

Pennsylvania: Grid Impacts of Geothermal Heat Pumps for Residential Buildings

Pennsylvania is expected to see increasing electricity demand driven by rapid data center load growth and the accelerating electrification of buildings and transportation, with space heating contributing to a shift from a summer-peaking to winter-peaking electricity system. Managing winter peak demand will therefore be essential to maintaining grid reliability and containing infrastructure spending.

This analysis is part of a [three-state study](#) — including Texas, Massachusetts, and Pennsylvania — that examines the system impacts of geothermal heat pump (GHP) (also called ground-source heat pump) deployment across climates, building types, and multiple adoption scenarios under both current and future load conditions.

In Pennsylvania, the analysis focuses on residential buildings, including single-family and multifamily homes, where heating and cooling demand often drives the system peaks. GHPs are particularly well-suited to these conditions due to their ability to maintain higher efficiency during extreme temperatures, reducing both peak demand and total energy consumption.

The study evaluates the impacts of GHPs in Low (2%), Medium (10%), and High (20%) Adoption Scenarios in single-family and multifamily homes in Pennsylvania under Today's timeframe (2025), based on current load profiles, and the Electrified Future timeframe (2040), reflecting electrification across transportation, industry, and buildings, where homes receive GHPs instead of air source heat pumps.

Key Takeaways

- Residential GHP deployment initially shifts Pennsylvania from a summer-peaking to a winter-peaking system under the Medium (10%) and High (20%) Adoption Scenarios, increasing annual peak demand in the Today (2025) timeframe. As the broader building stock electrifies, however, GHPs become a major peak reduction resource, lowering statewide peak demand by up to 12 gigawatts (GW) in the Electrified Future (2040) timeframe.
- Residential GHP deployment delivers overall utility system savings in both the Today and Electrified Future timeframes. In the Today timeframe, higher electricity system costs are more than offset by avoided natural gas and fuel oil costs. In the Electrified Future, utility system savings increase dramatically to approximately \$20 billion under the High Adoption Scenario, driven primarily by avoided generation capacity investments resulting from large peak demand reductions.
- In the Electrified Future timeframe, residential GHP deployment increases load factors, improving utilization of the electric system and helping place downward pressure on electricity rates for all customers.
- While current GHP installation costs exceed quantified utility system savings, the cost gap narrows significantly in the Electrified Future. Achieving utility system cost-effectiveness in Pennsylvania would require approximately a 30% reduction in residential installed GHP costs from the current average of \$14,930 per ton — an installed cost target of approximately \$10,610 per ton in 2025 dollars (equivalent to \$2,880 per ton incremental cost relative to air source heat pumps). Some European markets have achieved a similar scale of cost reductions, indicating that policies encouraging broader adoption could help drive down costs and unlock these utility system savings. Pennsylvania's existing drilling workforce provides a strong foundation to accelerate progress toward this target.
- Residential GHP deployment can make a meaningful contribution toward Pennsylvania's climate goals, with annual emissions reductions under the High Adoption (20%) Scenario exceeding the state's 2030 built environment emissions reduction target and providing nearly two-thirds of the projected 2050 built environment emissions reductions.
- The Pennsylvania Public Utility Commission, legislature, and utilities can accelerate GHP adoption by adding them to utility programs, aligning utility cost-benefit methodologies with their full system value, setting utility targets that support peak demand reduction, and establishing a framework to enable large-load customers seeking interconnection to expedite connection by funding GHP deployment.

Peak Load Reduction and Grid Impact

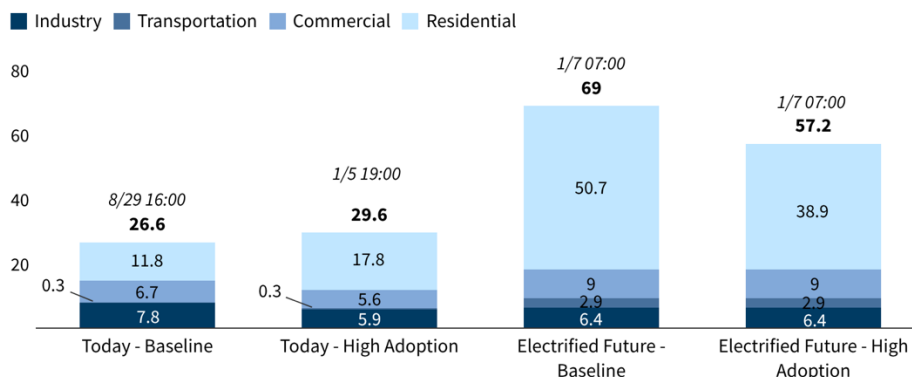
Pennsylvania exhibits different peak demand outcomes across the Today and Electrified Future timeframes. As shown in Exhibits 1 and 2, GHP systems reduce peak demand at Low Adoption (2% of single-family and multifamily homes), but increase peak demand by approximately 1 GW at Medium Adoption (10%) and 3 GW at High Adoption (20%) in the Today timeframe, reflecting a shift from summer peaking to winter peaking as fossil heating systems are replaced with electric heating.

In the Electrified Future timeframe, GHPs reduce peak demand across all adoption levels analyzed in Pennsylvania. The magnitude of peak demand reductions scales approximately linearly with increased adoption, with the High Adoption Scenario reducing statewide peak demand by approximately 12 GW. This indicates a high degree of coincidence between GHP savings and Pennsylvania's future peak electric demand hours.

Medium and High Adoption scenarios reduce statewide load factors in the Today timeframe due to the shift from summer peaking to winter peaking. In the Electrified Future timeframe, higher GHP penetration increases statewide load factor by 1%–9%, depending on the scenario. Higher load factors indicate improved utilization of the electric system, which can help place downward pressure on electricity rates by reducing the need for infrastructure built solely to serve infrequent peak demand.

Exhibit 1

PA peak demand contribution by sector and scenario (GW)



Peak hours varies for each scenario and are noted above.

Source: RMI analysis



Exhibit 2

PA 2025 and 2040 peak load and energy reduction by scenario

Scenarios	2025					2040				
	Peak Hour: 4 p.m. Aug 29 (baseline & low); 7 p.m. Jan 5 (medium and high)					Peak Hour: 7 a.m. Jan 7				
	Peak (GW)	Peak Reduction (GW, %)	Annual Total (GWh)	Total Energy Reduction (GWh, %)	Load Factor*	Peak (GW)	Peak Reduction (GW, %)	Annual Total (GWh)	Total Energy Reduction (GWh, %)	Load Factor*
Baseline	26.6		146,240		63%	69		250,336		41%
Low	26.6	0.02 (0.1%)	146,900	-664 (-1%)	63%	67.9	1.2 (2%)	250,148	188 (0.1%)	42%
Medium	27.7	-1 (-4%)	149,560	-3,320 (-2%)	62%	63	5.9 (9%)	249,395	941 (0.4%)	45%
High	29.6	-3 (-11%)	152,890	-6,639 (-5%)	59%	57.3	12 (17%)	248,453	1,883 (0.8%)	50%

* Load factor is calculated as average load divided by peak load.

Source: RMI analysis



Economic Value

Utility system savings

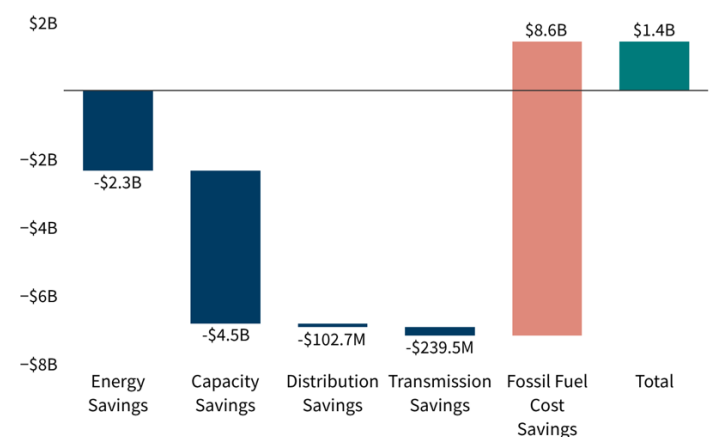
GHP deployment delivers net utility system savings in both timeframes, with substantially greater savings in the Electrified Future.

In the Today timeframe, replacing natural gas and fuel oil heating with GHPs increases electricity system costs but produces substantial wholesale fossil fuel savings, resulting in overall utility system savings overall. Under the Low Adoption (2%) Scenario, GHPs reduce peak demand, partially offsetting higher electricity system costs with capacity, transmission, and distribution savings despite increased electricity consumption. At Medium (10%) and High (20%) Adoption, GHPs increase both electricity consumption and peak demand (shifting it to winter), resulting in higher costs across all electricity system cost categories.

However, in all scenarios, these higher electricity system costs are more than offset by avoided natural gas and fuel oil costs. In the Electrified Future timeframe, large reductions in peak electricity demand relative to a baseline with air source heat pumps produce substantial capacity savings,ⁱ which drive the majority of utility system savings. Combined with modest electricity energy savings, GHP deployment results in up to \$20 billion in overall utility system savings under the High Adoption Scenario.

Exhibit 3

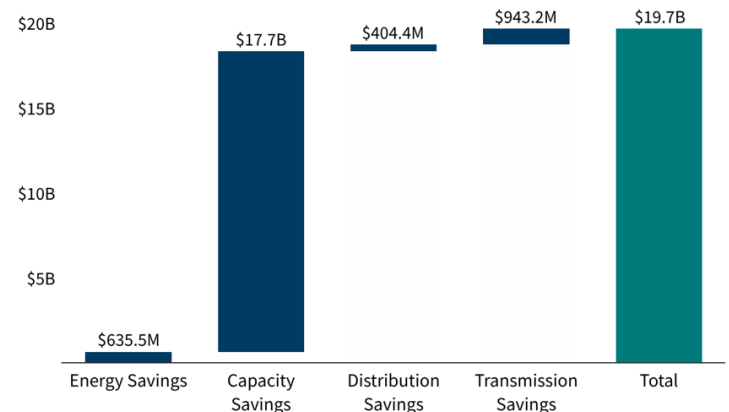
PA 2025 High Adoption Scenario utility system savings



Source: RMI analysis



PA 2040 High Adoption Scenario utility system savings



Source: RMI analysis



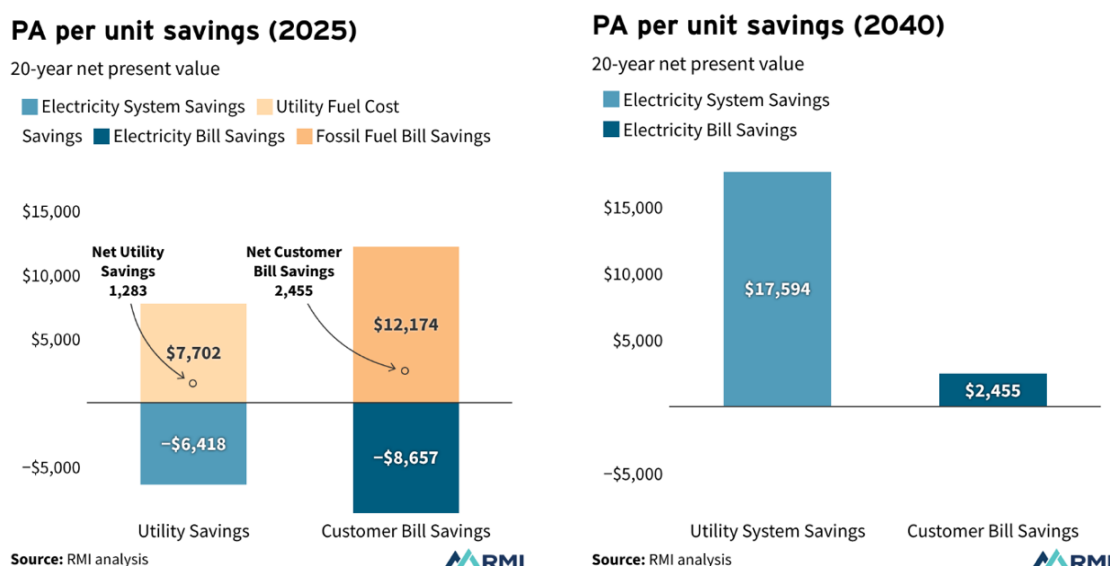
ⁱ The Electrified Future is based on the 2024 Annual Decarbonization Pathway central scenario, which projects that 76% of residential space heating is electrified by 2040 and 94% by 2050. Although the scenario includes a mix of heating technologies, this analysis assumes buildings receiving GHPs would otherwise have installed air source heat pumps, the predominant technology.

Customer bill savings

In addition to utility system savings, GHP deployment also delivers customer bill savings. Customer bill savings are based on full retail electricity rates, which include utility costs, utility returns, program costs, and other policy-related charges, whereas utility system savings reflect only avoided utility costs.

Under the Today timeframe, customer bill savings exceed utility system savings under the High Adoption (20%) Scenario, indicating that customers realize greater financial benefits than those delivered to the utility system under current utility rates. Under the Electrified Future timeframe, utility system savings substantially exceed customer bill savings. This suggests that as the electric system evolves, the value GHPs provide to the grid may not be fully reflected in customer electricity bills under today's retail rate structures. Because the Electrified Future analysis applies current retail electricity rates to a future scenario with a substantially different electric system, these results should be interpreted as illustrative rather than predictive.

Exhibit 4



Cost and cost gap

Across all scenarios, GHP deployment requires significant up-front investment that exceeds quantified utility system savings. Even if installed costs were reduced by half, a substantial gap would remain between total GHP system costs and quantified utility system savings in the Today timeframe, when the electric system is summer peaking and natural gas remains the predominant heating fuel. In the Electrified Future timeframe, however, substantially greater utility system savings significantly narrow the cost gap, making utility-system cost-effectiveness a more achievable target.

As Pennsylvania electrifies its building sector to meet long-term climate goals, the Electrified Future represents an increasingly relevant planning scenario. Based on projected utility system savings, GHP installation costs would need to decline from the current average of \$14,930 per ton (roughly \$74,650 for a single-family installation with a 5-ton system) by approximately 30% to achieve utility-system cost-effectiveness. This cost gap is slightly larger than in Massachusetts, primarily because the per unit peak demand saving is lower in Pennsylvania while requiring slightly higher average GHP system tonnage per dwelling unit.

Achieving this target would require installed GHP costs of approximately \$10,610 per ton (roughly \$53,000 for a single-family installation with a 5-ton system), or an incremental cost of approximately \$2,880 per ton relative to baseline air source heat pumps. This benchmark can serve as an installed cost target for policies aimed at accelerating market scale and cost reductions.

Rapid electricity demand growth from data centers is increasing the need for new generation and transmission investments across Pennsylvania and the PJM region.¹ Recent investments also provide useful context for evaluating this benchmark. In 2024, Amazon Web Services signed a 17-year power purchase agreement with Talen Energy valued at approximately \$18 billion for 1.92 GW of capacity from the Susquehanna nuclear power plant, equivalent to roughly \$9.4 million per megawatt (MW) of generation capacity for its data center.² By comparison, under the Electrified Future timeframe, GHP deployment provides peak demand reduction at an implied cost of approximately \$7.4 million per MW. As Pennsylvania faces growing pressure to rapidly connect

new data centers while managing load growth from other sectors, GHPs could provide peak capacity at a competitive cost with recent investments in new generation.

While not explicitly evaluated in this analysis, thermal energy networks (TENs) may provide an additional pathway to improve cost-effectiveness in appropriate applications. Although the cost difference between TENs and individual GHP systems is uncertain, TENs can provide greater value in districts with sufficient heating and cooling load diversity by improving system efficiency and further reducing electricity consumption and peak demand.

Pennsylvania's GHP market is still emerging, creating significant opportunities for future cost reductions. Pennsylvania is well positioned to accelerate market growth by leveraging its existing drilling workforce developed through the oil and gas industry.³ Combined with continued market expansion, and technology innovation, these advantages could help reduce installed costs and help achieve utility system cost-effectiveness.

Exhibit 5

PA GHP total system incremental cost by penetration level

Scenario	Number of Dwelling Units	GHP Tons Across All Units	GHP Incremental Cost Against Gas Furnace (billion \$)	2025 Utility System Savings (billion \$)	GHP Incremental Cost Against ASHP (billion \$)	2040 Utility System Savings (billion \$)
Low	111,795	683,000	7.2	0.7	4.1	2.0
Medium	558,974	3,417,000	36.1	1.5	20.5	9.8
High	1,117,949	6,834,000	72.3	1.4	41	19.7

Source: RMI analysis



Emissions Savings

GHP deployment can make a meaningful contribution toward Pennsylvania's climate goals by reducing emissions from both electricity use and on-site fossil fuel combustion. Pennsylvania has established ambitious greenhouse gas emissions reduction targets that will require substantial improvements in energy efficiency and widespread heating electrification to decarbonize the building sector.ⁱⁱ The annual emissions reduction achieved under the High Adoption Scenario (20% residential adoption) in the Today timeframe would exceed Pennsylvania's built environment sector target for **2030** and contribute approximately **63%** of the built environment emissions reductions projected for **2050** in the Pennsylvania Climate Action Plan. It also represents approximately **8%** of Pennsylvania's economy-wide emissions reduction target.

Exhibit 6

PA emissions reductions by timeframe for High Penetration Scenario

Timeframe	Annualized Emission Reduction (metric tons)		20-year Lifetime Emission Reduction (metric tons)	
	Per Building	Total	Per Building	Total
2025	5	5,640,671	101	112,813,418
2040	0.1	133,316	2	2,666,320

Source: RMI analysis



ⁱⁱ [Pennsylvania's Climate Action Plan 2024](#) projects annual greenhouse gas emissions reductions from built environment strategies of approximately 2.09 million metric tons of CO₂e by 2030 and 8.94 million metric tons of CO₂e by 2050, including reductions from building electrification, energy efficiency, building codes, and distributed solar. The plan also establishes an economy-wide greenhouse gas reduction goal of 80% below 2005 levels by 2050, equivalent to approximately 72.2 million metric tons of CO₂e of additional emissions reductions from 2005 levels.

Policy Recommendations

In colder weather states like Pennsylvania, the prospect of growing winter peak electricity demand poses new challenges to the electric grid, especially where annual peaks are expected to shift from summer to winter. Pennsylvania's policy and regulatory framework can adapt now in anticipation of this shift by supporting strategies such as ground-source heat pumps that mitigate winter peak demand while lowering utility system costs. Several actions by Pennsylvania utilities and policymakers can help better capture these grid benefits:

- **Adapt peak reduction targets to include winter months:** In Pennsylvania, utility peak reduction efforts have traditionally focused on summer demand. Utilities and regulators can adapt peak reduction targets to include winter months, providing a stronger foundation for recognizing the winter demand reduction benefits of GHPs as annual system peaks shift from summer to winter.
- **Update utility cost-benefit methodologies:** Pennsylvania has begun incorporating winter peak demand into Act 129, with Phase V requiring utilities to account for peak demand reductions in both summer and winter. As electrification increases winter electricity demand, regulators can build on these changes by continuing to update utility cost-benefit methodologies to better recognize the value of winter peak demand reduction and evaluate GHPs against appropriate future electrification baselines. More comprehensive recognition of these benefits can support larger customer incentives and broader deployment of ground-source heat pumps.
- **Incorporate GHPs into customer programs:** Pennsylvania utility programs have historically provided limited support for GHP deployment. Utilities can incorporate GHPs into customer programs, while regulators can establish utility performance incentives that encourage deployment of technologies that reduce winter peak demand.ⁱⁱⁱ
- **Evaluate thermal energy networks:** Gas utilities can evaluate thermal energy networks as cost-effective non-pipe alternatives when planning replacement of aging natural gas infrastructure. Expanding the use of thermal energy networks can reduce the need for new gas infrastructure while lowering utility system costs.
- **Encourage new large loads to invest in demand-side measures:** As Pennsylvania experiences rapid growth in electricity demand from large loads such as data centers, utilities and policymakers can establish frameworks that encourage new large loads seeking interconnection to invest in demand-side measures alongside their own demand flexibility to expedite connection. Such a framework could help offset a portion of the capacity needed to serve these new loads while identifying the demand-side measures businesses could fund, including ground-source heat pumps.

Limitation of the Analysis

1. The economic analysis uses a 20-year net present value period based on the expected lifetime of indoor GHP equipment. However, geothermal bore fields can last approximately 50–100 years, allowing the ground-loop infrastructure to serve multiple generations of indoor equipment. As a result, subsequent GHP replacements would not require the full initial investment, and the longer-term economics of GHP deployment may be more favorable than reflected in this analysis.
2. The GHP cost analysis also relies on a simplified \$/ton approach that combines drilling, equipment, installation, and other hard and soft costs. In practice, these cost components do not all scale proportionally with system capacity: some costs scale more directly with system size (e.g., piping), while others have a higher fixed cost component (e.g., drilling). Because GHP installations can have a significant share of fixed costs, scaling total costs linearly on a \$/ton basis may overestimate costs particularly for larger systems where those fixed costs are spread across greater system capacity.

Endnotes

¹ “2025 Long-Term Load Forecast Report Predicts Significant Increase in Electricity Demand,” PJM Interconnection, January 30, 2025, <https://insidelines.pjm.com/2025-long-term-load-forecast-report-predicts-significant-increase-in-electricity-demand/>.

² “Talen to sell Amazon 1.9 GW from Susquehanna nuclear plant to power AWS data centers,” Utility Dive, June 11, 2025, <https://www.utilitydive.com/news/talen-amazon-aws-susquehanna-nuclear-data-center/750440/>.

³ *Pennsylvania Geothermal Energy Report: Executive Summary*, Penn State Center for Energy Law and Policy & Project InnerSpace, February 2025, <https://celp.psu.edu/wp-content/uploads/2025/02/Pennsylvania-Report-Executive-Summary.pdf>.

ⁱⁱⁱ For example, Con Edison's *Smart Building Electrification Earnings Adjustment Mechanism* provides a financial incentive for utility deployment of qualifying measures, including ground-source heat pumps, that support cost-effective building electrification and efficient grid management.