs, and that ASHPs have a complementary role and value in reducing the carbon footprint of building heating & cooling systems.

As the grid system evolves, and summer-peaking systems transition to winter-peaking with greater electrification (particularly in northern regions), rate structures that reflect typically lower non-summer demand may need to evolve to properly reflect the costs of expanding and maintaining grid capacity.[87] Proposals for rate designs that limit fixed charges to certain customer-specific costs[88] and adopting TOU volumetric rates plus demand-dependent pricing may encourage electrification and energy efficiency while reducing utility revenue volatility.[89]

Rate and incentive innovations that allow for compensating customers for grid capacity benefits and avoided electrical transmission buildout could be a key enabler for TENs and GHPs. In general, most gas utilities are separate from their local electric utilities. A potential pivot from a gas utility to a "heat utility" introduces a new dynamic with the electric utilities. Electrified heat means larger winter peaks, which requires greater peak capacity and more build out of generation and transmission. In states where electrification is part of a wider mandate, installing maximally efficient electrified heating and cooling reduces cost to the grid. Rate mechanisms and utility incentives that compensate customers who adopt geothermal can better align customer behavior with desired peak reduction or load shape goals.[90] Industry groups such as the Utility Networked Geothermal Collaborative (UNGC),[91] which now comprises membership representing ~46 percent of U.S. gas customers, can be important to this effort to define and implement rate base mechanisms for building decarbonization through utility-financed GHP or TEN deployment.

Some states are pursuing innovative statutory or regulatory mechanisms for recovering costs of stranded gas infrastructure. For example, California recently passed SB 1221 (2024), which authorizes gas utilities within the state to implement pilot projects in and discontinue gas service in up to 1 percent of the utility's service area with approval of two-thirds of the service area customer base; the gas utilities would then be eligible to recover undepreciated costs for putting in the original, decommissioned gas infrastructure.[92] Cost allocation for electric utility service upgrades and new gas service connections should align with overall national, state, and local policy goals and be responsive to changing peaking dynamics of the evolving grid system. A cost allocation solution that allows for distribution service upgrades for customers installing electric heat pump systems who require additional capacity to be offset by reduction or avoidance of costs associated with replacement or buildout of a gas distribution network may be a key regulatory innovation.

Aligning regulation and planning with stated existing policy goal from states and localities

Capital costs to replace end-of-life gas distribution infrastructure are significant, and the value proposition for deploying electrified heating & cooling systems is strongest when installations are timed to allow retirement of gas distribution infrastructure at end of life. Allowing for electrification upgrades to be paid for by ratepayers within the rate base will help alleviate the financing gap for GHPs and TENs[93]. Concomitantly minimizing stranded gas assets by deploying heat pumps where gas distribution systems are in need of replacement can also help avoid shifting more of the cost burden onto an increasingly smaller fraction of remaining gas consumers[94]. It also addresses the stranded cost problem in a future scenario where migration from gas to electric heating systems occurs more rapidly than forecasted when setting gas rate cases, negatively impacting utilities' realized rates of return.[95]

Many older gas distribution systems in the United States, particularly those in the northeast, are leak-prone and feature diffuse leakages across numerous segments of the distribution network. The non-profit organization HEET (Home Energy Efficiency Team) has built several ArcGIS maps containing information queried from public utilities commission filings and from street-level surveys conducted with vehicle-mounted methane analyzers. These maps may be found at the following links:

Massachusetts Gas Leak Map (HEET)

Philadelphia Leak Survey Map (HEET with Gas Safety Inc)

Washington DC Leak Survey Map (HEET with Gas Safety Inc)

Twenty-six percent of the U.S. gas main system is >50 years old (primarily in the eastern United States). PG&E (California) has estimated that 0.3 percent of mains & distribution pipes need to be replaced per year.[96]

Recently published estimates for costs of replacing gas pipe include: (a) New York state: $28 billion to replace 8,177 miles of gas mains and >350,000 individual service lines by 2043[97]; (b) Massachusetts: $16 billion to replace gas pipe by 2039[98]; (c) Philadelphia: $8 billion to replace by 2055[99]; (d) Illinois: $80 billion by 2050[100]; and (e) nationally: ~$740 billion by 2040[101].

Based on data on the costs of replacing aging or leaking gas pipes on a per-mile-served or per-household basis, **Figure 36 shows that residential GHP retrofits may require less capital than replacement of end-of-life natural gas pipes in some areas.** Publicly available cost estimates for gas pipe replacement are scarce and vary significantly (by a factor of ~2) between different utilities for a given neighborhood density. Current net capital expenditure for replacement of gas pipe is estimated at ~$26k per household in suburban areas (range $23k to $47k) and ~$40k in urban areas (range $3k to $60k). Despite the significant uncertainties here, upfront costs for geothermal are conceivably comparable to or in some cases less than the cost to replace aging natural gas lines. The analysis shown here makes conservative assumptions on replacement costs for the central case; here, gas pipe replacement costs are assumed at $5.55 million/mi for urban settings; compare: Washington Gas (DC), $5–10 million/mi; ConEd (NYC), $6.18 million/mile. Further work is necessary on understanding the interplay of capital savings and customer electrification on gas & electric utility business models and rates.

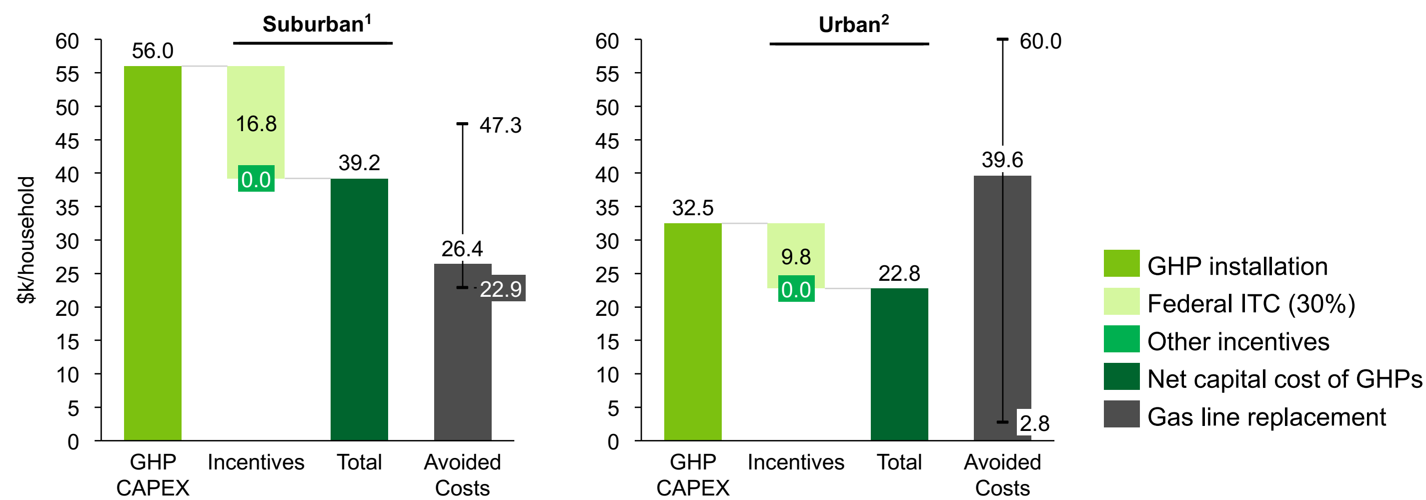


Figure 36: Capital expenditure for GHPs compared to gas pipe replacement. Residential GHP retrofits may require less capital than complete replacement of end-of-life gas pipes in some areas.

Notes: 1. Central case assumes a GHP capital cost of $14k/ton before incentives, a 30% Federal ITC, 4.0 tons of heating/cooling required per household, $1.85 million per mile of gas pipe replaced, and 70 households per mile of gas pipe (midpoint of NY utilities from Nadel 2023). High/low values represent scenarios assuming $3.20M/mi & 67.6 HH/mi (Nadel 2023 - midpoint from PG&E 2022) or $1.60M/mi & 70 HH/mi (E3 2024 - SDG&E), respectively. 2. Central case assumes a GHP capital cost of $14k/ton before incentives, a 30% Federal ITC, 2.5 tons per household, $5.55 million per mile replaced, and 140 households per mile (Nadel 2023). High/low values represent scenarios assuming $6.00M/mi & 100 HH/mi (Walsh & Bloomberg 2023 – NY uitilites) or $5.55M/mi & 2,000 HH/mi (Mendez et al., 2019 – extreme high density NY). Sources: S. Nadel (June 2023) *Impact of Electrification and Decarbonization on Gas Distribution Costs.* ACEEE Report; A. Mendez, et al. (January 2019) *Local Distribution Companies: Relationship between Pipeline Miles and Number of Customers, and Different Pipeline Diameter Sizes,* UT Energy Institute, Discussion Paper No. 2 for the Energy Infrastructure of the Future study; NYSERDA (2019) *New Efficiency: New York – Analysis of Residential Heat Pump Potential and Economics,* Report Number 18-44; S. Smillie, et al. (2024) *Avoiding Gas Distribution Pipeline Replacement Through Targeted Electrification in California*, E3.

Utility rate structure and incentive modifications have been identified previously by the DOE as a priority enabler for widespread adoption of energy-efficient technologies, aligning service upgrade costs with future infrastructure needs, and mitigation of energy transition impacts to low-income consumers:

> "State regulators, municipal utilities, and cooperatives can change policies on which types of electricity and natural gas infrastructure can be paid for by ratepayers. This can reduce the burden of grid edge and behind-the-meter electrical upgrades on customers, especially low-income customers, so they are not left behind on technology adoption." (*Decarbonizing the U.S. Economy by 2050: A Blueprint for the Buildings Sector*, April 2024, U.S. DOE) [102]

Such a mechanism could allow utilities to socialize distribution system service upgrades amongst ratepayers and incentivize customers to switch from gas (or heating oil) to electrified heat pump technologies. This mechanism is not specific to GHPs (as replacement of conventional heating & cooling systems by ASHPs also is advanced by the availability of such a mechanism). However, existing homes in the northern and northeast United States are more likely to have only legacy heating systems (e.g., gas boilers) and not existing electrical cooling systems; therefore, in the absence of new load management strategies, the simulated future electrification scenario is projected to increase peak demand in the winter in northern and northeastern states (Figure 14), owing primarily to replacement of fossil fuel heating by electric heat pumps. The case shown in the figure is likely to represent a conservative (pessimistic) demand endmember scenario and implementation of incentives, and demand-response rate programs, and other measures are likely to mitigate the additional electrical demand.

Utility-owned TEN Business Model Innovation

Traditional gas utilities earn most of their revenue from residential and commercial gas consumption for space and water heating. Widespread deployment of TENs and dispersed GHPs would displace demand from significant swathes of traditional gas consumers. Gas utilities, particularly those under state or local decarbonization mandates, may wish to plan for a "pipes-to-pipes" transition as a natural bridge to business models viable under future scenarios where mass electrification of heating & cooling and cooking has occurred.

At the same time, mass deployment of heat pump technologies, particularly GHPs, could reduce peak summer electrical demand across most of the Lower 48, but could also increase peak winter demand in the northern states, owing mostly to replacement of natural gas and heating oil systems with electricity-drawing HPs (e.g., Cold climate zones in Figure 14).

Stakeholders involved in the construction and operation of Utility Thermal Energy Networks (UTENs) pilots interviewed by DOE emphasized the importance of incorporating the costs of mass geothermal heating and cooling system buildout into utility rates as a Liftoff enabler. The nation's first UTEN pilot in Framingham, Massachusetts is an example of a "pipes-to-pipes" transition currently being trialed. This project received approval by Massachusetts DPU in a NSTAR Gas Company (d/b/a Eversource Energy) rate case in 2020.[103] The project converts customers reliant on natural gas, electric resistance heating, and heating oil to a UTEN system comprising geothermal borefields and an ambient temperature loop.[104] From conception to rate case approval, this process took several years and, according to stakeholders, was likely accelerated by Massachusetts's decarbonization mandates. After rate case approval, site selection and construction/building conversions took/will take several more years, resulting in a current timeline for first-of-a-kind projects from concept to commercial operation of ~6 years. This timeline needs to be shortened to enable Liftoff. Utilities in several other states, including New York and Colorado, are currently in the feasibility planning stages of additional UTENs.

Challenge 4: Clarify and standardize regulations and incentives

Federal tax regulations

The IRA unlocked, expanded, or extended tax credits for GHP units placed in service by residential or commercial taxpayers (see Table 1). The impact of the IRA can be seen in the uptick of individual tax returns claiming the Section 25D residential clean energy credit (RCEC) tax credit for qualified GHP property (Form 5695) for the most recent tax year (2023).[105,106]

Additional information from the IRS Statistics of Income (SOI) release shows that higher-income taxpayers were disproportionally likely to claim the RCEC compared to lower-income taxpayers; however, some of this effect may be due to taxpayers with lower income tax liabilities carrying over excess credits to future tax years[107].

Recent research on social acceptance and source credibility of government incentives for electric vehicles (EVs) suggests that tax credits and other policy incentives may receive a higher level of serious consideration by taxpayers when they learn about such incentives from a government entity (e.g., the IRS) rather than from information provided by companies (Stekelberg and Vance, 2024).[108] Currently, various manufacturers and installer companies issue their own clarifications and explainers on available tax incentives and the mechanisms by which homeowners (or certain renters) may claim them. DOE's Geothermal Technologies Office website also describes broadly the applicable tax credits for homeowners and renters under Section 25D;[109] however, stakeholder interviews indicated that stakeholders would appreciate the amplification of existing guidance and increased availability of government-branded literature to help guide taxpayers claiming this credit for the first time. **Additional federal agency and national labs' research actions can assist in understanding the breadth and content of information available on GHP tax incentives in the United States, the current degree of market understanding and willingness to claim the credits, and barriers to uptake.** Furthermore, the development of guides and pamphlets conveying authoritative technical information on tax credits available for various types of taxpayers may be valuable (an example of such is the Federal Tax Incentives for Low-Temperature Geothermal Technologies (Program Document) | OSTI.GOV – which was developed specifically for federal agencies with real estate assets seeking to decarbonize their building footprints and reduce heating & cooling costs to meet agencies' emissions and performance goals).[110] DOE's Geothermal Technologies Office is also currently working with NREL on developing additional technical assistance materials relating to the 25D and 48E tax credits. Additional information on state incentives and policy measures has been compiled in Database of State Incentives for Renewables & Efficiency® - DSIRE (dsireusa.org) by North Carolina State University.

In a notice of proposed rulemaking (REG-132569-17) published in the Federal Register on November 22, 2023, IRS issued proposed regulations governing the definition of energy property, including property seeking to qualify for Section 48E investment tax credits. As of the time of writing of this liftoff report, the Treasury Department had not yet released their final rule. Under the notice of proposed rulemaking, systems with split or third-party ownership are not eligible for the credit. Several public comments from private-sector stakeholders identified this as a key barrier to further deployment that they hoped would be revisited in the final rule.

Local incentives and mandates

Local Law 97 in New York City (NYC) provides an example of local mandates driving emissions reductions and uptake of GHPs. This law, passed under the Climate Mobilization Act (2019), requires most large buildings to meet certain energy efficiency limits by 2024 and 2030.[111] The law also sets penalties for CO_2 emissions that exceed statutory limits. Market feedback that DOE obtained suggests that LL97 has resulted in significantly increased levels of interest and demand for GHP systems in NYC.

A number of other municipalities in the United States have also implemented statutory limits or restrictions on building emissions. The Building Decarb Coalition's website hosts a database that tracks ongoing policy initiatives and local statutes implementing emissions targets on building heating & cooling (Zero Emission Building Ordinances - BDC).

Challenge 5: Realize network effects and achieve self-sustaining 10 percent CAGR

Addressing the above challenges will help catalyze healthy growth of this rapidly growing industry and ensure self-sustaining market-driven momentum in future growth of GHP installations. Achieving Liftoff (at 7 million equivalent household GHP units installed by 2035) generates the requisite market depth, cost competitiveness, and broad-scale adoption required to ensure the continued scaling of this industry and exceed >30 million units installed by 2050.

The value of geothermal heating and cooling systems must be calculated, communicated, and implemented appropriately in business- and consumer-facing products (e.g., electricity rates). A future where a consumer deciding on a heating and cooling solution for a new building or neighborhood, or industrial facility, has a clear understanding of the feasibility and economics of different decarbonization technologies will enable natural growth of the market without need for more direct intervention.

Demonstrated business cases for utilities providing geothermal heating and cooling via TENs could catalyze immense growth by providing a path forward for gas utilities in states that are committed to decarbonizing those industries and managing their seasonal electrical peaking as they electrify. Embedded network effects and standardized business models will grow this nascent segment of the geothermal heating & cooling sector. While already promising, a clearly successful economic case for exchanging a gas utility model with a TENs heat utility model could trigger substantial momentum with utilities beyond the early adopters.

Barriers to liftoff	Potential solutions
Workforce size and readiness are consistent areas of concern for GHP manufacturers, installers, and developers	▸ National and regional initiatives for developing workforce training & hiring pipelines in partnership with trade organizations, certification bodies, vocational schools, manufacturers, drilling / civil contractors, installers, utilities, and industry associations. ▸ States, utilities, or other entities could create incentives around energy jobs specifically including geothermal heat pump certification & apprenticeships.
Financing and upfront capital outlays render GHPs unattractive relative to other heating & cooling alternatives	▸ Business models incorporating third-party ownership of certain elements of GHP systems are important for various private-sector entities, including utilities seeking to build thermal energy networks. ▸ Declining interest rates improve economics of longer-payback GHPs vs lower upfront capital cost alternatives. ▸ Capital available for retrofits remains limited for many institutions or companies absent external or internal decarbonization mandates or announced goals. ▸ Lowest upfront cost option vs. lowest lifecycle cost option – for-profit property owners typically prioritize lowest upfront capital costs over lower lifecycle costs that require a longer payback period. ▸ Self-financed entities with very long institutional lifetimes (e.g., colleges, churches, government facilities) have been increasingly enthusiastic about GHPs and TENs systems. ▸ Lifecycle costs are not well-constrained given uncertainty in future fuel or electricity costs. ▸ Better quantification of capital expenditure for GHPs compared to the cost of replacing end-of-life gas infrastructure to help demonstrate additional value beyond utility bill savings. ▸ Market participants have suggested, but not yet implemented, innovative carbon pricing mechanisms in a way that allows for electric utilities to credit customers or GHP owners for avoided costs for peaker plant and transmission buildouts, then include sophisticated rate payments / credits for carbon savings to customers. ▸ Use DOE LPO's loan guarantees to reduce risks to uptake. ▸ Investigate means to reduce LPO loan application paperwork and compliance burden on smaller entities.

Barriers to liftoff	Potential solutions
No tried-and-true mechanism to equitably distribute the burdens of mass implementation of energy-efficient heat pumps on remaining gas utility customers	▸ Utility rate structure and incentive modifications to tap into rate base financing for mass GHP deployment. ▸ State and local decarbonization mandates for utility thermal energy network (UTENs) pilots. ▸ DOE's Loan Programs Office (LPO) as financing partner for gas or integrated utilities seeking to build GHPs instead of new gas distribution lines.
Consumer Knowledge / Skepticism, Timelines	▸ Improve time-to-delivery and drive prompt installation by ensuring a sustainable water well drilling workforce is staffed and ready to drill vertical boreholes within ~2 weeks of purchase. ▸ Improve permitting timelines by increasing confidence with AHJ's across the United States – by way of community demonstration projects. ▸ Improve awareness of available federal tax incentives (e.g., 25D, 175D, LIHTC) to individual homeowners; develop federal agency-branded informational materials to improve source credibility. ▸ Federal and state technical and financial assistance for pilots and demonstration projects to de-risk FOAK and NOAK technologies and increase familiarity with such GHP and TENs systems amongst industry, utilities, consumers, and ratepayers.
Some consumers and developers perceive payback periods for GHPs as undesirably long	▸ Even with creative financing measures and long term bill savings, customers may not be quite ready to install GHPs when capital costs for ASHPs are significantly lower. ▸ Costs for installing ground heat exchangers must be brought down via technological innovation and workforce scaling, particularly in the area of borehole drilling. ▸ Development of low-footprint borehole drilling technologies may substantially reduce cost-per-foot to drill and install vertical heat exchangers. ▸ Incorporating the value of heating & cooling technologies in real estate property valuation by standardizing the treatment of GHP, ASHP, and other heating & cooling technologies' impacts on bill payments and asset value to assist in incorporating the value of ground heat exchangers / borefields in real estate property valuation. ▸ Develop and standardize energy savings performance contracting methods for securitizing the savings streams of GHP systems. Develop methods to calculate value premiums associated with reducing energy price volatility. ▸ Focus deployment efforts on long-standing institutions and buildings with expected service life >50 years. Examples include government buildings & facilities, key data centers, corporate campuses, university campuses, hospitals, museums, churches, national park facilities, and large industrial facilities. ▸ Develop utility incentive programs to capture benefits accrued to utilities and pass them along to GHP customers (see Figure 34).

Chapter 5: Metrics and Milestones

Progress towards geothermal heating and cooling liftoff and full commercial scale should be tracked at the regional, state, and national level. Two categories of metrics—outcomes and progress indicators—can track the progress and impact of geothermal heating and cooling sector growth.

Outcomes: Track the benefits of geothermal heating and cooling to the grid, economy, and communities:

- **GHP System efficiencies (kw/ton heating and cooling, COP)**
  As the industry scales and standardized products reach the market, system efficiencies should become more uniform and improve.
- **Overall TEN efficiency (kW / ton heating and cooling)**
  As TENs deployments reach higher numbers and market-ready products are perfected, the achieved efficiency of the systems should also become more uniform and improve.
- **Waste heat capture (GJ)**
  Any TEN system designs that leverage waste heat can measure energy that would have otherwise been rejected to environment instead of leveraged.
- **Peak summer and winter power demand (GW)**
  As peak demand is projected to increase, the actual demand by season can be tracked and compared to GHP installation to estimate avoided peak demand.

Progress Indicators: Track observed progress towards geothermal heating and cooling liftoff:

- **Investment ($)**
  Total spend on GHP and TENs will indicate level of investment and deployment, and progress towards liftoff.
- **Utility investments ($)**
  Utility deployment, especially of TENs, but also of single building GHPs, will indicate progress in the business model.
- **Installation incentives used ($)**
  Total installation incentives deployed in support of GHP installation will provide an indicator of the cost recovery for these systems based on societal benefits.
- **Installations (# of systems)**
  Number of GHPs installed in homes and businesses will indicate progress towards Liftoff.
- **Boreholes installed (ft, m)**
  Total borehole depth installed indicates the activity of the drilling industry, its scale, and ultimately the scale of GHP systems in the building stock.
- **Borehole cost ($/ft)**
  Average borehole cost will indicate the maturity of the drilling industry and workforce.

APPENDICES

Appendix A: Climate Zone Map

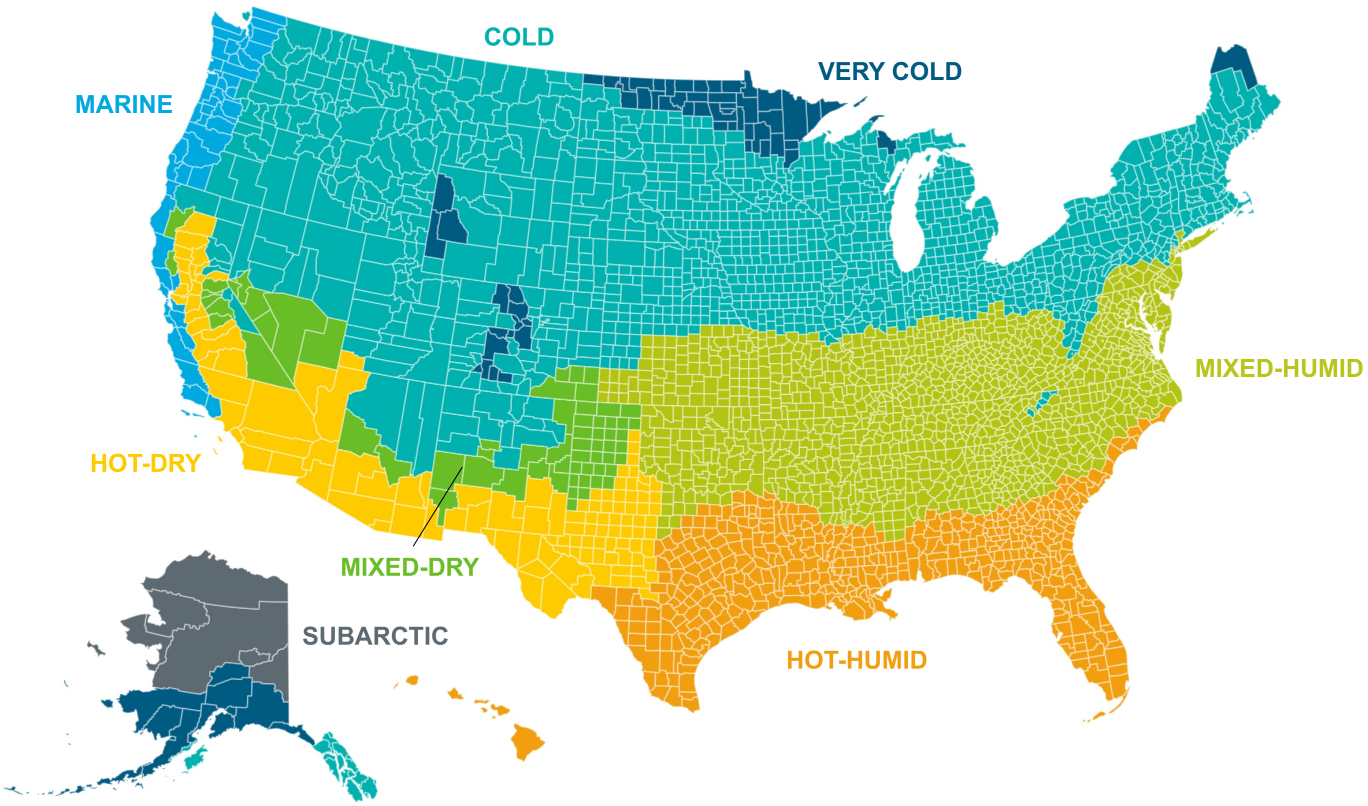


Figure 37: Climate Zone Map

Notes: Adapted from Fig. 7 from Antonopoulos, C., T. Gilbride, E. Margiotta, and C. Kaltreider. 2022. *Guide to Determining Climate Zone by County: Building America and IECC 2021 Updates*. PNNL-33270. Richland, WA: Pacific Northwest National Laboratory. https://doi.org/10.2172/1893981.

Appendix B: Summary of key benefits from widespread GHP deployment

Table 3: Summary of key metrics from maximum geothermal heat pump deployment in electrified and decarbonized scenarios

	2035 ***(46.3 million tons deployed)***	**2050** ***(101 million tons deployed)***
Summer peak demand reduction	**45 GW** *(0.97 kW / ton)*	**121 GW** *(1.2 kW / ton)*
Winter peak demand reduction	**166 GW** *(3.6 kW / ton)*	**425 GW** *(4.2 kW / ton)*
Cumulative system cost savings	**$750 M** *($1,620 / ton)*	**$539 B** *($5,340 / ton)*
Annual customer payment savings	**$18 B** *($389 / ton)*	**$77 B** *($762 / ton)*
Annual generation reduction	**365 TWh** *(7.88 MW / ton)*	**937 TWh** *(9.28 MW / ton)*
Capacity reduction	**112 GW** *(2.41 kW / ton)*	**410 GW** *(4.06 kW / ton)*
Transmission buildout avoided	**8.0 TW-mi** *(0.17 MW-mi / ton)*	**65 TW-mi** *(0.65 MW-mi / ton)*
Transmission cost savings	**$6.5 B** *($140 / ton)*	**$74.0 B** *($733 / ton)*

Notes: Values reported from Liu et al. (2023)[112], corresponding to a scenario with high electrification and decarbonization. Savings pathway with no GHP deployment vs. a scenario that reaches 67% overall building stock with GHP deployed by 2050, deployed linearly starting in 2022.

Appendix C: Geothermal Heating and Cooling Industrial Growth Trajectory and Liftoff Details

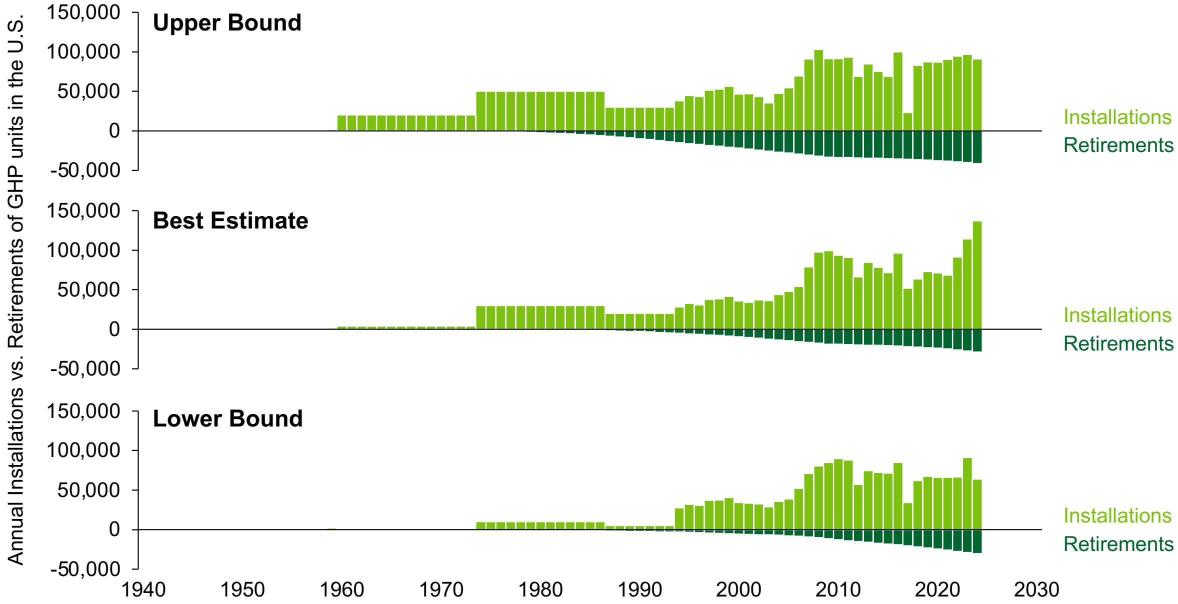


Figure 38: Annual estimated installations vs. retirements of GHP units (commercial + residential, in equivalent # of households) since 1948, showing lower bound, best estimate, and upper bound scenarios as depicted in Figure 15. Installations are derived from deployment data available in literature and assumptions where data are missing (e.g., 1990s and prior). Retirements were calculated from survival curve assumptions fitted to available data on similar types of HVAC equipment. The difference between annual installations and retirements represents cumulative net additions to GHP stock.

GHP shipments are correlated with and lag oil & gas price swings by ~1 to 3 years (Figure 39). We attribute the observed lags to consumer utility bill escalation during annual renewals of rate plans, as well as time needed to design, purchase, and implement GHP systems.

In addition to energy prices, tax incentives also play an important role for the deployment of GHPs. The Residential Clean Energy Credit (25D) has been available for geothermal heat pumps from 2008 onwards,[113] with one year (2017) where no tax credits were available during the calendar year but were made available retroactively upon reinstatement later. As seen in Figure 39, GHP shipments dropped significantly after expiry of the 25D on January 1, 2017, and slowly increased after the tax credits were reinstated the following year (in early 2018).[114] However, these effects are intertwined with the significant drop in energy prices after the oil price crash of 2014–2015, so isolating the effect of tax credits alone is difficult. Additionally, tax credits were set to stage down from 30 percent to 26 percent in tax year 2022 had the Inflation Reduction Act not been passed in August of that year.[115]

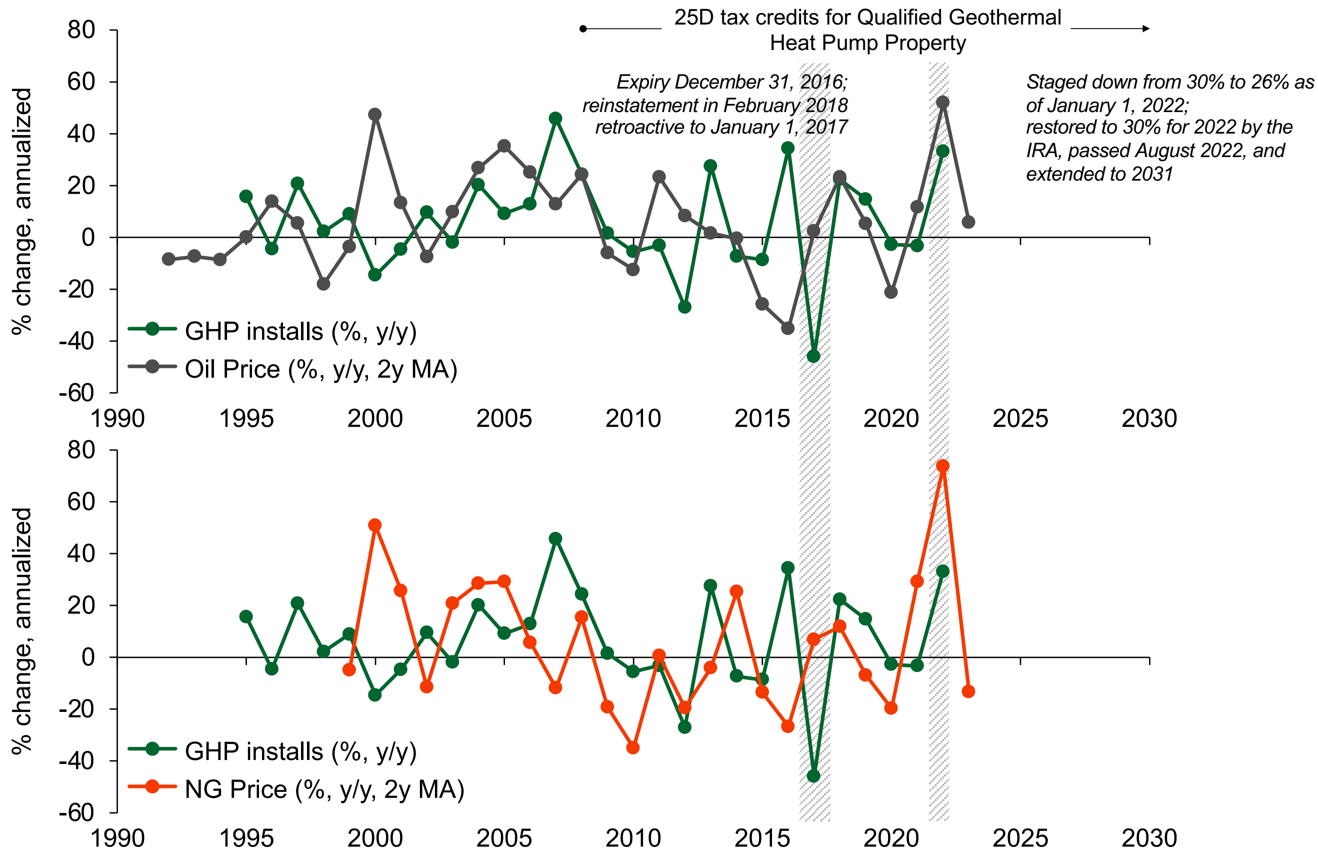


Figure 39: Annual percentage change in installations of GHPs in Best Estimate case compared against percentage changes in oil price (top) and natural gas price (bottom). Energy prices shown are 2-year moving average of annualized changes. Data from FRED for data series WTI Crude Oil (DCOILWTICO) and Henry Hub Natural Gas (MHHNGSP), taken as average price over each calendar year.

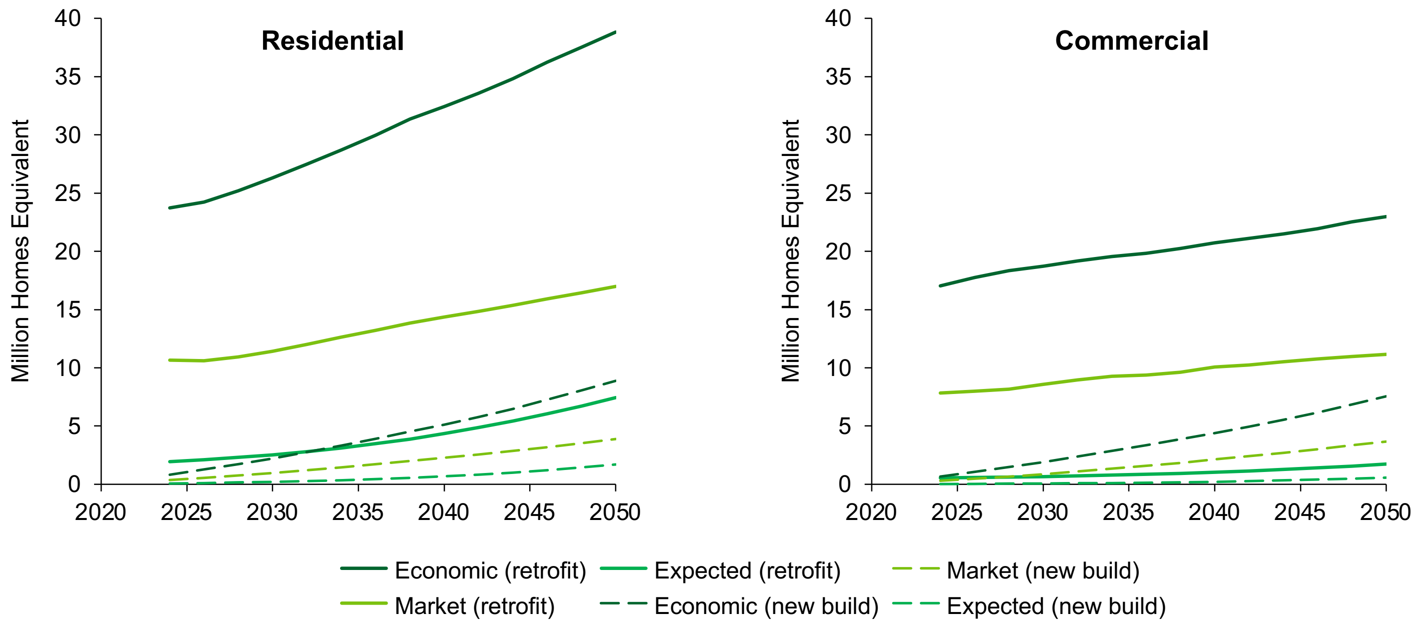


Figure 40: Residential and commercial installation potential (million homes equivalent) for retrofits and new builds

Notes: Sources and assumptions same as Figure 24.

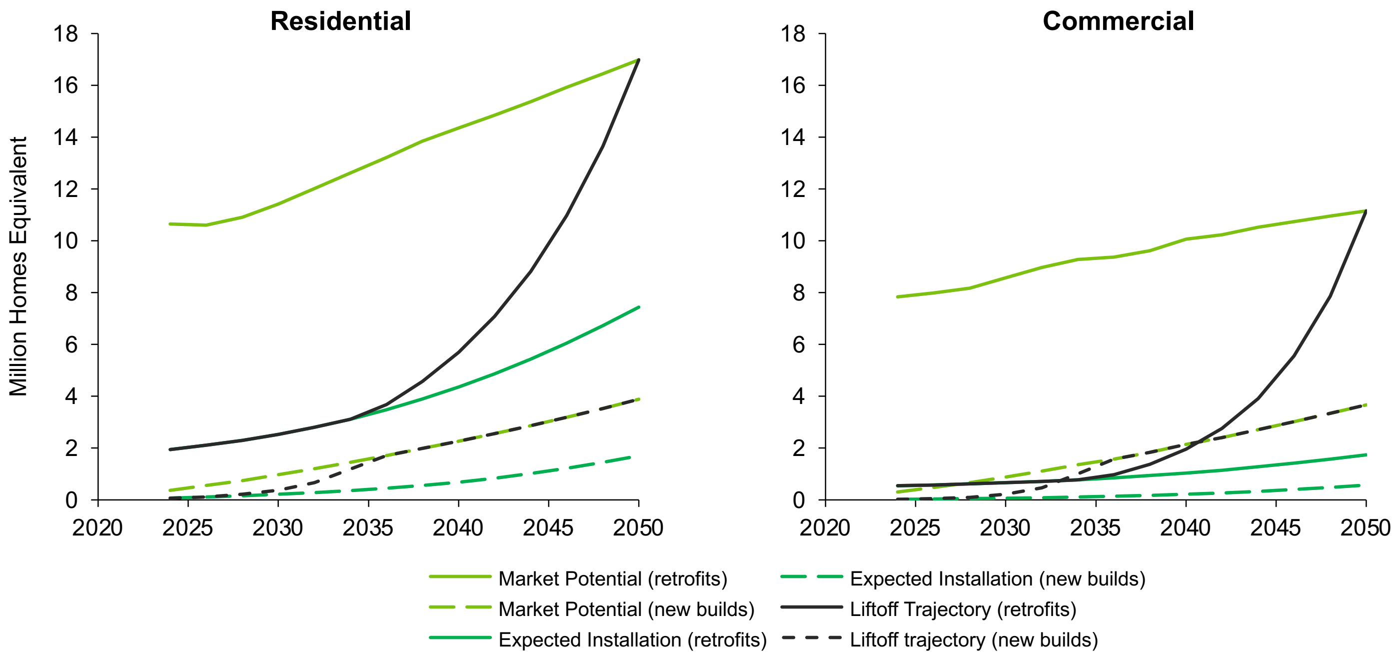


Figure 41: Liftoff trajectory breakdown between retrofits and new builds

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Errata

January 13, 2025

The following corrections have been made to the version initially published online on Jan. 10, 2025:

Figure 20 was missing unit labels. Values are in units of ($/ton).

Figure 21 was missing unit labels. Values are in units of ($/ton).

Figure 24 was missing the left y-axis label "Million Homes Equivalent".

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These errors have been corrected in the current version.