Water Heating Economics in a Dynamic Energy Landscape

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Notice

PLEASE NOTE

This report was prepared for the Beneficial Electrification League with funding from Wells Fargo in accordance with The Brattle Group's engagement terms and is intended to be read and used as a whole and not in parts.

Brattle developed the analytical framework, quantified the total costs of water heating technologies across different housing configurations, and performed the sensitivity analysis. GDS simulated fuel consumption patterns, collected equipment and installation costs, and advised on the analytical approach and assumptions.

The authors are grateful to Keith Dennis of the Beneficial Electrification League for his valuable leadership and insights throughout the development of this report. The report reflects the analyses and opinions of the authors and does not necessarily reflect those of The Brattle Group's clients or other consultants.

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See technical appendix for additional detail on assumptions and data sources.

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Study Purpose

Water heating electrification is emerging as a key area of focus. Stakeholders performing home upgrades or developing policies, programs, and other initiatives need to assess water heating options for single family homes of all shapes and sizes. This research informs those decisions by examining the economics and applicability of the full range of electric water heating technologies.

Converting end-uses from running on fossil fuels to running on clean electricity has become a cornerstone of the decarbonization plans of most electric utilities and policymakers in the U.S.

Among major end uses, water heating stands out as a significant source of residential energy use and emissions in the U.S., accounting for 19% all household energy consumption.

There is increasing attention and focus on heat pump water heating (HPWH), a technology that provides significant energy efficiency benefits and performs well in a wide range of climates.

However, adoption of HPWH has been limited to date, in part because of the technology’s higher upfront costs, presenting a barrier particularly to low-income consumers. Space requirements can provide an additional barrier for HPWH installation in existing homes with space constraints.

Maximizing customer adoption of electric water heating likely will require a suite of electric water heating technology options. **In this study we analyze the total societal cost of key water heating technologies across various home configurations to determine the most cost-effective and applicable options.**

Summary of Findings

The economically optimal heating option varies by building type and size.
Electric resistance, heat pump water heaters, and gas water heaters all could be the most economic option depending on building type.

The most economic option is sensitive to market and policy factors.
Our findings regarding the socially optimal water heating technology change based on a range of plausible assumptions about equipment costs, fuel prices, and carbon reduction benefits.

Propane water heating consistently results in the highest total cost.
The high cost of propane fuel is not offset by a lower installed cost or efficiency advantage of the technology. Further, the environmental cost of propane water heaters is material, due to high emissions coefficients (higher than natural gas).

Tankless water heaters could be attractive options in smaller dwellings.
However, tankless water heaters can have very high instantaneous electricity demand, which could require significant upgrades to the panel and supporting distribution infrastructure.

Grid interactivity enhances value, but benefits are market-specific.
In our results for the Southeastern US, grid interactivity increases the value of standard electric resistance water heaters, but typically is not a prerequisite for electric resistance water heating to be the most economic option. Value will improve as renewables deployments and electrification initiatives mature.

Water heating economics are different from the customer's perspective.
In cases where electric heating is the cheapest option from a societal perspective, gas often is cheapest from a customer's perspective. This highlights misalignment between retail energy prices and the actual system costs of operating water heaters.

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Study Perspective

Our study focuses on the relative *societal costs* associated with the adoption and operation of various residential water heating technologies. That is a different – and more holistic – view of costs than those faced by an individual household.

Societal cost factors:

- Equipment and installation costs
- Wholesale fuel costs (*e.g.*, electricity, natural gas, propane)
- Infrastructure costs to deliver fuel to end-use consumers
- Losses in the delivery of fuel to consumers
- Greenhouse gas emissions associated with the production, delivery, and consumption of fuel

PRIMARY FOCUS OF THIS STUDY

Household adoption decision factors:

- Equipment and installation costs
- Retail fuel costs
- Customer's personal preferences (*e.g.*, technology familiarity, "green" proclivity, comfort considerations, aesthetics, contractor availability and familiarity, etc.)

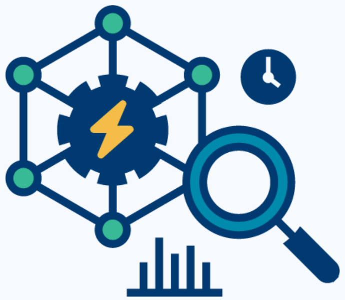
Analytical Framework

We quantify the total societal costs of different water heating technologies across multiple housing configurations using latest modeling tools and data developed by Brattle and GDS.

1

Determine suitable housing types and water heating technologies to model (we analyze roughly 100 different combinations)

2



Simulate fuel consumption patterns for each water heating technology/housing configuration combination, based on Southeastern U.S. market and climate characteristics

3

Develop estimates of the marginal energy system cost, emissions cost, and water heating technology cost using recent historical market data

4

Evaluate the total societal cost of installing and operating each water heating technology for each housing type, considering grid-interactivity where applicable

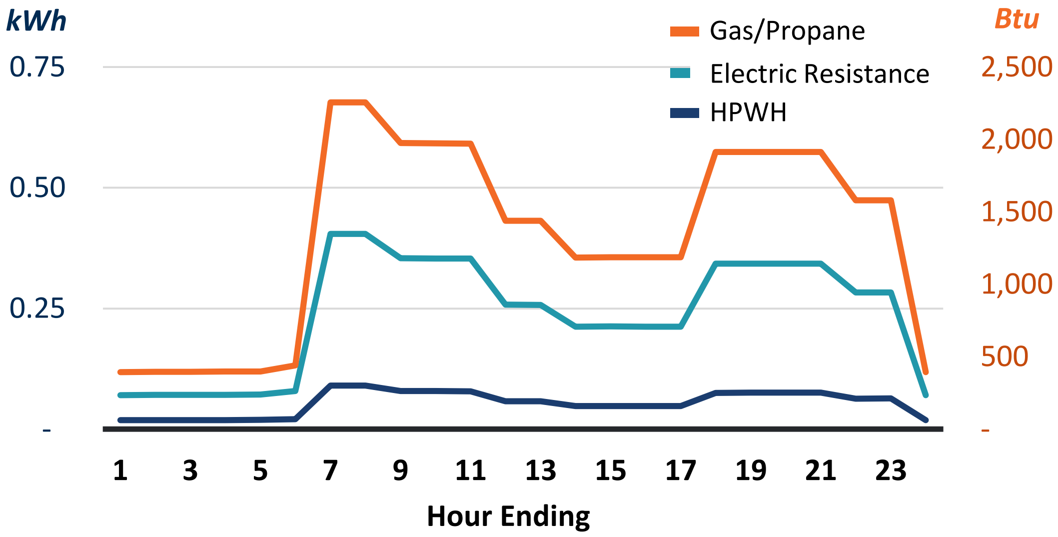
5

Perform sensitivity analyses to estimate the impact of changes in equipment costs, fuel prices, power grid carbon intensity, and the assumed cost of carbon

Housing Configurations and Water Heating Technologies

We develop hourly energy consumption profiles for 98 different housing types and water heating technology combinations in the Southeastern U.S.

DAILY ENERGY CONSUMPTION PROFILE FOR A 2-BR MFG HOME



Note: Figure shows energy profile for a 40-gallon electric resistance water heater.

We consider both single family (SF) homes (1-4 bedrooms) and manufactured (MFG) homes (1-3 bedrooms) that have the following water heating technologies:

- **Gas/Propane Water Heater (40/50 gal)**
  A common water heating technology in the U.S. with relatively low upfront costs.
- **Electric Resistance Water Heater (40/50/80 gal)**
  Another common technology with relatively low upfront costs. We evaluate options with and without grid-interactive capabilities.
- **Heat-Pump Water Heater (50 gal)**
  As opposed to conventional water heaters that produce heat from fuel, HPWHs pull heat from the surrounding air, making them more efficient than conventional heaters (but have higher upfront costs).
- **Electric Tankless Water Heater**
  Tankless water heaters can produce instant hot water, but can create a very high instantaneous demand for electricity.

Modeled Costs

For each housing/technology combination, we consider five key cost categories:

1. **Installed Cost:** A water heater's upfront retail price as well as installation labor costs, which are annualized over the life of the water heater (13 years) at an 8% discount rate.
2. **Energy Cost:** The wholesale price of natural gas, propane, or electricity for a particular combination.
3. **Capacity Cost:** Serving electric water heaters requires a certain amount of electricity generation, transmission, and distribution capacity from the grid. We assume a marginal generation capacity cost of $65/kW-yr and combined T&D capacity costs of $50/kW-yr based on national averages.
4. **Emissions Cost:** We rely on NREL's Cambium dataset for the long-run marginal CO_2 emissions rate for electricity generation in Georgia.*
5. **System Losses:** We assume a loss of 5% for electricity delivery, and 3.7% leakage rate for natural gas.

SOCIETAL COSTS MODELED IN THIS STUDY

	Electric Water Heating Costs	Gas/Propane Water Heating Costs
Energy Cost	✓ WHOLESALE ELECTRICITY	✓ WHOLESALE GAS/PROPANE
Equipment + Labor	✓	✓
Generation Capacity	✓	
Transmission and Distribution Capacity	✓	
Emissions Cost	✓	✓
System Losses	✓	✓

*

To calculate the **Emissions Costs** associated with operating water heaters, we use the following carbon costs:

- Low Case: zero social cost of carbon
- High Case: $190/ton CO_2 based on recent estimates from the U.S. EPA
- Base Case: $95/ton CO_2 , a midpoint between the Low Case and High Case

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See technical appendix for additional detail on assumptions and data sources.

The economically optimal heating option varies by building type & size

The summary table shows the total system costs of different housing/technology combinations for our base case scenario.

The economically optimal heating option varies by customer type. Electric resistance (grid-interactive), heat pump water heaters, and gas water heaters all could be the most economic option depending on building type.

> HPWHs are more economical for larger homes, since their large upfront cost is offset by higher annual energy savings.

> There is only a modest price difference between standard electric resistance water heaters and gas water heaters, but GIWHs provide additional load shifting benefits which reduce their overall cost.

> Certain options may have technical restrictions which further limit their applicability. For example, there may be size restrictions to installing heat pump water heaters or 80 gallon electric resistance water heaters in smaller homes.

ANNUAL COST FOR WATER HEATING TECHNOLOGIES ($/YEAR)

	SF-1	SF-2	SF-3	SF-4	MFG-1	MFG-2	MFG-3
Std Electric Resistance	$300	$359	$419	$480	$293	$342	$388
GIWH (40/50 Gal)	$297	$350	$404	$459	$291	$334	$376
GIWH (80 Gal)	$355	$402	$451	$496	$350	$389	$425
HPWH	$393	$409	$426	$442	$386	$397	$407
Gas	$310	$350	$395	$472	$304	$337	$373
Propane	$355	$419	$493	$594	$346	$399	$457

Most Expensive Option | Cheapest Option

The most economic option is sensitive to market and policy factors

CHEAPEST WATER HEATING TECHNOLOGIES BY SCENARIO

	SF-1	SF-2	SF-3	SF-4	MFG-1	MFG-2	MFG-3
Base Case	GIWH	GIWH	Gas	HPWH	GIWH	GIWH	Gas
High Installed Cost	GIWH	GIWH	GIWH	HPWH	GIWH	GIWH	GIWH
Low Installed Cost	Gas	Gas	Gas	Gas	Gas	Gas	Gas
Higher Fuel Prices	GIWH	Gas	Gas	HPWH	GIWH	Gas	Gas
Carbon-free Electricity	GIWH	GIWH	GIWH	GIWH	GIWH	GIWH	GIWH
High Carbon Price	Gas	Gas	HPWH	HPWH	Gas	Gas	HPWH
Low Carbon Price	GIWH	GIWH	GIWH	GIWH	GIWH	GIWH	GIWH
HEEHRA Rebate	HPWH	HPWH	HPWH	HPWH	HPWH	HPWH	HPWH

Note: *High/Low Installed Costs* scenarios represents the upper and lower ranges of commercially available water heater costs. *Higher Fuel Prices* scenario includes adjustments for higher fuel prices due to global fuel supply shocks. *Carbon-Free Electricity* scenario assumes electricity production in a high decarbonized grid has zero marginal emissions. *High/Low Carbon Price* scenarios account for both a relatively high ($190/ton of CO_2) and low (zero) cost of carbon. *HEEHRA Rebate* scenario assumes 100% of the $1,750 rebate available through the High-Efficiency Electric Home Rebate Act applies to low-income households, though we note that total system cost calculations in certain jurisdictions may exclude tax credits and rebates.

To explore the impacts of underlying cost drivers and market dynamics on overall water heating economics, we consider several different sensitivity scenarios.

Conclusions about the most economic water heating technology change across all scenarios.

Results are sensitive to installed cost assumptions. Gas water heaters, particularly older models, can be bought at relatively low prices. They therefore have the cheapest low-end of the cost range, and consistently out-compete other technologies at that end of the range.

GIWHs are advantageous in scenarios with lower emissions costs and lower electricity costs, where the lower efficiency of the technology is offset by its lower up-front cost and incremental benefits to the power system.

HPWHs remain viable for larger homes across most scenarios (especially when rebates are available), but cost-effectiveness from high efficiency is reduced when emissions are not a factor.

Propane water heating consistently results in the highest total cost

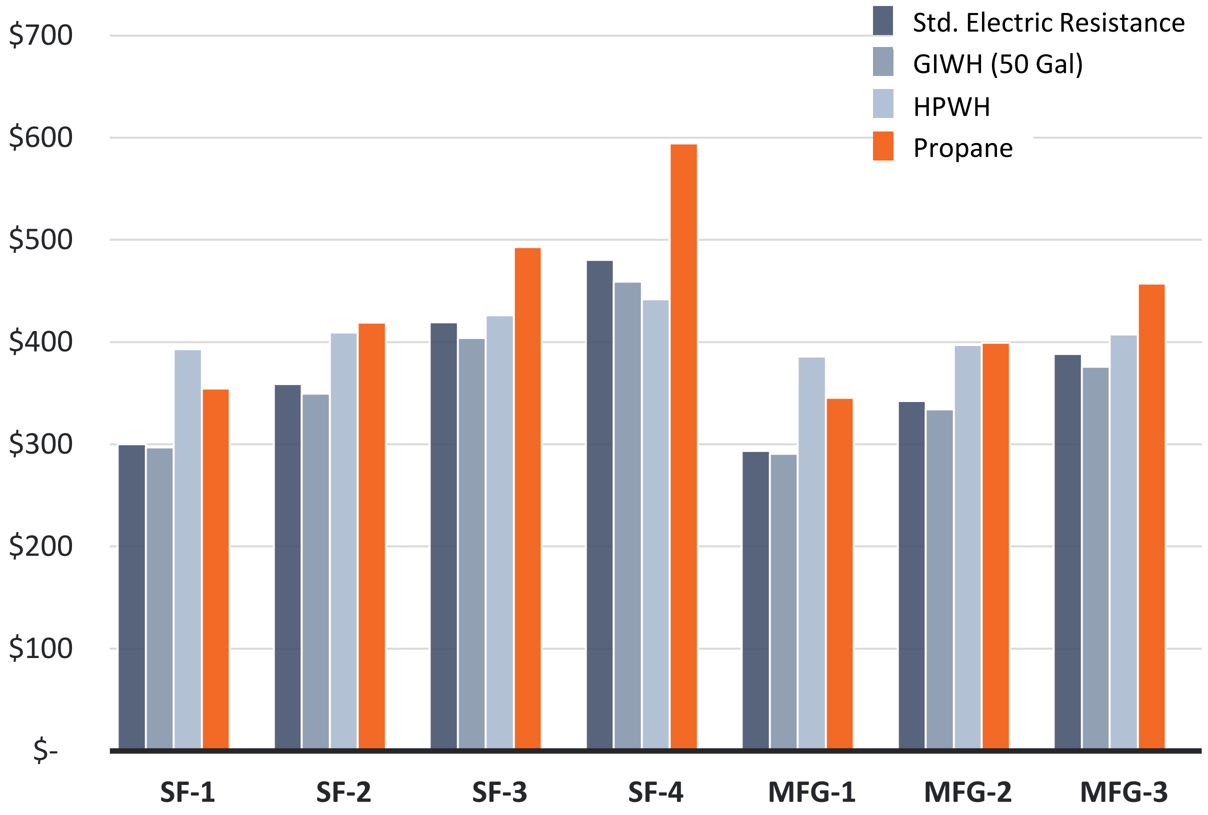
Propane is only used by around 3% of residential customers in Georgia, but is common in some other parts of North America. It consistently yields higher societal costs compared to conventional gas and electric water heaters.

The high cost of propane fuel is not offset by a lower installed cost or efficiency advantage of the technology.

Further, the environmental cost of propane water heaters is material, due to high emissions coefficients (higher than natural gas).

Propane is used by a relatively small share of customers. However, in cases where propane is being used currently, it often is due to the lack of a gas connection. So while the most economic alternative to propane varies by building type, it is likely that electric options will be the only technically feasible replacement alternatives.

ANNUAL COST FOR WATER HEATING TECHNOLOGIES ($/YEAR)



Note: Figure shows propane plus the three most economic water heating technologies for comparison.

Tankless water heaters could be attractive options in smaller dwellings

While tankless water heaters are relatively new in the U.S., this technology potentially could be an economic option due to a **modest up-front technology cost and competitive efficiency**, in the absence of additional electric make-ready costs.

However, tankless water heaters can have **very high instantaneous electricity demand**, which could require significant upgrades to the panel and supporting distribution infrastructure. Widespread adoption of this technology could place a significant burden on parts of the distribution system.

Therefore, tankless water heaters are most likely to be attractive solutions for **homes with lower hot water needs and/or space limitations that prohibit the installation of other options.**

Source: Lowe's

Grid interactivity enhances value, but benefits are market-specific

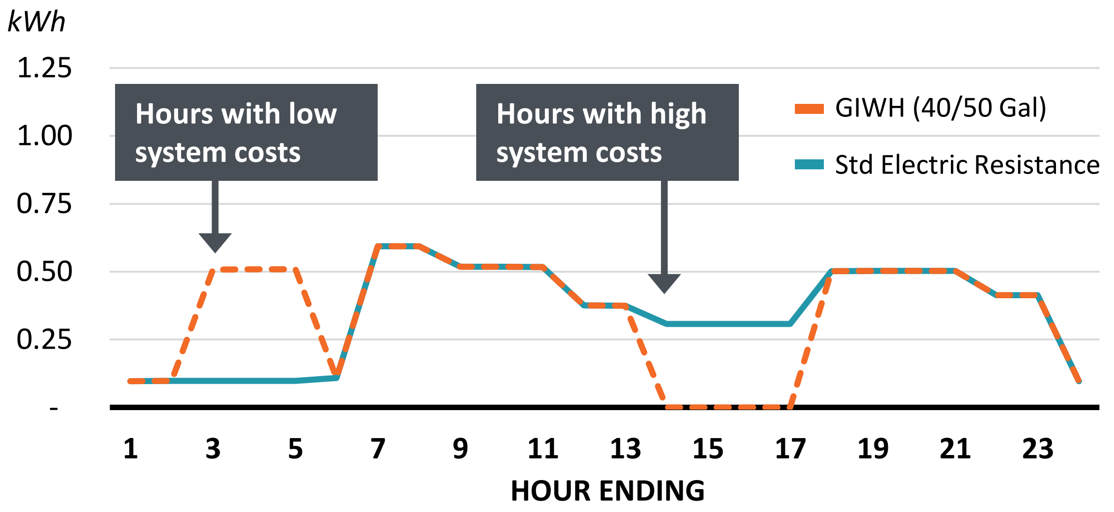
The net benefits of grid interactivity heavily depend on market conditions. We expect the value of grid interactivity to increase across the U.S. with growth in the need to integrate renewables and new electric loads.

Grid-interactive water heaters provide grid services through demand response. Value is higher in markets with high energy price volatility (*e.g.*, due to high renewable energy deployment), and in markets with significant generation, transmission, and distribution capacity constraints.

We estimate relatively modest incremental demand response value in this study (**up to $21 per customer per year**), due to factors such as lower energy price volatility and limited carbon emissions reduction opportunities from load shifting in the Southeast region currently.

In our results, grid interactivity increases the value of standard electric resistance water heaters, but typically is not a prerequisite for electric resistance water heating to be the most economic option.

WATER HEATING LOAD SHAPE FOR A 3-BR SF HOME



Note: We do not model demand response for HPWHs because grid interactivity is a relatively new feature for this technology, and there is a high degree of uncertainty regarding their load shifting performance. Ongoing experiments and demonstration projects, including BEL's electric water heating project with La Plata Electric, will inform the value of demand response of HPWH in future work.

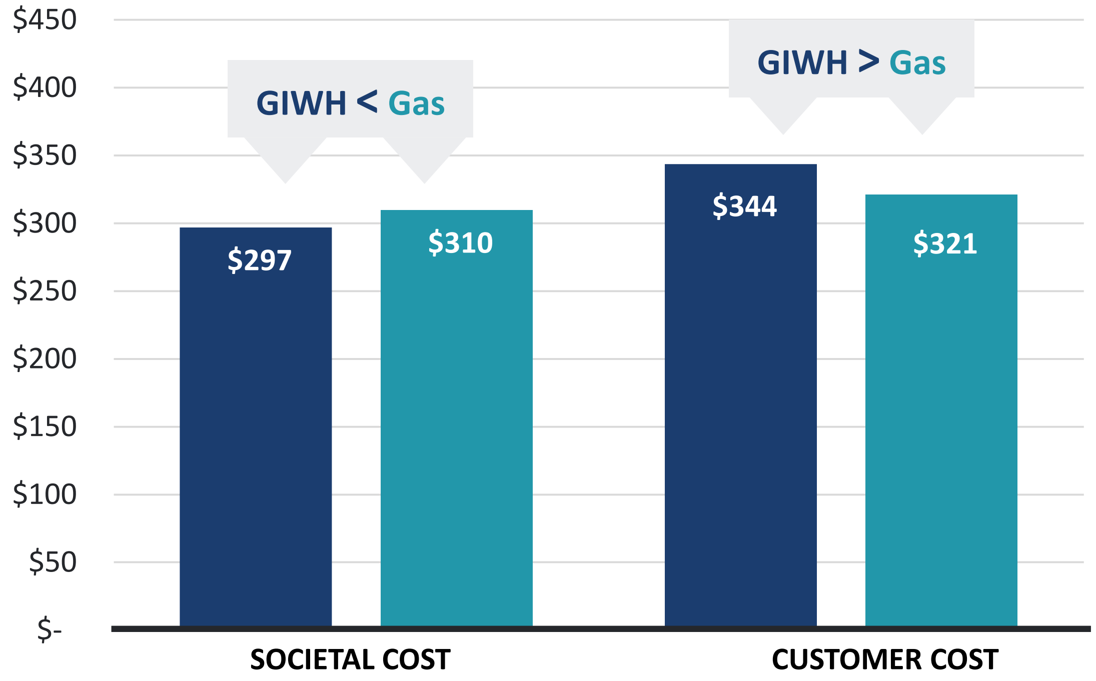
Water heating economics are different from the customer's perspective

The societal perspective on costs in this study is useful to direct policy decisions for promoting economically optimal water heating decarbonization. Our findings are different when taking the customer's perspective on water heating costs. In cases where electric heating is the cheapest option from a societal perspective, gas often is cheapest from a customer's perspective. This highlights misalignment between retail energy prices and the actual system costs of operating water heaters.

COST COMPONENTS

	Total Societal Cost (Electric)	Total Customer Cost (Electric)
Energy Cost	✓ WHOLESALE	✓ RETAIL
Equipment + Labor	✓	✓
Generation Capacity	✓	
Transmission and Distribution Capacity	✓	
Emissions Cost	✓	
System Losses	✓	✓

COMPARISON OF COSTS FOR SF-1 HOMES ($/YEAR)



Note: Customer costs based on residential electricity and gas prices for Georgia from the U.S. Energy Information Administration and the American Gas Association.

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Policy Implications & Conclusion

Residential water heating electrification is likely to be a cornerstone of many emerging decarbonization initiatives across North America.

Heat pumps are an energy efficient option for electrifying water heating. However, maximizing customer adoption of electric water heating will require a suite of water heating technology options due to diversity in customer preferences and circumstances.

The full range of electric water heating technologies, including electric resistance water heaters, grid-interactive water heaters, and tankless water heaters should be considered when developing policies, programs, and other initiatives to promote their adoption. Under some conditions, natural gas may remain the socially optimal water heating option for some customers.

Currently, customers often do not have the economic or practical incentive to adopt electric water heating when it is the socially optimal option. New policies, program designs, and rate designs are needed to align customer adoption decisions with outcomes that are most beneficial to society.

Source: Gettyimages

Clarity in the face of complexity

Brattle