Geothermal Heating and Cooling

Pathway to Commercial Liftoff

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Pathways to Commercial Liftoff:

Geothermal Heating and Cooling

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Pathways to Commercial Liftoff:

Geothermal Heating and Cooling

Report Overview

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Top-Line Messages

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 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
- Geothermal heating and cooling technologies can **reduce peak electricity demand, increase resilience**, and **lower ratepayer energy bills**
- Geothermal heating and cooling systems have **a multi-pronged and unique value proposition** among building decarbonization technologies
- 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. Still, in some cases, **GHPs can be the lowest first cost option.**

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, ($100-150 billion)

- **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.**

5 major imperatives that increase the value proposition (by reducing costs or increasing benefits) and expand the market size of GHPs

- **Scale and train workforce**
- **Develop and standardize market-ready products and protocols**
- **Develop ratemaking or other frameworks to incorporate benefits and refine planning**
- **Clarify and standardize regulations**
- **Realize network effects**

U.S. DEPARTMENT OF ENERGY

Chapter 1: Introduction and Objectives

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.

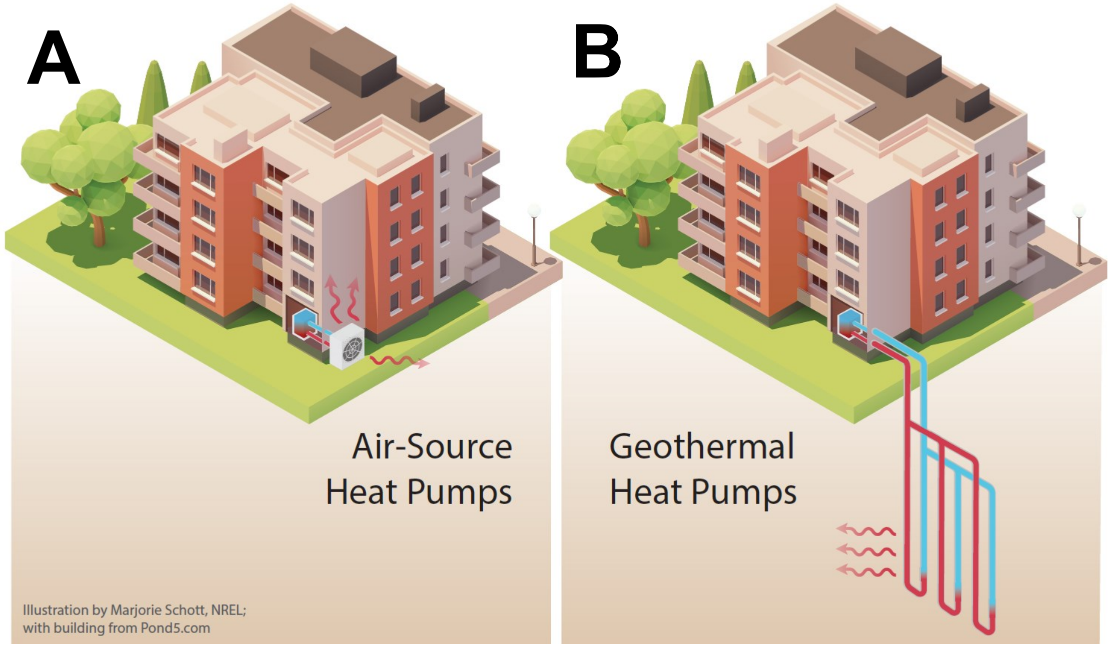
Geothermal heating and cooling contributes to three key levers for building decarbonization: energy efficiency, efficient electrification, and grid edge resource management.

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.

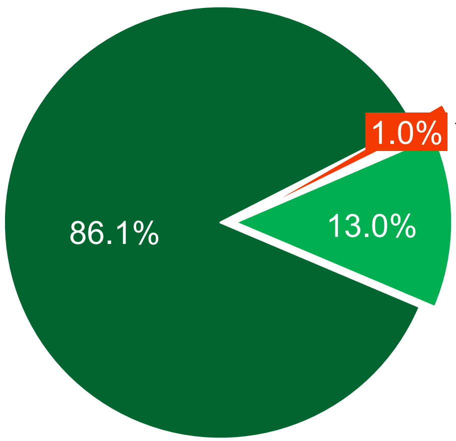
Geothermal heating and cooling systems have a multi-pronged and unique value proposition among building decarbonization technologies, including the highest efficiency of all heat pump options in most states, large grid benefits and savings associated with deployment, and broad geographic availability. Additionally, TENs provide opportunities for bundled financing and advantages for gas utilities that deploy them.

What are geothermal heating and cooling solutions?



Notes: Images adapted with permission from Marjorie Schott, National Renewable Energy Laboratory.

C **Heating and cooling installation overview (% of homes by primary heating system type)**

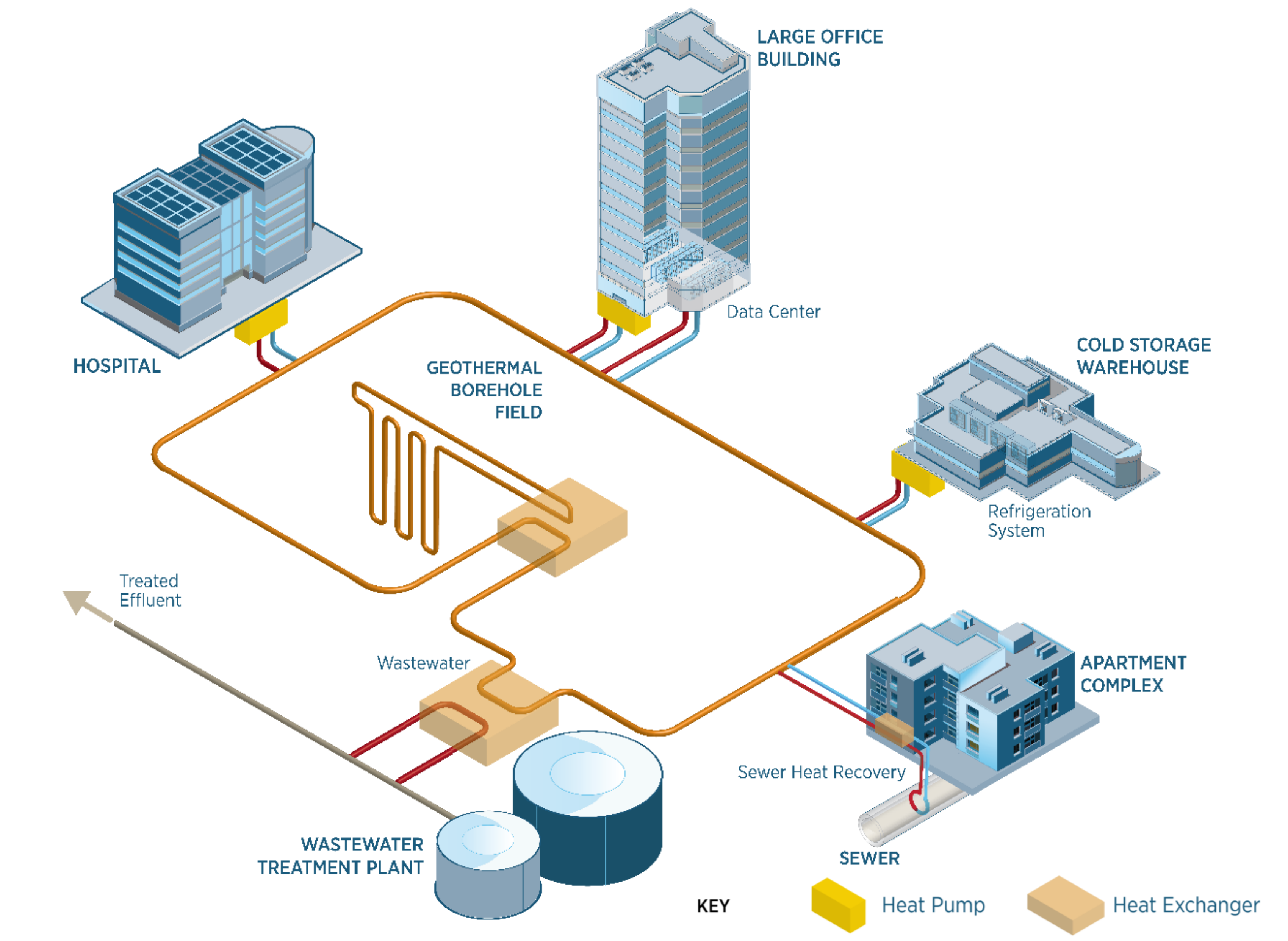


Total U.S. homes in dataset = 123.5 million

Percentages may not add to 100% due to rounding.

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.

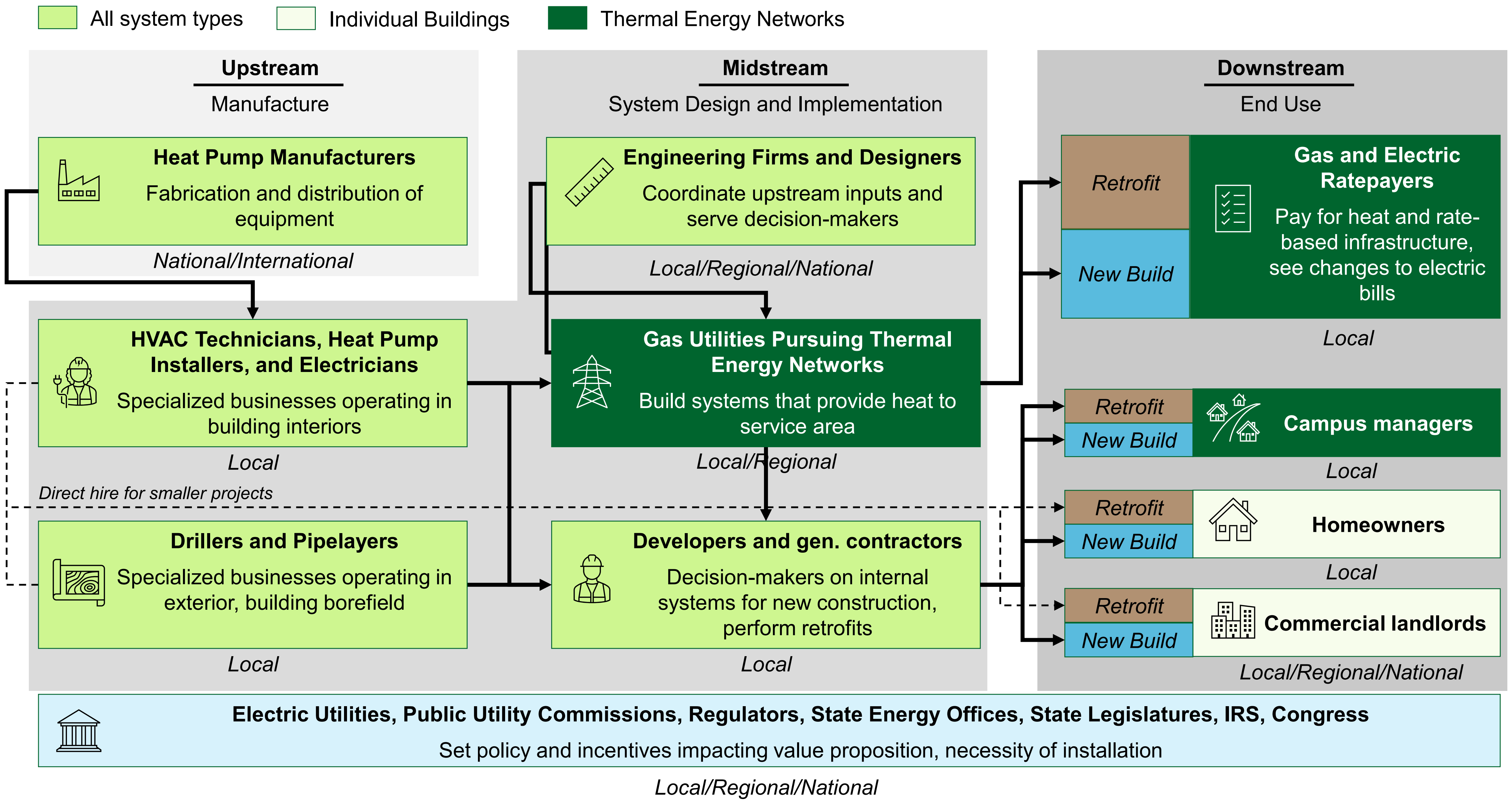
Thermal Energy Networks (TENs) principles and attributes



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

Geothermal Heating and Cooling Value Chain



Geothermal heating and cooling value proposition

- Highest efficiency electrification
- Large grid benefits and savings
- Broad geographic availability
- Long lifespan
- Local quality employment
- High resiliency

Thermal Energy Networks additional value

- Project-level financing
- Gas utility advantages
- Environmental justice and equity benefits

Chapter 2: Current State – Technologies & Markets

Annual estimated installations suggest that the current level of GHP installations as of tax year 2023 is on the order net additions around 85,000 units per year after accounting for retirements.

The cost of a GHP installation 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.

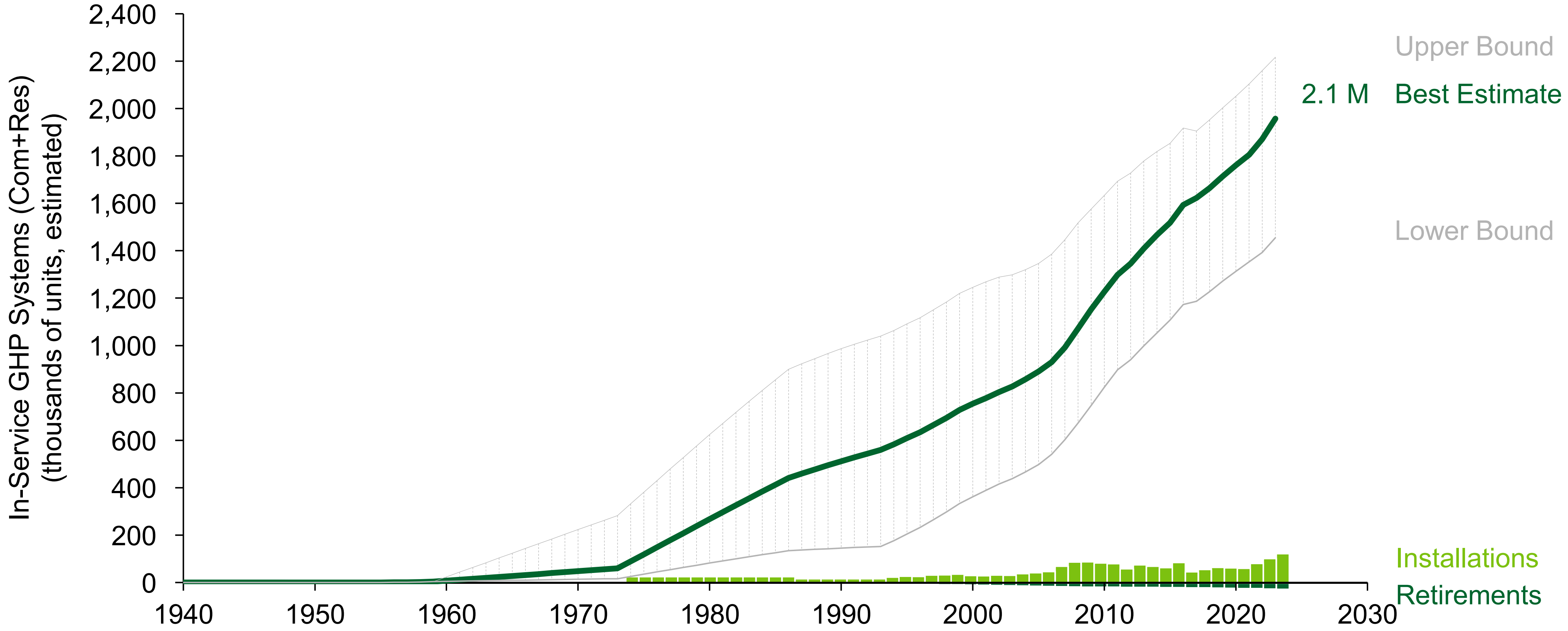
Regional differences in GHP installation costs are driven by drilling and labor costs, which vary based on the availability and experience of local drilling companies and installers, as well as variations in both local regulation and geological subsurface characteristics.

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.

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.

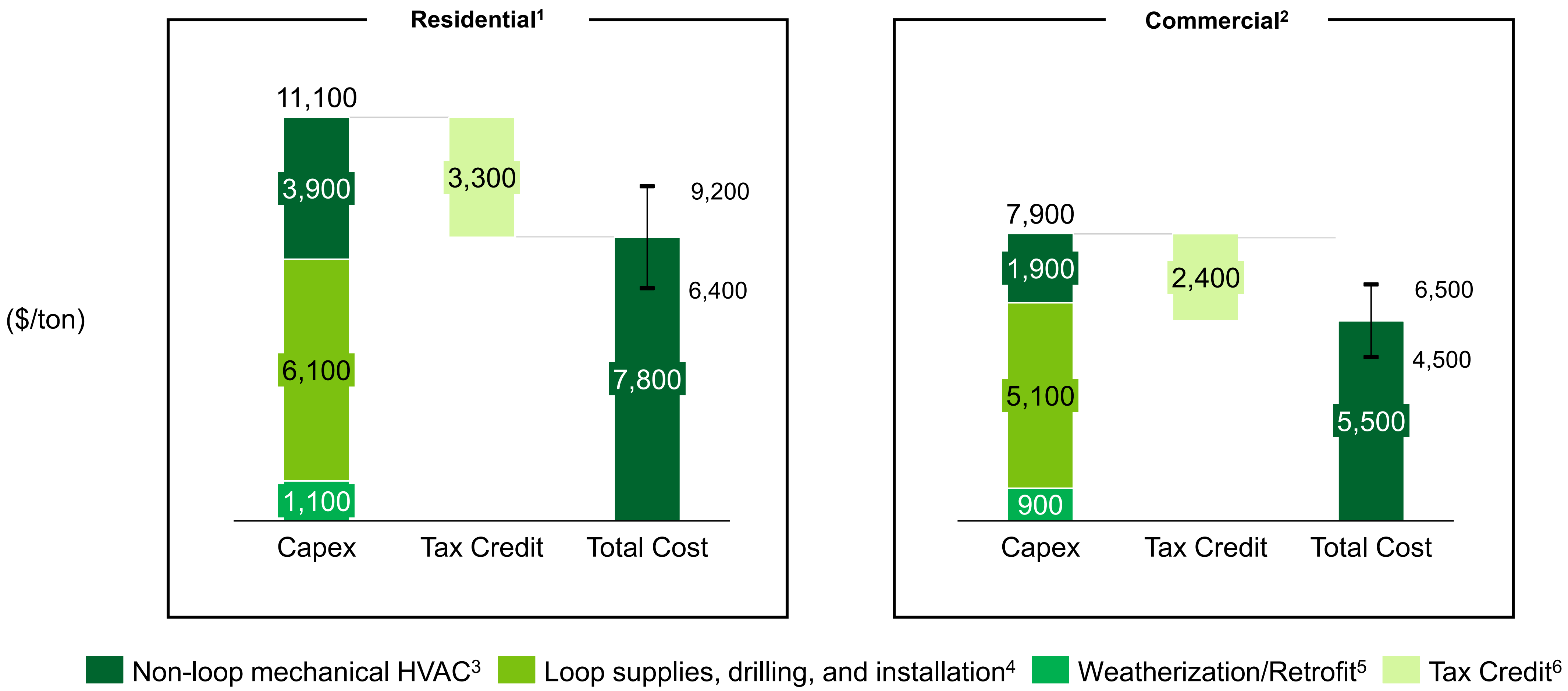
Current GHP capacity stands at 2 million GHP units in service with annual additions exceeding 100,000 units (+5% p.a.)

Estimated deployment of GHPs since 1948

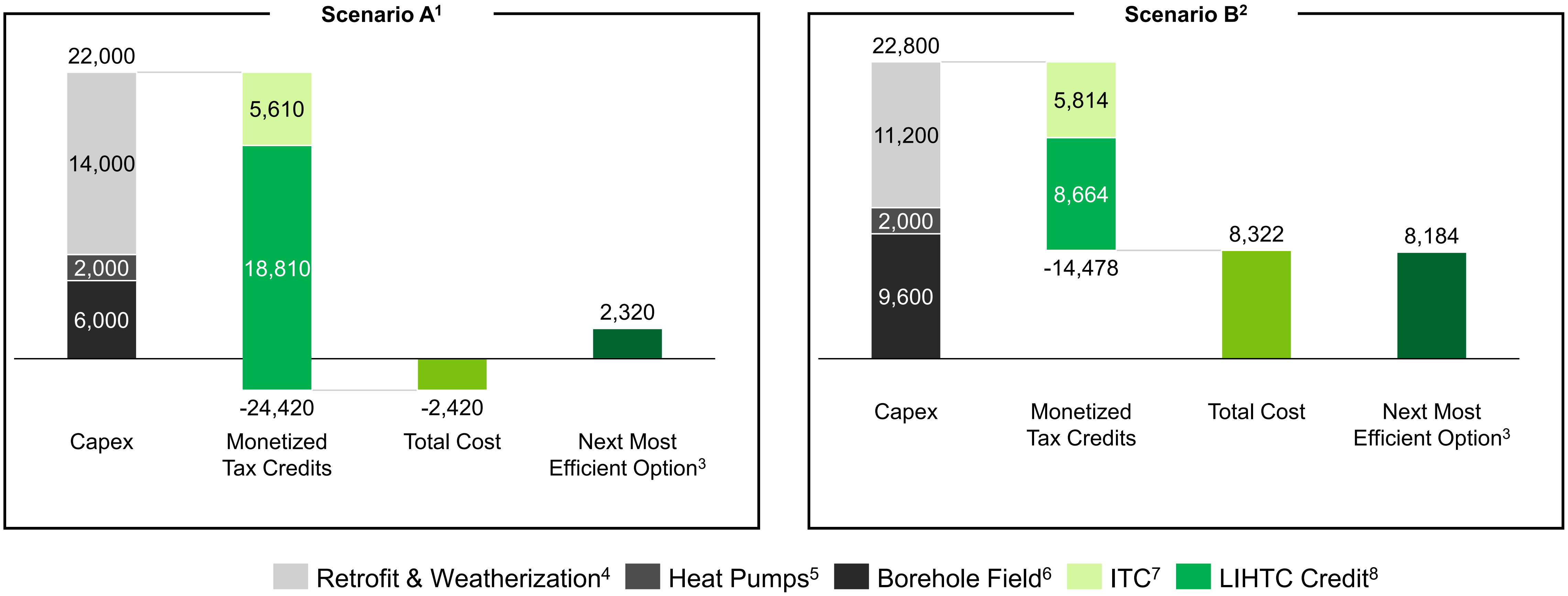


Sources: IRS Statistics of Income, Pub. 4801 (2008-2021); Holihan (1998) *Analysis of Geothermal Heat Pump Manufacturers Survey Data*; EIA (1997, 2003, 2009) *Geothermal Heat Pump Manufacturing Activities*; EIA (2020) RECS; ENERGY STAR Shipment Data (2003-2015); BRG Building Solutions (2022) *The North 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); DOE analysis & model

Estimated National Median Cost of GHP Installation



Economics of hypothetical affordable housing retrofits in Northeast ($/ton)



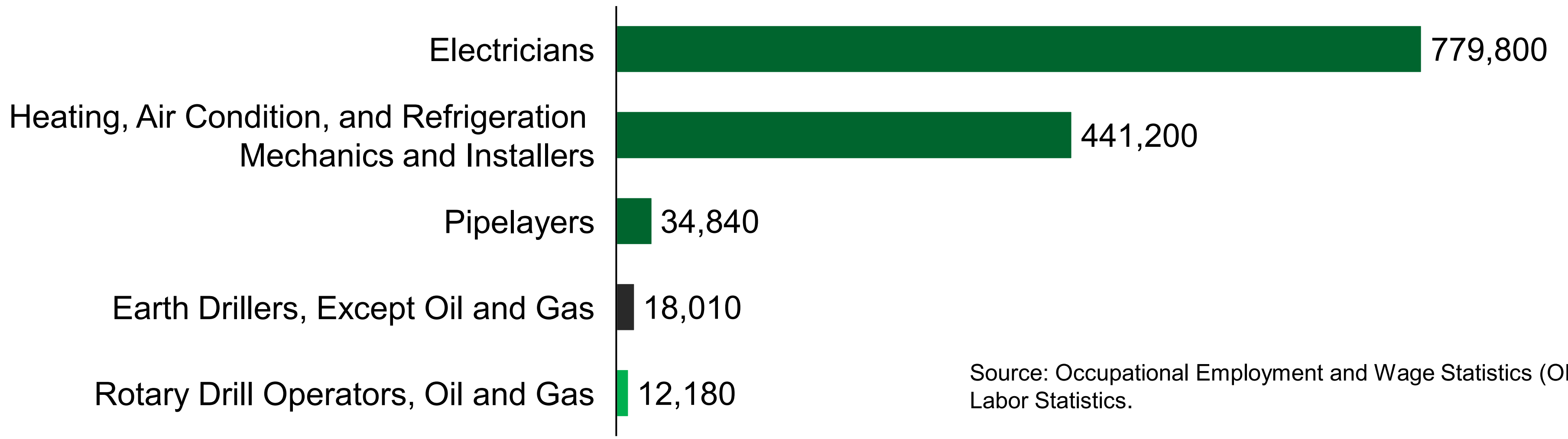
All sectors of GSHP workforce have high transferability; drillers have greatest training duration and capital costs

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

The United States has a small drilling workforce that is in high demand and under constant flux

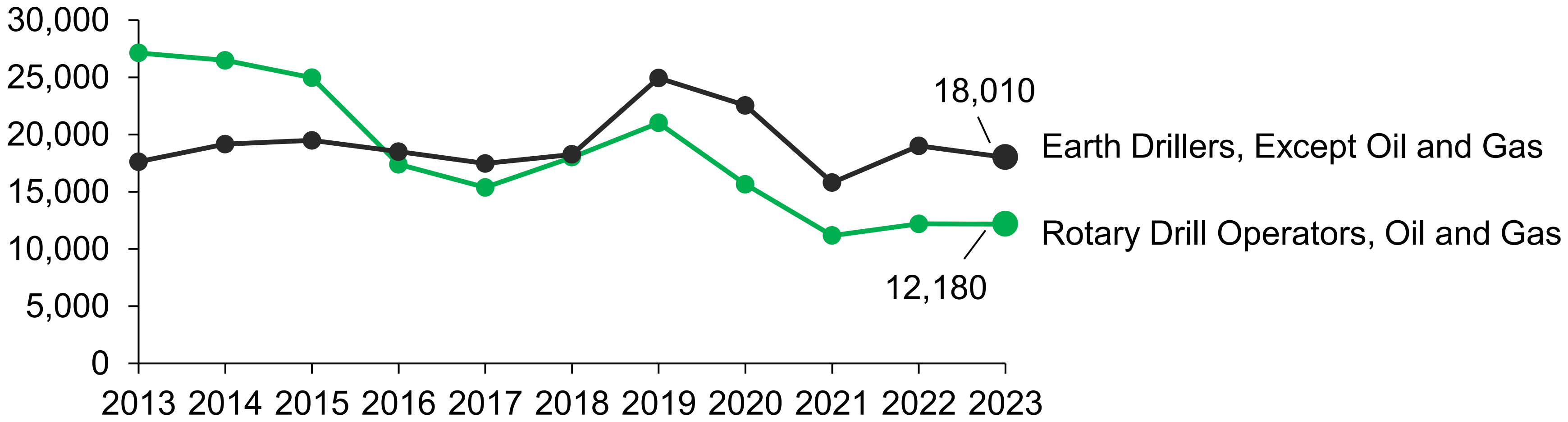
Relevant workforce in 2023



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)]

Variability in drilling workforce



Chapter 3: Pathway to Commercial Liftoff and Scale

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% ± 2%

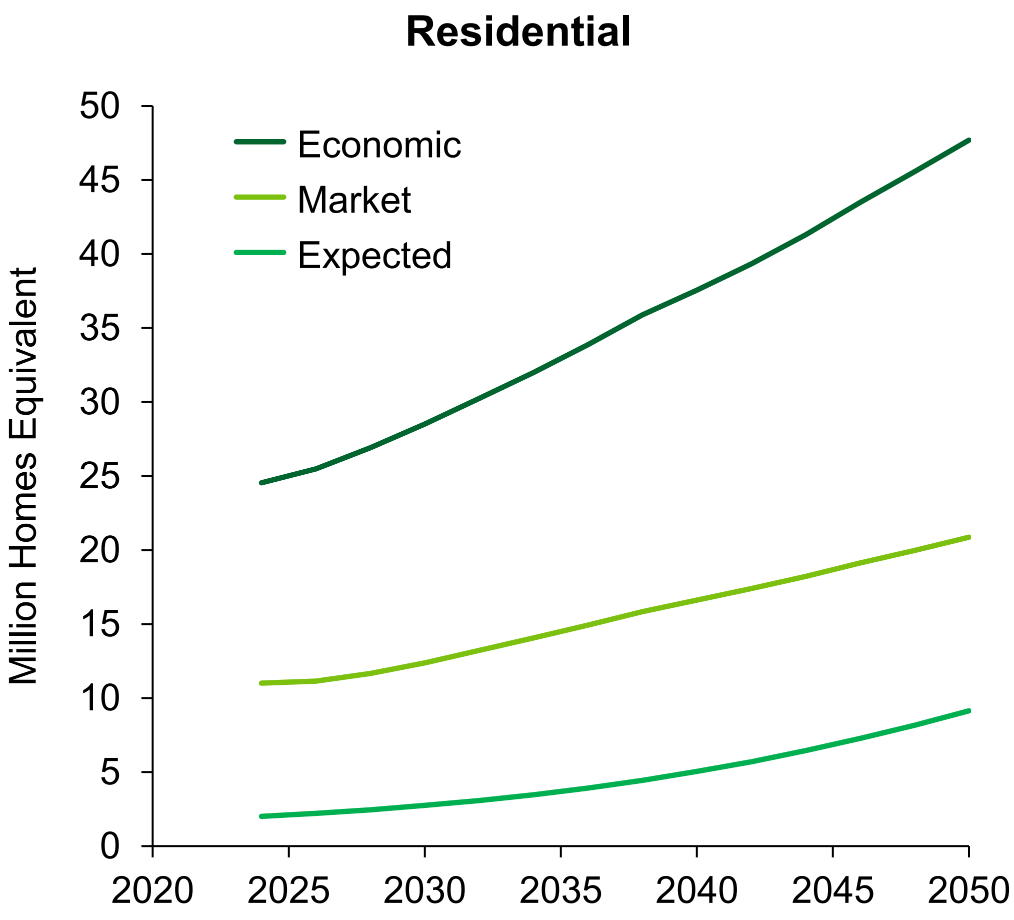
The geothermal heating and cooling industry can reach Liftoff in 2035 by focusing on scaling near-term opportunities for installation of GHPs in the equivalent of 7 million homes, a $100-150 billion cumulative market opportunity with the potential for $4B in annual grid savings.

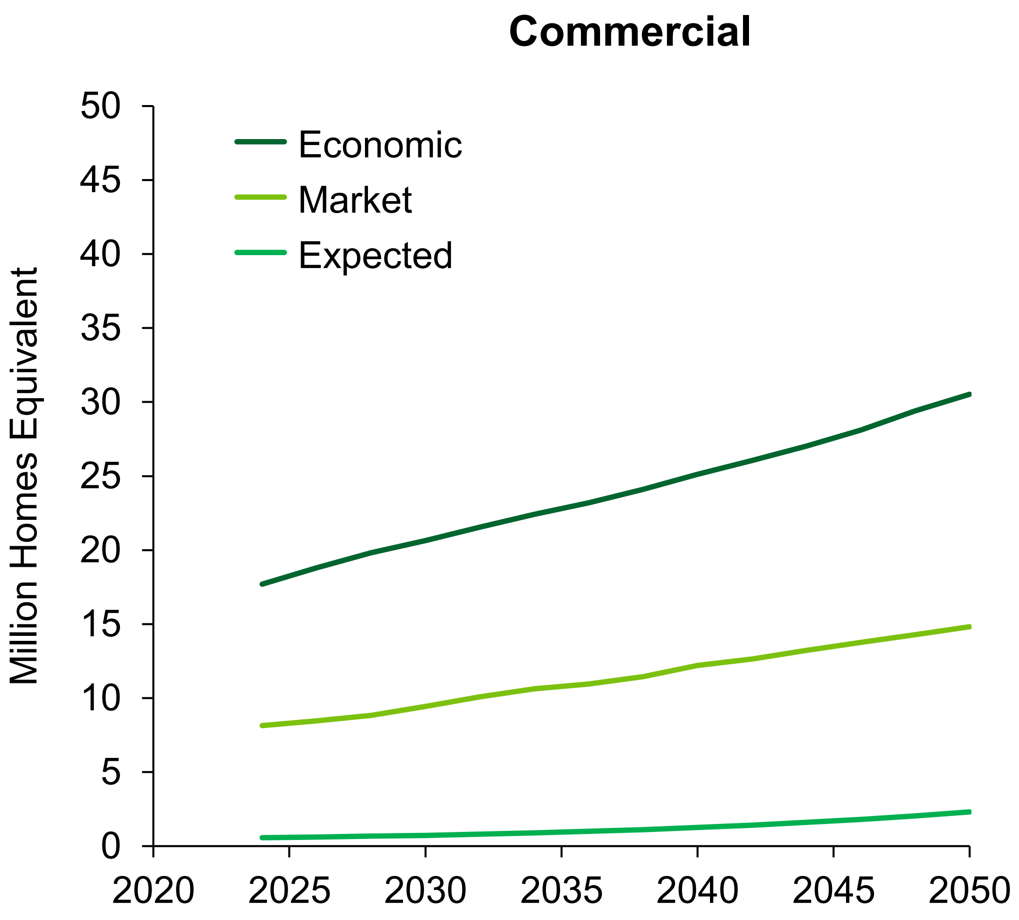
Installation incentives alone, provided at a similar overall level to the annual grid system cost savings, could increase expected installation to levels close to Liftoff by 2035.

The geothermal heating and cooling industry can reach commercial scale in 2050 by expanding and industrializing a repeatable development process that includes retrofits, installing GHP units in the equivalent of 36 million homes, a $500-700 billion cumulative market opportunity

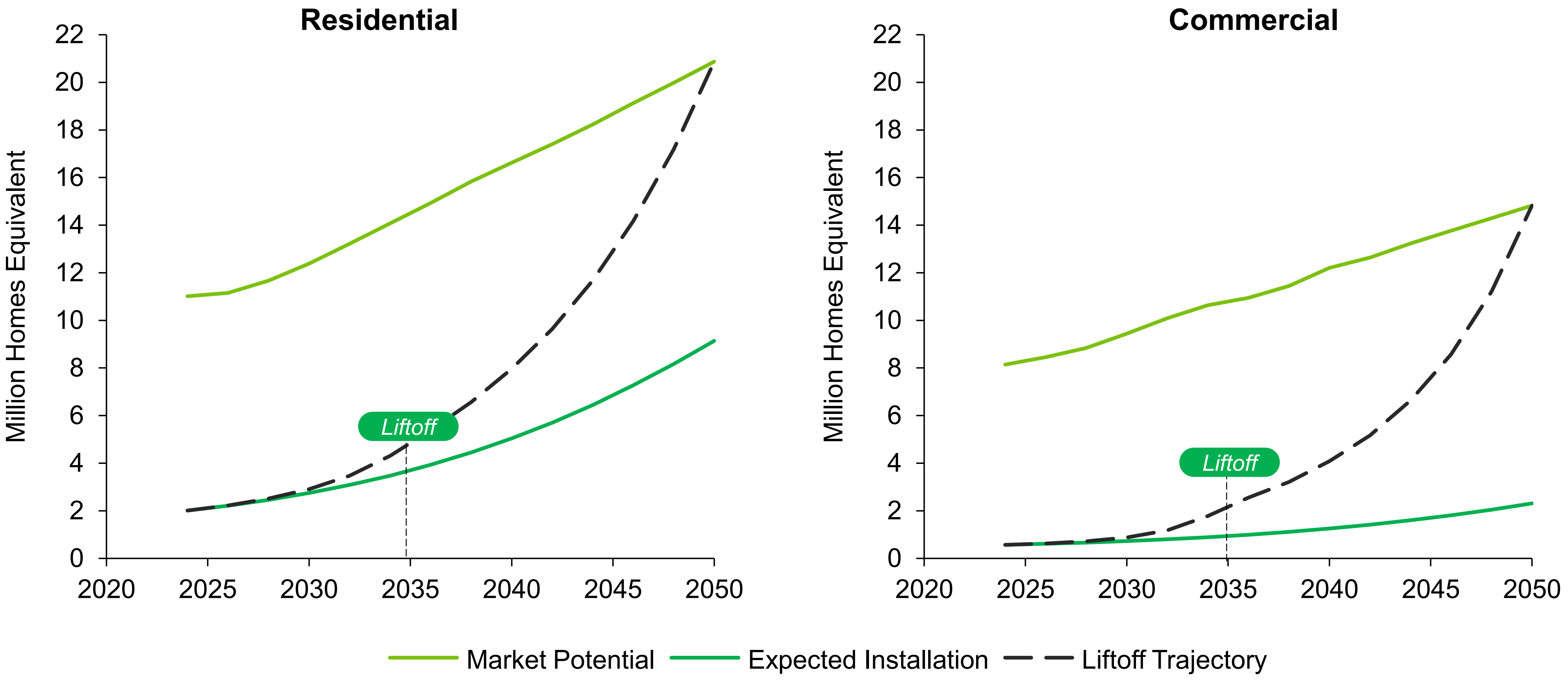
Tens of millions of homes and businesses could install GHPs by 2050 with a positive lifetime payback

Residential and Commercial total potential (Million homes equivalent)





Industry can stay on track to reach its full market potential in 2050 with a steady industry annual growth rate of ~10% ± 2%



Scale new builds — **Liftoff** — **Scale retrofits**

Today — 2035 — 2050

7M homes equivalent ($100 - $150B investment)

- Scale **new builds** to full market potential, continue growth in retrofits
- Achieve network system cost reductions to reach unit cost parity with single building systems

Pursue near-term opportunities

Individual Buildings

Profitable new construction; planned replacements

Thermal Energy Networks

Complete pilot projects

Expanded pilots; new neighborhood developments; profitable campus systems

36 M homes equivalent ($500 - 700B investment)

- Scale **retrofits** to full market potential, continue growth in new builds
- Mobilize ecosystem of consumers, service providers, and financing to deploy individual buildings and networked systems at large scale

Expand and industrialize repeatable development process

Profitable retrofits; profitable new construction; planned replacements

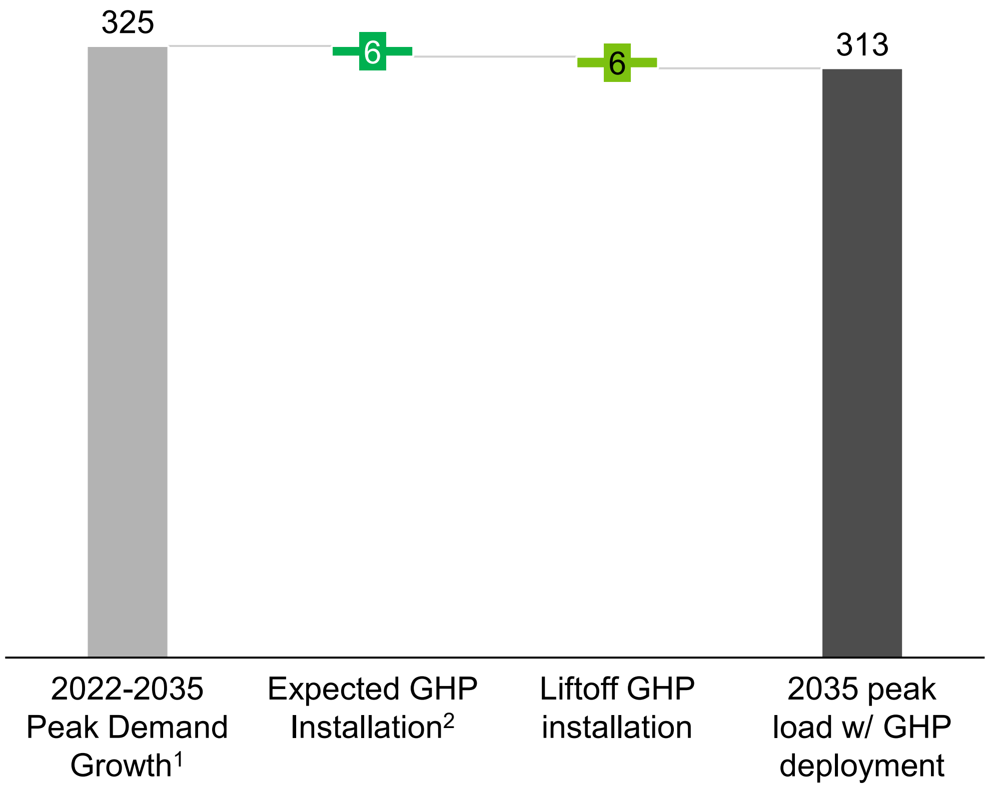
New neighborhood developments; gas pipeline replacement; profitable campus systems; profitable retrofits

Pursue imperatives to increase value proposition and expand market size

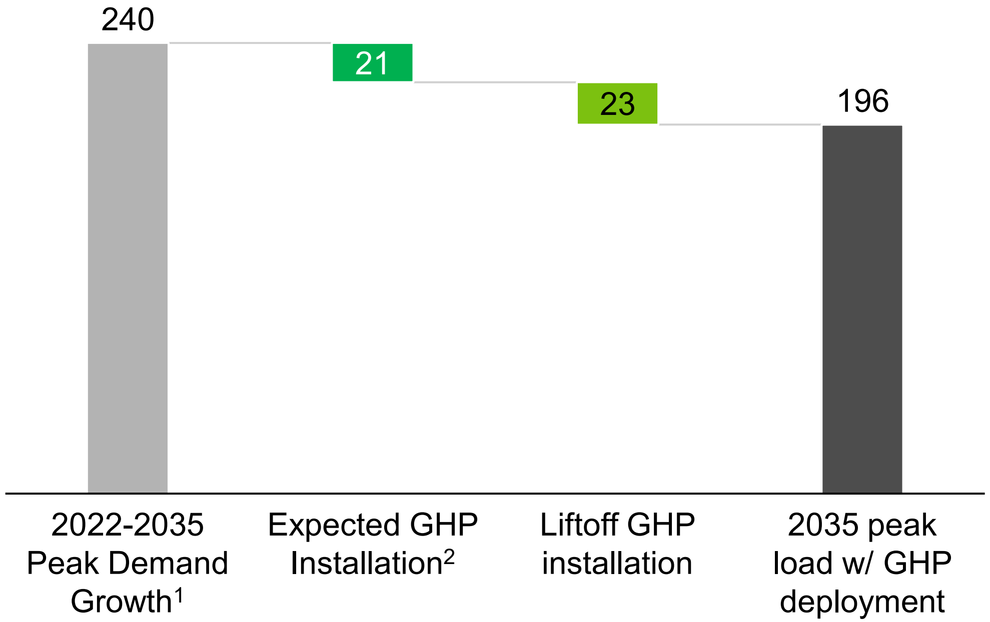
Campus managers
Homeowners
Commercial Landlords
Gas and electric ratepayers
HVAC technicians, heat pump installers, and electricians
Drillers and pipelayers
Developers and gen. contractors
Heat pump manufacturers
Engineering firms and designers
Utilities
Policy/regulation

Reaching GHP liftoff by 2035 could address 12 GW of Summer Peak and 44+ GW of Winter Peak Demand

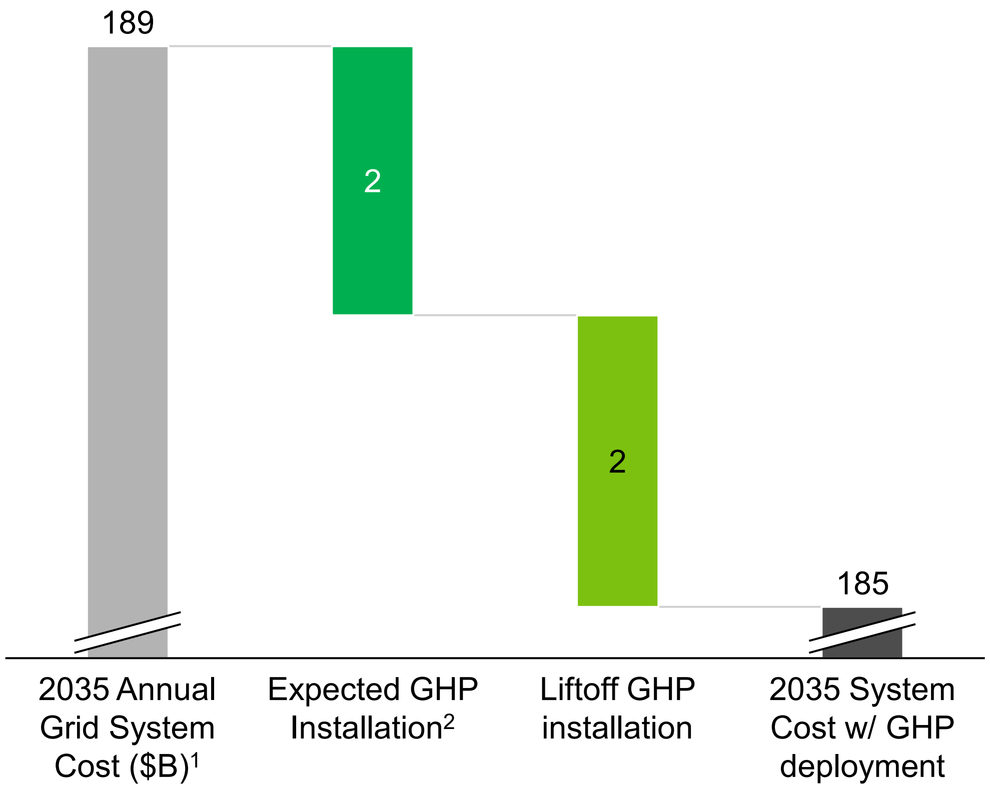
2022-2035 Summer Peak Demand (GW)



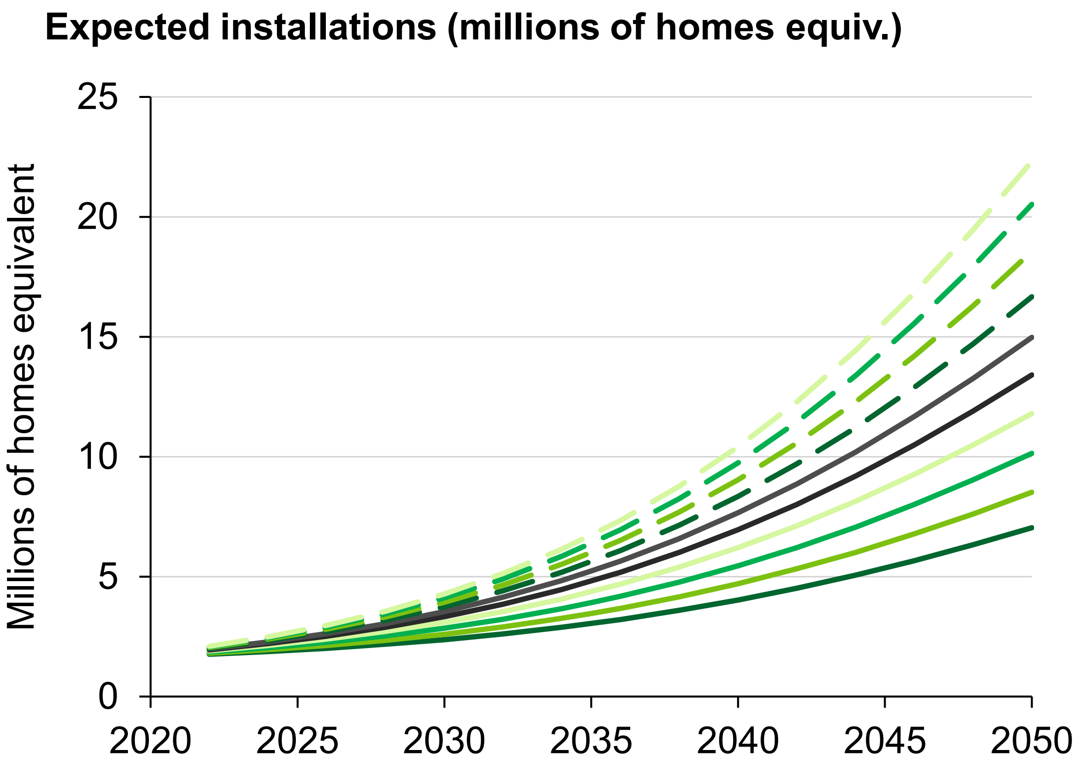
2022-2035 Winter Peak Demand (GW)

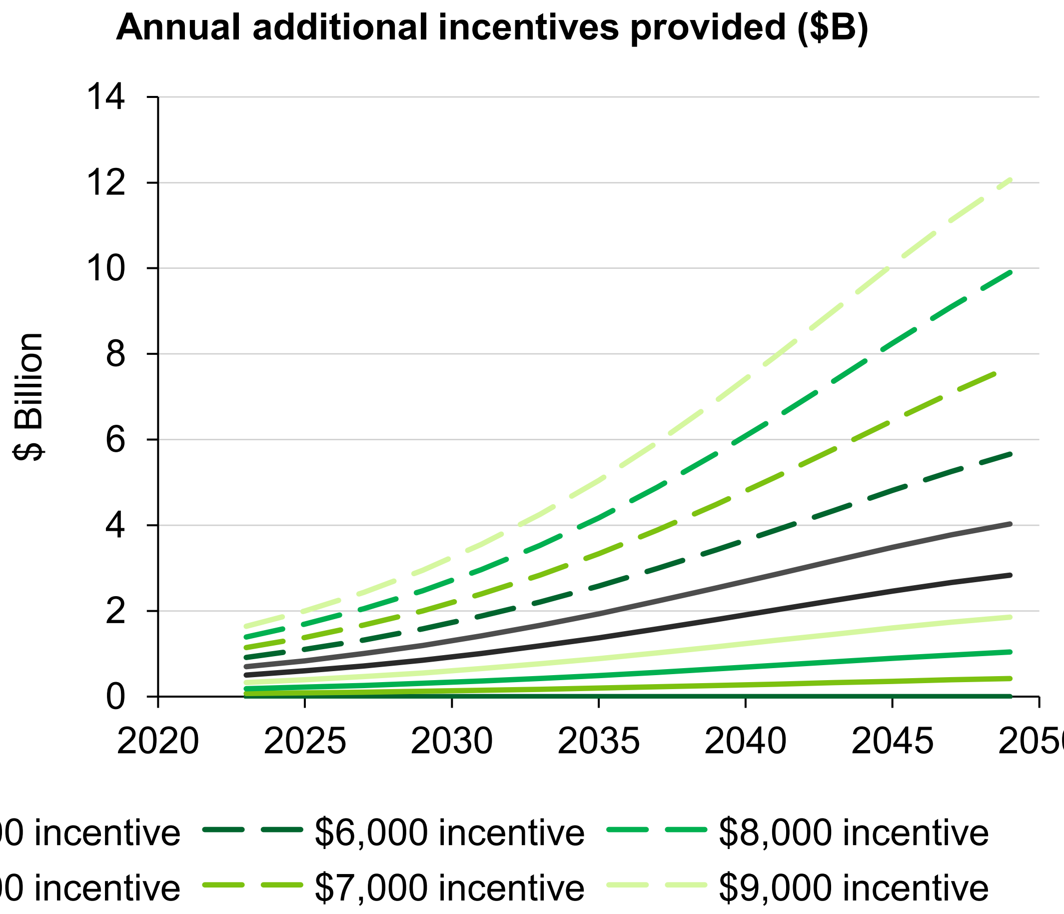


Reaching GHP liftoff by 2035 could reduce grid system costs by $4B



Installation incentives alone could increase expected installation to levels close to Liftoff by 2035.





Notes: Residential GHP retrofits only. Modeling performed by NREL (K. Beckers et al.) using same tools and assumptions, 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. NPV calculated at a 7% discount rate.

Chapter 4: Challenges to Commercialization and Potential Solutions

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 goals supports and helps compensates consumers who adopt GHP systems

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

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

Rapid and sustainable growth of the GHP workforce is a necessary enabler for widespread GHP adoption

Because of the relatively small size of the drilling workforce and number of existing rigs, the ability of the drilling workforce to scale is a key determinant of the capacity for Liftoff of geothermal heating and cooling.

Including GHP installations in HVAC installer training programs will ensure that GHPs are offered as an option to more and more consumers.

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.

Regional train-to-hire partnerships and GHP workforce pipelines accelerate and streamline training, certification, and licensing

	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

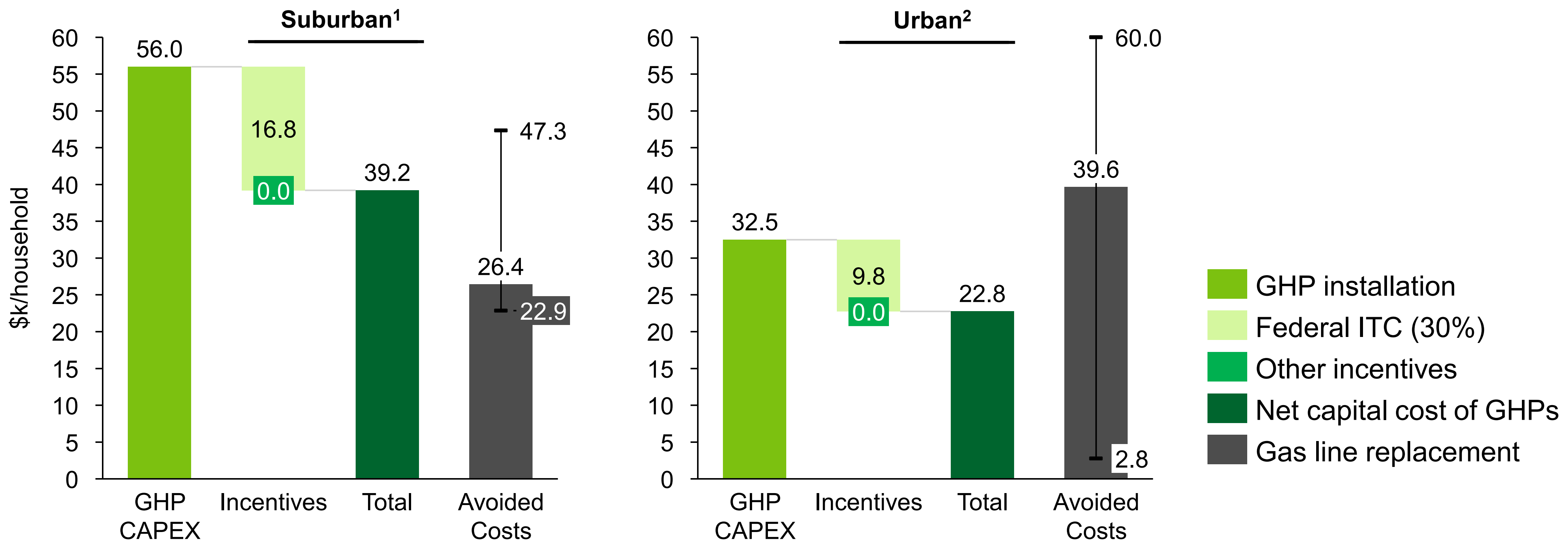
Submissions open!

Partnerships to Accelerate Training & Hiring for Geothermal Heat Pumps Prize

www.herox.com/GHPPATHS

Phase I submissions due February 12, 2025

Residential ground source heat pump retrofits may require less capital than replacement of end-of-life gas pipes in some areas



Thank you!

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To help inform future Liftoffs, please submit feedback at:

liftoff.energy.gov/input

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