Model Rule 1.0:

NOx and GHG Emissions Standards for Space and Water Heaters

Technical Support Document 1.2

December 12, 2024

NESCAUM
NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT

Summary of TSD Versions and Updates

<table>
<tr><th>TSD Version</th><th>Publication Date</th><th>Changes Made</th></tr>
<tr><td>TSD 1.0</td><td>October 30, 2024</td><td>N/A</td></tr>
<tr><td>TSD 1.1</td><td>November 5, 2024</td><td>Minor edits to the HVAC cost analysis sections and tables upon receiving additional clarification on HVAC cost study data from Energy Solutions. Specific tables updated include:
Table 7: State-by-State Total Installation Costs for Select Space Heating Equipment With AC, Assuming Compatible Distribution Systems (No Incentives)
Table 9: 15-Year Net Present Value of Installing Heat Pump Space Heating Systems Compared to Baseline Space Heaters With AC, Assuming Compatible Distribution Systems
Table 12: Incremental Cost-Effectiveness ($1000/ton) for NOx Emissions Reductions Associated with Heat Pump Space Heaters with AC
Table 13: Incremental Cost-Effectiveness ($/ton) for CO2 Emissions Reductions Associated with Heat Pump Space Heaters with AC
Appendices C1, C3, C4, and C5</td></tr>
<tr><td>TSD 1.2</td><td>December 12, 2024</td><td>Clarifying text edits to the following sections:
11. Cost Analysis
Clarifying label edits to the following tables:
Table 8: State-by-State Average Annual Operating Costs for Select Space Heating Equipment Plus Central AC</td></tr>
</table>

Table of Contents

1. INTRODUCTION

The model NOx and GHG Emissions Standards for Space and Water Heaters (Model Rule) are state-level emissions standards targeted at reducing nitrogen oxides (NOx) and greenhouse gas (GHG) pollution from space and water heating equipment. States can use the Model Rule as a template for developing their own regulations to achieve public health and climate goals.

Northeast States for Coordinated Air Use Management (NESCAUM) is a nonprofit association of state air agencies in the Northeast. We provide policy and technical assistance to states and work to coordinate air regulations in the region and nationally. The Model Rule was developed by NESCAUM and states participating in an Equipment Emission Standards Cohort (EESC) co-convened by NESCAUM and US Climate Alliance, in collaboration with the Regulatory Assistance Project (RAP) and consultants Energy Solutions and Dwight Alpern.

Version 1.0 of the Model Rule establishes zero-emission heating equipment standards (ZEHES) for small water heaters, furnaces, and boilers, as well as ultra-low-NOx (ULN) standards for both small and large water heaters. We use the terms "small" and "residential-scale" interchangeably in this document to describe smaller-sized equipment.[1] The Model Rule covers small space and water heating equipment regardless of whether the equipment is installed in a residential or commercial building.

NESCAUM intends to update the Model Rule over time to add new equipment types, such as commercial-scale heating systems, and to incorporate new information and analyses. We will release updates to Model Rule 1.0 as Model Rule 2.0, Model Rule 3.0, and so on, as needed.

Technical Support Document Introduction:

This Technical Support Document (TSD 1.2) is intended to provide state agency staff with information and analysis that may inform development of ZEHES and ULN standards for space and water heaters. We also explain key Model Rule 1.0 considerations and rationale to provide clarity and transparency to stakeholders around decisions made during Model Rule development. Topics covered by TSD 1.2 generally fall into two major categories: Model Rule Development & Details and Implementation & Technical Support.

Model Rule Development & Details:

Sections 2 through 6 of TSD 1.2 provide background on Model Rule 1.0, including ZEHES objectives, overviews of the heating technology and policy landscapes, and summaries of the development process and key Model Rule 1.0 provisions. In these sections, we highlight state authority under the Clean Air Act to regulate pollution from heating equipment, and emphasize the long history of state and local NOx regulations on residential equipment as predecessors to

[1] Throughout this report, we also refer to "equipment," "technology," and "heaters" interchangeably when referencing space and water heaters.

Model Rule 1.0. We also describe how Model Rule 1.0 aligns with or differs from existing and upcoming regulations issued by state or local jurisdictions.

Implementation & Technical Support:

Sections 7 through 12 of TSD 1.2 include implementation support and technical analysis intended to inform state ZEHES development. We review stakeholder input on Model Rule 1.0 from NESCAUM's Environmental Justice Advisory Group (EJAG) and heating equipment manufacturers, as well as best practices for community engagement and program implementation.

For technical support, NESCAUM details a variety of studies we performed or commissioned regarding emissions reductions potential, estimated health benefits, and costs associated with transitioning to zero-emission space and water heating. We use results from these studies to compare the net present value of purchasing polluting versus zero-emission technologies in a 2024 market, and estimate the cost or savings per ton of emissions reduced associated with switching to zero-emission heating equipment.

2. BACKGROUND

Zero-emission heating equipment standards (ZEHES) are an emerging policy to address criteria air pollutants and GHG emissions from combustion equipment used for space and water heating in buildings. When implemented, ZEHES ensure that specified equipment sold or installed in implementing jurisdictions after the compliance date does not generate on-site emissions. The ZEHES outlined in Model Rule 1.0 do not require early replacement of functioning equipment in buildings, but ensure that polluting space and water heaters will be replaced by zero-emission alternatives at the end of life.

ZEHES for residential space and water heating present a significant opportunity for states to improve public health. In the US, space and water heating make up almost two-thirds of total household energy consumption and associated emissions, with the vast majority coming from on-site combustion of methane gas,[2] propane, and fuel oil.[3] Fossil fuel combustion emits air pollutants including coarse (PM10) and fine (PM2.5) particulate matter,[4] sulfur dioxide (SO2) and nitrogen oxides (NOx), all of which are US Environmental Protection Agency (EPA) criteria

[2] In this report, 'methane gas' refers to a fossil fuel commonly combusted in gas furnaces, boilers, and water heaters, also known as 'natural gas,' 'pipeline gas,' and 'fossil gas.' For the purposes of the Model Rule and TSD, methane gas does not necessarily refer to pure CH4, but rather to a gaseous mixture of hydrocarbon compounds with CH4 as the primary compound and sufficient energy content and a small enough share of impurities for transport through commercial gas pipelines and sale to end-users.

[3] US Energy Information Administration, "Space heating and water heating account for nearly two thirds of US home energy use," November 7, 2018.

[4] Fine particulate matter is of particular health concern due to its small size, which enables PM2.5 particles to pass through the lungs and into the bloodstream (US EPA, "Particulate Matter (PM) Basics," June 20, 2024).

pollutants known to harm human health.[5] NOx and SO2 also contribute to secondary PM2.5 formation,[6] and NOx reacts with other compounds to create ground-level ozone.[7] These pollutants contribute to a variety of respiratory, cardiovascular, neurological, and reproductive issues.[8] ZEHES can help improve these health outcomes by limiting emissions of NOx and other air pollutants from heating equipment.

ZEHES can also be an important tool in achieving state GHG reduction targets. In 2022, buildings produced 13% of all US GHG emissions through on-site emissions, mostly from fossil fuel combustion.[9] As renewable energy continues to decarbonize the electricity grid, on-site combustion of fossil fuels in buildings will represent a larger and larger percentage of total US GHG emissions,[10] making building decarbonization a vital component of state GHG reduction plans. ZEHES are one strategy that states can use to address building-related emissions and support achievement of climate goals.

Space and Water Heating Technologies

In New England, the building sector is the second-largest GHG emitter after transportation,[11] with space and water heating comprising approximately three-quarters of those emissions.[12] Space and water heating also emit over 95% of residential building NOx pollution in the Northeast, with space heating responsible for around 83% of building NOx emissions and water heating adding another 13%.[13] Phasing in zero-emission space and water heating technologies by implementing a ZEHES regulation can therefore significantly reduce GHG and NOx pollution from the building sector. The following subsections review space and water heating technologies that may be affected by implementation of Model Rule 1.0.

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[5] US Department of Energy, "Decarbonizing the US Economy by 2050", April 2024, https://www.energy.gov/eere/articles/decarbonizing-us-economy-2050.
[6] Guerra et al. (2014), "Evaluation of the SO2 and NOx offset ratio method to account for secondary $PM_{2.5}$ formation", *Journal of the Air & Waste Management Association*, 64(3), 265–271.
[7] Sillman et al. (1990), "The sensitivity of ozone to nitrogen oxides and hydrocarbons in regional ozone episodes", *Journal of Geophysical Research: Atmospheres*, 95(D2), 1837-1851.
[8] Manisalidis et al. (2020), "Environmental and Health Impacts of Air Pollution: A Review," *Frontiers in Pubilc Health*, 8, 14.
[9] US EPA, "Sources of Greenhouse Gas Emissions," last updated July 8, 2024.
[10] DOE, "Decarbonizing the US Economy," 2024.
[11] Masterson, K., "Buildings are a Big Part of New England's Emissions. States are Working to Change That," *WBUR*, April 22, 2024.
[12] Boland et al., "Building value by decarbonizing the built environment," McKinsey & Co., 2023.
[13] NESCAUM, "Residential Building Electrification in the Northeast and Mid-Atlantic: Criteria Pollutant and Greenhouse Gas Reduction Potential", August 2023.

Water Heating Technologies

In the US, the average household consumes over 300 gallons of water per day, over half of which is heated for use in showers, faucets, dishwashers, and washing machines.[14] Common water heating technologies include:[15]

- **Storage Water Heaters:**[16] Powered by electricity, methane gas, propane, or fuel oil, this is the most common water heating equipment found in American households. Conventional storage water heaters provide a steady supply of on-demand hot water by storing it in a tank. Because storage water heaters keep the tank at a constant temperature, customers will experience standby heat losses.
- **Tankless Water Heaters:**[17] Tankless water heaters are powered by either electricity or fossil fuels and produce hot water on an as-needed basis, eliminating the heating losses associated with storage water heaters. However, they are often limited to smaller heating loads (approximately 2-5 gallons per minute for residential uses), which can require multiple installations at different water heating outlets and increase costs.
- **Heat Pump Water Heaters (HPWHs):**[18] HPWHs are a type of storage water heater and use electricity to move heat rather than create it. They can be several times more energy-efficient than conventional equipment without producing local air pollution. Homes with existing electric water heaters can readily transition to 240-volt HPWHs. A 120-volt HPWH may be an option for homes that cannot immediately accommodate a 240-volt HPWH, while others may require an electrical upgrade.[19]
- **Combination Water and Space Heaters:**[20] Powered by electricity, methane gas, propane, or fuel oil, combination heaters use a space heating system to indirectly heat water either stored in a tank ("indirect water heater") or for instant use ("tankless coil water heater"). These typically cost more than separate installations of space and water heaters but run more efficiently and can yield operational savings.

Space Heating Technologies

Nationwide, space heating accounts for 42% of residential energy consumption, representing the largest residential energy end use.[21] While the average US household spends $519 annually

[14] US EPA, "How We Use Water," April 3, 2024.
[15] US DOE, "Selecting a New Water Heater," accessed July 16, 2024.
[16] US DOE, "Storage Water Heaters," accessed July 16, 2024.
[17] US DOE, "Tankless or Demand-Type Water Heaters," accessed July 16, 2024.
[18] US DOE, "Heat Pump Water Heaters," accessed July 16, 2024.
[19] ENERGY STAR, "Is a Heat Pump Water Heater Right for Your Home?" accessed July 16, 2024.
[20] US DOE, "Tankless Coil and Indirect Water Heaters," accessed July 16, 2024.
[21] US EIA, "Space heating consumed the most energy of any end use in homes, according to latest data," June 15, 2023.

on heating, New England and Mid-Atlantic states have much higher heating costs, averaging $914 and $715 respectively in 2020.[22] Common space heating technologies include:[23]

- **Furnaces:[24]** Furnaces utilize fuel oil, methane gas, propane, or electric resistance to heat air, which is then distributed by a furnace fan through ductwork. Because furnaces create heat, they are less energy-efficient than heat pump alternatives that move heat, and they can have energy losses through chimney venting.
- **Boilers:[25]** Boilers use fuel oil, methane gas, propane, or electric resistance to create steam or hot water, which is distributed through radiators or radiant floor systems. Like furnaces, boilers create heat and can have energy losses through chimney venting.
- **Electric Resistance Heaters:[26]** Electric resistance heaters convert electricity directly into heat and distribute it either in furnace form (moving heated air through ducts), as baseboard heaters against exterior-facing walls, or as wall heaters against interior-facing walls. While free of local emissions, electric resistance heaters are much less energy-efficient than heat pumps and can have significantly higher operating costs.
- **Heat Pump Space Heaters:[27]** Electric heat pumps concentrate and transfer heat rather than create it, making them significantly more energy-efficient than furnaces, boilers, and electric resistance heaters. They provide both heating and cooling; like a refrigerator, heat pumps use electricity to transfer heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. Heat pumps can reach up to five times the energy-efficiency of methane gas boilers[28] and over twice the efficiency of electric resistance heating.[29] They can connect to ducted distribution systems and are also available as ductless mini-splits. Air-source heat pumps (ASHPs) draw heat from the air while ground-source heat pumps (GSHPs) draw heat from the ground. While most heat pumps have separate outdoor and indoor units, expanded offerings now include heat pumps that connect directly to outside air through the wall (no separate outdoor unit required), and window heat pumps that connect outdoor and indoor units across a windowsill.[30]
- **Wood and Pellet Heaters:** [31] Wood-burning heaters include fireplaces, wood stoves, pellet stoves, hydronic boilers, and masonry heaters. While wood-burning heaters can

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[22] US EIA, "Table CE3.7. Annual household site end-use expenditures in the Northeast – totals and averages, 2020," revised March 2024.
[23] US DOE, "Home Heating Systems," accessed July 16, 2024.
[24] US DOE, "Furnaces and Boilers," accessed July 16, 2024.
[25] *Ibid*.
[26] US DOE, "Electric Resistance Heating," accessed July 16, 2024.
[27] US DOE, "Heat Pump Systems," accessed July 16, 2024.
[28] International Energy Agency (IEA), "The Future of Heat Pumps: World Energy Outlook Special Report," December 2022.
[29] US DOE, "Heat Pump Systems," accessed July 16, 2024.
[30] US DOE, "A New Frontier – Electrification in Multifamily Housing," 2021 Better Buildings Summit.
[31] US DOE, "Wood and Pellet Heating," accessed July 16, 2024.

have lower operating costs than electric resistance heating or oil, they are a major source of harmful air pollutants, especially PM2.5. Some jurisdictions may regulate certain equipment types such as outdoor wood boilers due to air pollution concerns.[32]

3. POLICY LANDSCAPE

ZEHES rely on existing federal and state authority to regulate air pollution and build on a track record of states and air districts regulating NOx emissions from space and water heating equipment in buildings.

Federal Policy

As of 2024, EPA has not listed space and water heating equipment as a source category under section 111(b) of the Clean Air Act or promulgated performance standards to regulate emissions from this equipment. However, the Clean Air Act specifically authorizes states to adopt lower emissions limits than those imposed by EPA (except for motor vehicles), thereby allowing states to adopt emissions standards for heating equipment.[33,34]

The Clean Air Act also requires states that have not attained the National Ambient Air Quality Standards (NAAQS) to submit and implement State Implementation Plans (SIPs) that include "enforceable emission limitations and other control measures, means, or techniques"[35] to bring pollution under control.[36] Of states in the Ozone Transport Commission (OTC),[37] Connecticut, Delaware, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, and Virginia all have at least one county out of compliance with the ozone or SO2 NAAQS, with Connecticut and New Jersey experiencing nonattainment statewide.[38]

State and Air District Policies

In addition to their authority under the Clean Air Act, most states have statutory and regulatory authority to regulate air pollution, although the specifics vary from state to state. Many states have also passed statutory requirements to reduce statewide GHG emissions or have given their air or energy agencies the authority to limit GHG emissions.[39] Statutory authority to regulate GHG emissions from building combustion may also be strengthened when states designate GHGs as air pollutants due to climate change-related health hazards.[40]

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[32] Vermont Department of Environmental Conservation, "Special Considerations for Outdoor Hydronic Heaters," accessed October 25, 2024.
[33] US EPA, "Regulatory and Guidance Information by Topic: Air", accessed June 27, 2024.
[34] US CAA, 74 U.S.C. 7416.
[35] US CAA, 74 U.S.C., Section 7410(a)(2)(A).
[36] US EPA, "Basic Information about Air Quality SIPs," January 12, 2024.
[37] Ozone Transport Commission (OTC), "About the OTC," accessed September 30, 2024.
[38] US EPA, "Current Nonattainment Counties for All Criteria Pollutants," May 31, 2024.
[39] States/jurisdictions with statutory requirements to achieve statewide GHG reductions include CT, DC, ME, MD, MA, NJ, NY, RI and VT.
[40] US EPA, "Climate Change and Human Health," June 4, 2024.

Over the past few decades, several air districts and states, including California, Utah, Texas, and Colorado, have established emissions limits for heating equipment, with the earliest regulation initiated in 1978 by a California air district.[41] California air districts have also recently adopted the nation's first zero-emission standards for space and water heating equipment with the state of California soon to follow, and Maryland is on track to propose a ZEHES regulation within the next year, as described below.

Bay Area Air Quality Management District (BAAQMD)

BAAQMD has regulated NOx emissions from methane gas-fired furnaces since 1983, and boilers and water heaters since 1992, to comply with federal air quality limits.[42] On March 15, 2023, BAAQMD approved amendments to these rules, thereby adopting the first ZEHES requirements in the nation. The 2023 amendments establish ULN limits of 14 nanograms per joule (ng/J) for methane gas-fired furnaces sold or installed starting in 2024, and subsequent zero-NOx limits for furnaces and water heaters.[43,44] Zero-NOx compliance dates take effect in 2027 for methane gas water heaters rated less than 75,000 Btu/hr, in 2029 for methane gas furnaces, and in 2031 for methane gas water heaters and boilers rated up to 2,000,000 Btu/hr.

South Coast Air Quality Management District (South Coast AQMD)

Like BAAQMD, South Coast AQMD has a long history of limiting emissions from residential-scale water heaters and furnaces, with its first regulations dating back to 1978.[45] South Coast AQMD is now in the process of amending these rules to set zero-NOx limits for residential-type heating equipment, with compliance dates starting in 2026 for new buildings and 2028 for existing buildings.[46] On June 7, 2024, South Coast AQMD also established the nation's first ZEHES requirement to limit NOx emissions from commercial-scale water heaters, boilers, and process heaters in Rule 1146.2.[47] Zero-emission compliance dates under this rule take effect between 2026 and 2033.

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[41] Dennison et al., "How Air Agencies Can Help End Fossil Fuel Pollution from Buildings," RMI, 2021.
[42] Bay Area Air Quality Management District (BAAQMD), "Final Staff Report: Proposed Amendments to Building Appliance Rules," March 2023.
[43] Bay Area Air Quality Management District, Regulation 9, Rule 4: "Nitrogen Oxides from Natural Gas-Fired Furnaces", amended March 15, 2023.
[44] BAAQMD, Regulation 9, Rule 6: "Nitrogen Oxides Emissions from Natural Gas-Fired Boilers and Water Heaters", amended March 15, 2023.
[45] South Coast AQMD, "Preliminary Draft Staff Report for Proposed Amended Rule 1111 and Proposed Amended Rule 1121," September 2024.
[46] *Ibid*.
[47] South Coast AQMD, Rule 1146.2: "Emissions of Oxides of Nitrogen from Large Water Heaters and Small Boilers and Process Heaters", amended June 7, 2024.

San Joaquin Valley Air Pollution Control District (San Joaquin Valley APCD)

The San Joaquin Valley APCD has regulated NOx emissions from residential water heaters since 1993[48] and from central furnaces since 2005.[49] Currently, water heater NOx emissions are limited to 10 ng/J of NOx for storage water heaters and 14 ng/J of NOx for instantaneous water heaters. Furnaces must also abide by 14 ng/J NOx emission limits.

California Air Resources Board (CARB)

As of October 2024, CARB is actively developing zero-GHG emission standards for new space and water heaters. These standards are part of California's climate strategy outlined in a 2022 Scoping Plan to assist with achieving carbon neutrality by 2045.[50] Zero-GHG emission standards for new space and water heaters are also under development due to CARB's commitment to improve air quality in its 2022 State Strategy for the State Implementation Plan (SIP), achieve compliance with state and federal air quality standards, and promote public health. [51] At a public workshop in May 2024, CARB staff shared a draft regulatory proposal in alignment with air districts' adopted and proposed zero-NOx rules.[52] Currently, CARB staff plan to take a proposed regulation to the Board for consideration in 2025.

Utah Air Quality Board

In 2015, the Utah legislature passed a law establishing NOx emission limits of 10 ng/J for natural gas water heaters rated up to 75,000 Btu/hr and 14 ng/J for those rated up to 2,000,000 Btu/hr. [53] Implementation of the rule began in July of 2018,[54] and 2020 amendments also include provisions for mobile homes and pool heaters.[55]

Texas Commission on Environmental Quality (TCEQ)

TCEQ has implemented NOx standards for methane gas-fired water heaters since 2000 as part of their ozone SIP.[56] The current rule establishes NOx emission limits of 10 ng/J for boilers and process heaters sized up to 75,000 Btu/hr, 40 ng/J for water heaters, boilers, and process

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[48] San Joaquin Valley APCD, "Rule 4902: Residential Water Heaters," amended March 19, 2009.
[49] San Joaquin Valley APCD, "Rule 4905: Natural Gas-Fired Fan-Type Central Furnaces," amended March 21, 2024.
[50] California Air Resources Board (CARB), "2022 Scoping Plan for Achieving Carbon Neutrality," December 2022.
[51] California Air Resources Board (CARB), "Zero-Emission Space and Water Heater Standards", accessed October 22, 2024.
[52] *Ibid*.
[53] Utah State Legislature, Title 15A, Rule 6-102, "Nitrogen Oxide Emission Limits for Natural Gas-Fired Water Heaters", amended July 1, 2020.
[54] Utah Office of Administrative Rules, R307-230, "NOx Emission Limits for Natural Gas-Fired Water Heaters," August 3, 2017.
[55] *Ibid*.
[56] Texas Commission on Environmental Quality (TCEQ), "Rule History Title 30 Texas Administrative Code Chapter 117 Water Heaters, Small Boilers, and Process Heaters," accessed September 30, 2024.

heaters up to 400,000 Btu/hr, and 0.037 lbs/MMBtu for water heaters, boilers, and process heaters over 400,000 Btu/hr.[57]

Colorado General Assembly

The Colorado General Assembly passed a 2023 bill establishing ULN standards for water heaters and furnaces manufactured, distributed, sold, or leased in the state, starting in 2026. The law creates a standard of 10 ng/J of NOx for water heaters under 75,000 Btu/hr and 14 ng/J of NOx for furnaces and water heaters between 75,000 and 2,000,000 Btu/hr.[58]

Maryland Department of the Environment (MDE)

In alignment with Maryland's Pollution Reduction Plan[59] and as directed by a 2024 Executive Order,[60] MDE intends to propose a ZEHES regulation by the end of 2025. To accomplish this goal, MDE will begin a regulatory and stakeholder process using Model Rule 1.0 in 2024.

4. MODEL RULE DEVELOPMENT PROCESS

In September 2023, ten US states in the US Climate Alliance[61] committed to "explore the adoption of zero-emission standards for space and water heating equipment" as part of a broader Commitment to Decarbonize Buildings.[62] These states, and others interested in exploring these standards, are participating in an Equipment Emission Standards Cohort (EESC) co-convened by NESCAUM and US Climate Alliance. The EESC is developing technical resources and model rules to support states interested in advancing ZEHES policies.

NESCAUM worked with the EESC and the Regulatory Assistance Project (RAP) to develop Model Rule 1.0: NOx and GHG Emissions Standards for Space and Water Heaters. Under contract to NESCAUM, Energy Solutions provided technical and market expertise, and attorney Dwight Alpern provided legal writing and consulting support.

As a starting point, NESCAUM used RAP's *Model Rule: NOx Standards for Water Heaters* (RAP Model Rule), published in February 2023,[63] and worked with the EESC to gather additional state feedback. Most notably, states indicated that they would be more likely to advance ZEHES rules for water heating and space heating equipment at the same time, rather than proposing emission standards only for water heaters. NESCAUM also reviewed the zero-emission

[57] TCEQ, Title 30, Rule 117.3, "Control of Air Pollution from Nitrogen Compounds Multi-Region Combustion Control Water Heaters, Small Boilers, and Process Heaters", amended June 14, 2007.
[58] Colorado General Assembly, "House Bill 23-1161: Environmental Standards for Appliances," effective August 7, 2023.
[59] MDE, "Maryland's Climate Pollution Reduction Plan," December 28, 2023.
[60] State of Maryland Executive Department, Executive Order 01.01.2024.19, "Implementing Maryland's Climate Pollution Reduction Plan," June 4, 2024.
[61] US Climate Alliance, "States United for Climate Action," accessed September 30, 2024.
[62] US Climate Alliance, "US Climate Alliance Announces New Commitments to Decarbonize Buildings Across America, Quadruple Heat Pump Installations by 2030," September 21, 2023.
[63] Seidman et al. (2023), "Model Rule: NOx Standards for Water Heaters," Regulatory Assistance Project.

standards adopted by the Bay Area and South Coast AQMDs, both of which were passed after publication of the RAP Model Rule.

NESCAUM also undertook research and analysis to guide Model Rule development. Specifically, NESCAUM conducted or commissioned the following studies:

- State-by-state analysis of GHG and criteria air pollution emissions impacts associated with residential building electrification;
- State-by-state analysis of health benefits and impacts associated with residential building electrification; and
- Market and cost studies assessing the cost impacts and market trends associated with replacing residential heating, ventilation, and air conditioning (HVAC) and water heating equipment with ASHPs and HPWHs.

These studies are discussed further in Section 9.

NESCAUM worked with the EESC and RAP to draft a Model Rule for both space and water heating, incorporating input from EESC member states, insights from the ZEHES rules under development and adopted in California, and results of NESCAUM technical analyses. NESCAUM then undertook a stakeholder engagement process to collect feedback on the draft Model Rule from HVAC and water heater manufacturers, technical experts, and members of NESCAUM's EJAG. This stakeholder process is described further in Section 7.

5. MODEL RULE SUMMARY

Model Rule Objectives

Model Rule 1.0 sets air pollution standards for space and water heating equipment. It was designed to help states meet the following objectives:

- **Air quality:** Improve outdoor air quality and address ozone-forming NOx emissions to promote public health and prevent avoidable deaths.
- **Climate change:** Reduce building-sector GHG emissions to help states achieve climate goals and slow global warming.
- **Market guidance:** Provide a clear market signal about the pace of the transition to zero-emission buildings in order to guide heating equipment manufacturer, distributor, and contractor planning and allow time for the market to prepare.
- **Policy coordination:** Align regulatory approaches across states to provide consistency and predictability for market actors, while allowing for adaptation to meet an individual jurisdiction's objectives.

Model Rule Use

Model Rule 1.0 is a template regulation that states can utilize to improve air quality and reduce GHG emissions. Interested states can use Model Rule 1.0 as a starting point for state-specific rulemaking and stakeholder engagement processes. Some aspects of the Model Rule were designed to ensure applicability in Northeast and Mid-Atlantic states, and the supporting analyses that NESCAUM commissioned to inform Model Rule 1.0 focused on these regions. However, any state may use the Model Rule, and other jurisdictions such as air districts and cities may also find it a valuable resource.

Model Rule 1.0 is intended as an informational resource for states and is not binding. It is free to use for noncommercial purposes and can be adapted as users see fit. NESCAUM intends to update the Model Rule in the future as new information becomes available. For example, it may be expanded to include additional equipment types, such as commercial-scale space and water heating equipment, as well as to incorporate learnings from jurisdictions working on ZEHES. We will release updates as Model Rule 2.0, Model Rule 3.0, and so on, as needed.

Key Provisions

Model Rule 1.0 supports a market transition to zero-emission equipment by establishing limits on NOx and combustion GHG emissions from covered space and water heating equipment sold or installed in a jurisdiction. **It does not require early replacement of functioning equipment in buildings**, but ensures that polluting equipment will be replaced with zero-emission alternatives at the end of life. Key provisions include:

- **Zero-emission NOx and GHG limits** for residential-scale water heaters, furnaces, and boilers sold, leased, or installed in adopting jurisdictions starting on January 1, 2029.
- **ULN emissions limits** for some water heaters (not space heaters) sold, leased, or installed in adopting jurisdictions starting 12 months after state rule promulgation.
- **Certification procedures for covered equipment** aligning with existing certifications procedures and qualified product lists maintained by government entities such as BAAQMD and South Coast AQMD.[64]
- **Labeling and record-keeping requirements** for manufacturers, refurbishers, distributors, and retailers regarding space and water heating equipment sales.

For ease of implementation, Model Rule 1.0 was designed to keep compliance requirements primarily at the manufacturer, distributor, and retailer levels and avoid compliance obligations for contractors and customers.

Table 1 summarizes emission limits and effective dates for equipment types within the scope of Model Rule 1.0, referred to in TSD 1.2 as covered equipment. Details and rationale for key elements of Model Rule 1.0 are described in the next section.

[64] South Coast AQMD, "Rule 1121 – Control of Nitrogen Oxides from Residential-Type, Natural Gas-Fired Water Heaters," December 15, 2023.

Table 1. Summary of Model Rule Emissions Limits and Compliance Dates

Category	Covered Equipment Definition and Size (expressed as Rated Heat Input Capacity in Btu/hr)	Low-NOx Compliance Date	Ultra-Low NOx Emissions Limit (per Joule)	Ultra-Low NOx Emissions Limit (per MMBtu)*	Zero-NOx & Zero-GHG Compliance Date	Zero-Emission Limits (per Joule)	Zero-Emission Limits (per MMBtu)*
Category 1 Water Heater	Designed to combust methane gas: • Small storage water heaters <75,000 Btu/hr	[12 months after rule promulgation]	10 ng NOx	2.326×10^{-2} lbs NOx	January 1, 2029	0.0 ng NOx 0.0 g GHG	0.0 lbs NOx 0.0 lbs GHG
Category 2 Water Heater	Designed to combust methane gas: • Storage water heaters ≥75,000 and ≤105,000 Btu/hr • Instantaneous water heaters <200,000 Btu/hr	[12 months after rule promulgation]	14 ng NOx	3.256×10^{-2} lbs NOx	January 1, 2029	0.0 ng NOx 0.0 g GHG	0.0 lbs NOx 0.0 lbs GHG
Category 3 Water Heater	Designed to combust methane gas: • Storage water heaters >105,000 and ≤2,000,000 Btu/hr • Instantaneous water heaters ≥200,000 and ≤2,000,000 • Hot water boilers ≥300,000 and ≤2,000,000 Btu/hr	[12 months after rule promulgation]	14 ng NOx	3.256×10^{-2} lbs NOx	________	________	________
Category 4 Water Heater	Designed to combust heating oil or propane: • Storage and instantaneous water heaters <210,000 Btu/hr	________	________	________	January 1, 2029	0.0 ng NOx 0.0 g GHG	0.0 lbs NOx 0.0 lbs GHG
Category 1 Boiler	Designed to combust methane gas, oil, or propane: • Boilers <300,000 Btu/hr	________	________	________	January 1, 2029	0.0 ng NOx 0.0 g GHG	0.0 lbs NOx 0.0 lbs GHG
[Category 2 Boiler]	Designed to combust methane gas, oil, or propane: • Boilers ≥300,000 and ≤2,000,000 Btu/hr	[RESERVED]					
Category 1 Furnace	Designed to combust methane gas, oil, or propane: • Furnaces <225,000 Btu/hr	________	________	________	January 1, 2029	0.0 ng NOx 0.0 g GHG	0.0 lbs NOx 0.0 lbs GHG
[Category 2 Furnace]	Designed to combust methane gas, oil, or propane: • Furnaces ≥225,000 and ≤2,000,000 Btu/hr	[RESERVED]					

Note: Model Rule 1.0 sets emissions limits in nanograms or grams per Joule of output. This table also expresses these limits in pounds per MMBtu of output for the convenience of states who prefer to use these units to measure heating equipment emissions.

6. MODEL RULE DETAILS AND RATIONALE

This section provides details on the scope and design of Model Rule 1.0, including the rationale for key components of the rule.

Regulated Pollutants

Model Rule 1.0 regulates NOx and GHG emissions from space and water heaters. This section explains why these pollutants are targeted.

NOx

Model Rule 1.0 focuses on NOx instead of other criteria pollutants due to the threat NOx poses to public and environmental health, and the critical need to reduce ozone precursors such as NOx to meet the NAAQS for ozone.

- **Air quality requirements:** States have strong authority to regulate criteria air pollutants, including NOx. Nationwide, 21 states and the District of Columbia currently have areas in moderate to extreme nonattainment with the 2015 ozone NAAQS.[65] As part of SIPs to address current and historical ozone nonattainment, several jurisdictions across the country have already implemented a variety of NOx regulations, including for industrial combustion, polluting vehicles, and specific sources.[66,67] NOx emissions limits for space and water heating equipment would fill current regulatory gaps by complementing pollution regulations for transportation and other sectors.
- **Health harms:** NOx creates a unique health threat because it can cause harm directly on its own and indirectly by forming secondary PM2.5 and ground-level ozone. NOx emissions often cause nonattainment of health-based NAAQS for ozone, which is particularly relevant to states with ozone nonattainment areas.[68,69]
- **Environmental damage:** NOx pollution contributes to acid rain, which damages ecological health by killing trees, harming aquatic wildlife, and causing eutrophication in water bodies.[70,71] NOx controls have also been identified as a key component to addressing regional haze, improving visibility, and achieving compliance with the EPA Regional Haze Rule by 2064 in the Northeast and Mid-Atlantic.[72]

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[65] US EPA, "8-Hour Ozone (2015) Designated Area/State Information," accessed September 30, 2024.
[66] Texas Commission on Environmental Quality, "Controlling NOx Emissions from Major Combustion Sources," May 2, 2024.
[67] US EPA, "EPA Approved New Jersey Source-Specific Requirements," November 7, 2023.
[68] Michigan Department of Environment, Great Lakes, and Energy, "Ozone and Nonattainment," June 2023.
[69] Georgia Environmental Protection Division, "Georgia EPD Statement on the Redesignation of the Atlanta Nonattainment Area to Attainment for the 2015 Ozone Standard," October 17, 2022.
[70] US EPA, "Effects of Acid Rain," May 7, 2024.
[71] European Environment Agency, "Eutrophication caused by atmospheric nitrogen deposition in Europe," November 28, 2023.
[72] Davis et al. (2022), "The Changing Nature of Visibility Impairment in the Mid-Atlantic/Northeast Visibility Union (MANE-VU) Region," *The Magazine for Environmental Managers*.

- **Co-pollutant reduction:** Reducing NOx emissions by promoting low- or zero-NOx technologies will necessarily decrease emissions of co-pollutants like SO2 and PM2.5. Furthermore, establishing NOx limits alongside GHG limits ensures that novel climate-friendly technologies do not create new health burdens.

State agencies who have not been granted the authority to regulate GHG emissions, or who do not have climate pollution reduction goals, may adapt Model Rule 1.0 to exclusively focus on NOx as a public health regulation.

Combustion GHGs

Model Rule 1.0 also targets GHG emissions produced due to the on-site operation of a space or water heater, known as combustion GHGs. Specifically, it regulates the quantity of carbon dioxide, methane, and nitrous oxide emitted from the flue of the water heater, boiler, or furnace, expressed as grams of carbon dioxide equivalent (CO2e). Model Rule 1.0 regulates combustion GHG emissions in addition to NOx to support states in achieving climate and GHG reduction goals.

- **Climate change:** Climate change is already affecting Northeast states as warmer temperatures increase Lyme disease,[73] wildfire smoke increases asthma risk,[74] extreme flooding damages property,[75] and mortality rises during heat waves.[76] Addressing climate change has become a priority in many jurisdictions.
- **GHG reduction requirements:** Most jurisdictions in the Northeast and Mid-Atlantic have statutory requirements to achieve GHG reductions, including Connecticut, Maine, the District of Columbia, Maryland, Massachusetts, New Jersey, New York, Rhode Island, and Vermont.[77] Many state agencies also have explicit authority to issue regulations to achieve GHG reductions as combustion pollutants or implement state climate action plans and achieve GHG targets.[78] States that are in attainment for ozone may be more interested in regulating GHG emissions than NOx emissions to meet their climate goals.

[73] Couper et al. (2020), "Impact of prior and projected climate change on US Lyme disease incidence," *Global Change Biology* 27(4): 738-754.
[74] Chen et al. (2023), "Canadian Wildfire Smoke and Asthma Syndrome Emergency Department Visits in New York City," *JAMA* 330(14): 1385-1387.
[75] Rathke, L., "A second person has died in Vermont flooding from Hurricane Beryl's remnants, officials say," *The Associated Press,* July 12, 2024.
[76] NYC Department of Health, "2024 NYC Heat-Related Mortality Report," June 18, 2024.
[77] Center for Climate & Energy Solutions, "State Climate Policy Maps," accessed September 30, 2024.
[78] See, for example: DC: Code §8-101.05(a) & (b)(1)(D) & §8-101.06(c); ME: 38 M.R.S.A. §585 & §585-A; MD: Md. Code Enviro. §2-103(b)(1) & §2-301(a)(1); MA: M.G.L. c.111 §142A; NY: NY ENG 16-104.1 & .2 & 16-106.1(a), (b), (c) & (d); RI: RI Gen L §23-23-5(12) & §42-17.1-2(1) & (19), VT: 10 V.S.A. §558.

Covered Equipment

This section describes the equipment types covered by Model Rule 1.0 and the technologies available to achieve the emissions limits for NOx and combustion GHGs. In jurisdictions that adopt Model Rule 1.0 or similar ZEHES regulations, once the zero-emissions limits take effect in 2029, most residential space and water heater installations will eventually transition to zero-emission equipment. Electric technologies such as heat pumps are expected to be the most common zero-emission option, but other existing and future technologies such as solar hot water, hydrogen, and zero-emission fossil fuel combustion could also be adopted.

Model Rule 1.0 was designed to cover the vast majority of small water heaters, boilers, and furnaces that emit NOx and GHGs in significant amounts. It is comprehensive in that it covers sales, lease, and installation of new, pre-owned, and refurbished equipment. Should additional types of residential-scale space and water heating equipment not covered by Model Rule 1.0 enter the market that emit significant amounts of these pollutants, NESCAUM will consider updating the Model Rule to cover them.

NESCAUM's technical consultant, Energy Solutions, provided market and technical expertise on equipment types and sizes to cover and zero-emission alternatives.

Covered Equipment Types, Sizes, and Compliance Options

Ultra-Low-NOx (ULN) Standards

Methane gas is the most common fuel used for water heating, with 48% of US and 52% of Northeast households relying on it for hot water.[79] Like propane and heating oil, methane gas combustion by residential water heaters generates NOx emissions and contributes to ground-level ozone formation (see Section 2 for more). To address this issue, jurisdictions with high prevalence of methane gas water heaters, including the San Joaquin Valley,[80] South Coast AQMD,[81] BAAQMD,[82] and the states of Utah[83] and Colorado,[84] have passed ULN requirements between 2006 and 2023 to reduce water heater emissions to a maximum of 14 ng/J.

Due to these longstanding ULN requirements, there is a high availability of ULN water heaters, including hundreds of qualifying models on South Coast AQMD's certified list.[85] While not all

[79] US EIA, "The Majority of US Households Used Natural Gas in 2020," March 23, 2023.
[80] San Joaquin Valley Air Pollution Control Districts, Regulation IV: Rule 4902 – Residential Water Heaters.
[81] South Coast AQMD, Rule 1121 – Control of Nitrogen Oxides from Residential Type, Natural Gas-Fired Water Heaters.
[82] BAAQMD, Rule 9-6: Nitrogen Oxides Emissions from Natural Gas-Fired Boilers and Water Heaters.
[83] Utah Office of Administrative Rules, Rule R307-230: NOx emission Limits for Natural Gas-Fired Water Heaters.
[84] Colorado General Assembly, HB 23-1161: Environmental Standards for Appliances.
[85] South Coast AQMD, "List of Certified Units Pursuant to Rule 1121," revised May 17, 2024.

methane gas water heaters currently in the market are ULN, there are many residentially sized ULN products available that are only $80-$140 more expensive than average.[86]

To achieve near-term emissions reductions from equipment that is already available with little cost difference, Model Rule 1.0 includes ULN requirements for water heaters as a stepping-stone to zero-NOx water heaters. Methane gas water heaters with rated heat input capacity up to 2,000,000 Btu/hr are required to achieve ULN standards within 12 months of rule promulgation.

Model Rule 1.0 does not include ULN standards for heating oil or propane water heaters and for furnaces and boilers. The ULN in effect to date generally rely on certification procedures and qualified product lists maintained by South Coast AQMD or BAAQMD, which only cover methane gas equipment. A state interested in developing certification procedures for heating oil and propane equipment could consider setting ULN standards for those product types.

While some California air districts and Colorado have established or proposed ULN standards for residential furnaces, these ULN standards are more recent (e.g., BAAQMD Rule 9-4 establishes ULN standards for furnaces starting in 2024).[87] Energy Solutions research identified limited market availability of ULN furnaces as a current constraint. Additionally, given that no state is likely to adopt Model Rule 1.0 before 2025, ULN limits would be in effect for a short time before zero-emission limits for furnaces begin in 2029. Manufacturers also responded negatively to the inclusion of ULN furnace standards, highlighting the cost and complexity of shifting supply chains to reach ULN compliance in the Northeast – especially considering the higher demand for heating equipment in the Northeast relative to California. Given these considerations, NESCAUM decided to omit ULN standards for furnaces from Model Rule 1.0.

Zero-NOx and Zero-GHG Standards

Model Rule 1.0 sets zero-emission limits for small furnaces, boilers, and water heaters that produce direct NOx and GHG emissions in buildings. It covers the most common types of residential-scale central space heaters (furnaces and boilers) and water heaters based on prevalence in the Northeast's housing stock, and covers equipment designed to combust methane gas, propane, and heating oil because those fuels comprise over 95% of regional fossil fuel use.[88]

Following recommendations from Energy Solutions and manufacturer input, Model Rule 1.0 generally aligns with US Department of Energy (DOE) appliance/equipment category definitions that are used to define these equipment types in the US market.[89] This will help with market understanding of Model Rule 1.0 and ensure comprehensive coverage of covered equipment

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[86] US DOE, "Technical Support Document: Energy Efficiency program for Consumer Products and Commercial and Industrial Equipment – Consumer Water Heaters," April 2024.
[87] BAAQMD, "Regulation 9-4: Nitrogen Oxides from Natural Gas-Fired Furnaces," amended March 15, 2023.
[88] EIA RECS 2020.
[89] US DOE 10 Code of Federal Regulations (CFR), Section II, Subchapter D, Part 4300.

types. A comprehensive list of sources for equipment definitions in Model Rule 1.0 is provided in Appendix A, and a summary of covered equipment types, definitions, and prevalence is provided in Table 2.

Table 2. Definitions and prevalence of equipment types covered by Model Rule 1.0.

Product	Definition	Northeast Prevalence
Residential-scale Furnaces	Equipment with a rated heat input capacity of less than 225,000 Btu/hr designed to supply heated air through a system of ducts for space heating applications, including but not limited to a forced air or gravity central furnace, and be the principal heating source for a residence's living space. In Model Rule 1.0, covered furnaces are defined as being designed to combust methane gas, propane, or heating oil.	Present in around 49% of housing units.[90]
Residential-scale Boilers	Equipment with a rated heat input capacity of less than 300,000 Btu/hr designed to supply low-pressure steam or hot water for space heating applications and be the principal heating source for a residence's living space. In Model Rule 1.0, boilers are defined as using only a single-phase electric current or DC current in conjunction with methane gas, propane, or heating oil combustion, and supplying either low pressure steam or hot water at or below 250°F.	Present in around 26% of housing units.[91]
Residential-scale Water Heaters	Instantaneous water heaters with a rated heat input below 200,000 Btu/hr and storage water heaters with a rated heat input of up to 105,000 Btu/hr designed to combust methane gas, as well as storage and instantaneous water heaters with a rated heat input capacity up to 210,000 Btu/hr designed to combust heating oil or propane.	Present in around 67% of housing units.[92]

A variety of zero-emission technologies are currently available in the market to meet the limits set by Model Rule 1.0. Additionally, new technologies are emerging that should provide new zero-emission options for space and water heating by the time that standards take effect. Zero-emission technology options include:

Water Heating:

- **240-Volt HPWHs:** Until recently, most HPWHs required a 240-volt non-standard outlet, requiring some residents to upgrade their electric panel or run a new electrical line prior

[90] US EIA, "Table HC6.7 Space heating in homes in the Northeast and Midwest regions, 2020," March 2023.
[91] *Ibid*.
[92] US EIA, "Table HC8.7 Water heating in homes in the Northeast and Midwest regions, 2020," March 2023.

to installation, both of which can significantly increase costs.[93] This makes 240-volt HPWHs an easy upgrade option for homes that do not need electrical upgrades, including those using electric resistance water heaters that already have 240-volt outlet capacity,[94] and newer construction that already builds higher service capacity into the main electric breaker.[95]

- **120-Volt HPWHs:** This emerging technology can enable easier installation of HPWHs in homes with electrical capacity constraints. 120-volt HPWHs can be plugged into standard electrical outlets and are easier to install than 240-volt HPWHs. While the upfront cost of 120-volt HPWHs is higher than 240-volt HPWHs,[96] reducing electrical service upgrade needs can make them a more affordable option for some older homes and during emergency replacements.[97]
- **Solar Water Heaters:** Solar water heaters use solar power to heat and store water, essentially providing free hot water while the sun shines. [98] However, solar water heaters usually require backup systems for high demand or cloudy days, which can increase installation costs and may prevent them from being a fully zero-emission option.
- **Electric Resistance Water Heaters:** Because they use electricity instead of direct fossil fuel combustion to generate heat, electric resistance water heaters would comply with Model Rule 1.0. However, because they create heat rather than move it as heat pumps do, they are significantly less efficient and result in much higher energy bills than HPWHs.[99] Updated DOE efficiency standards are expected to transition many electric water heaters away from electric resistance and toward heat pump technology starting in 2029 to help customers save money on electric bills.[100]

Space Heating:

- **Ducted Air-Source Heat Pumps (ASHPs):** Ducted ASHPs can connect to the distribution system (ductwork) previously used by a fossil fuel-burning furnace and/or air conditioning (AC) system, and deliver central heating and cooling.[101] These heat pumps are a good option for homes with pre-existing ductwork, where they can serve as 'drop-in' replacements for aging heating and/or cooling equipment.[102] Ducted ASHPs

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[93] NYSERDA, "All About Heat Pump Water Heaters," accessed October 1, 2024.
[94] *Ibid.*
[95] US EPA ENERGY STAR, "Heat Pump Water Heater Guide," June 2024.
[96] Booth, K., and Fosberg, C., "Heat Pump Water Heaters in the Northeast and Mid-Atlantic: Costs and Market Trends," October 30, 2024.
[97] Bay Area Air Quality Management District (BAAQMD), "Final Staff Report: Proposed Amendments to Building Appliance Rules," March 2023.
[98] US DOE, "Solar Water Heaters," accessed July 16, 2024.
[99] US DOE, "Electric Resistance Heating," accessed October 1, 2024.
[100] US DOE, "DOE Finalizes Efficiency Standards for Water Heaters to Save Americans Over $7 Billion on Household Utility Bills Annually," April 30, 2024.
[101] US EPA ENERGY STAR, "Air-Source heat Pumps," accessed October 1, 2024.
[102] *Ibid.*

can also be a great option for homes looking to install a central AC system, and who are already planning for the increased cost of setting up a distribution system.

- **Ductless ASHPs:** Ductless ASHPs, often referred to as mini (or, with multiple indoor units, multi) splits, can be installed in homes without existing forced-air ductwork. Mini-split units are mounted onto walls or ceilings and connected to an outdoor heat-absorbing unit via small refrigerant lines. Since they do not require ductwork, mini split ASHPs provide an alternative to hydronic boiler-radiator systems and baseboard heat, and can also provide efficient cooling in households without central AC.[103]
- **Cold-climate ASHPs (ccASHPs):** ccASHPs are specifically designed to perform well without supplemental heat in cold temperatures down to 5°F,[104] and to continue producing heat at high efficiencies at temperatures well below zero.[105] They can be ducted or ductless, and can be installed in homes located in cold areas such as in the Northeast or Midwest to eliminate the need for backup heating systems.
- **Ground-Source Heat Pumps:** Also known as geothermal heat pumps, ground-source heat pumps draw on heat from the ground, rather than from the air. Because the ground maintains a more constant temperature than air, ground-source heat pumps operate even more efficiently than ASHPs and can cost less to operate.[106] However, ground source heat pumps have significantly higher upfront costs than ASHPs. Ground-source heat pumps can also be deployed as part of a thermal energy network (TEN).[107]
- **Active Solar Heating:**[108] These systems transfer solar heat into an air or liquid medium that can provide instantaneous heat or be stored for later. Solar heating systems can distribute heat through radiant floors, hot water radiators, or forced-air systems, but often require supplemental heat on cloudy or high-demand days.
- **Electric Resistance Space Heaters:** Like electric resistance water heaters, electric resistance space heaters are an option for zero-emission heating, but they are much more inefficient and costly to operate than heat pumps.[109] Electric resistance space heaters are generally only an economical option in warmer climates with modest heating needs.[110] Even in these cases, heat pumps can be preferable because they also provide energy-efficient cooling.

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[103] US EPA ENERGY STAR, "Ductless Heating & Cooling," accessed October 2, 2024.
[104] Northeast Energy Efficiency Partnerships (NEEP), "ccASHP Specification & Product List," accessed October 2, 2024.
[105] Gartman & Shah (2020), "Heat Pumps: A Practical Solution for Cold Climates," RMI.
[106] US DOE, "Geothermal Heat Pumps," accessed October 9, 2024.
[107] Building Decarbonization Coalition, "Thermal Energy Networks," accessed October 11, 2024.
[108] US DOE, "Active Solar Heating," accessed July 16, 2024.
[109] Booth, K., et al., "Heat Pump Water Heaters in the Northeast and Mid-Atlantic: Costs and Market Trends", October 30, 2024.
[110] US DOE, "Electric Resistance Heating," accessed October 2, 2024.

Up-and-Coming Technologies:

- **Air-to-Water Heat Pumps (AWHPs):** AWHPs transfer heat from the air to a fluid (generally a combination of water and glycol) and utilize a hydronic distribution system to circulate warmth, similar to a boiler. AWHPs can also provide air conditioning by reversing the process and running cold fluid through an air coil in the summer.[111]
- **Window Heat Pumps:**[112] An emerging solution for multifamily heating and cooling, window heat pumps are inserted over a windowsill and plug into a standard outlet. Window heat pumps provide zonal heating room-by-room and are easily installable, similar to window AC units.
- **Hydrogen Heating Systems:** While hydrogen-based residential heating systems are not currently commercially available, production and use of clean hydrogen is under active exploration.[113] Hydrogen boilers are similar in design to gas boilers but burn hydrogen instead of gas, producing water vapor emissions. Hydrogen combustion is inherently GHG-free, and should a zero-NOx hydrogen-combusting residential heater come to market, it would be a viable zero-emission alternative.
- **Zero-Emission Methane Gas-Fired Heaters:** While not market-ready for residential applications, some carbon capture systems have already been deployed in large multifamily buildings to capture CO2 emissions from methane gas-powered heating.[114] Innovative approaches like these would comply with Model Rule 1.0 if they achieved the zero-NOx and zero-GHG limits by preventing or capturing flue emissions.

Exclusions and Equipment Not Covered by Model Rule 1.0

Certain equipment types are not covered by Model Rule 1.0 due to low market prevalence and/or relatively small emissions impacts in the Northeast and Mid-Atlantic. Future iterations of the Model Rule could include these equipment categories.

The following types of equipment are not covered by Model Rule 1.0:

- **Direct Heating Equipment:** As opposed to central heating systems covered by Model Rule 1.0, direct heating equipment typically refers to smaller space heaters that produce hot air directly into a living space from the heating device without ductwork.[115] Examples include wall heaters, portable space heaters, stoves, and fireplaces (which may be heated with gas, wood, or pellets). Energy Solutions determined that direct heating equipment is typically used as supplemental heating, sized below 46,000 Btu/hr, and only present in around 2% of NESCAUM-region homes.[116] Direct heating

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[111] Energy Star, "2019-2020 Air-to-Water Heat Pumps," accessed October 21, 2024.
[112] ENERGY STAR, "Window of Opportunity: New Room Heat Pumps," accessed October 25, 2024.
[113] US DOE, "US National Clean Hydrogen Strategy and Roadmap," June 2023.
[114] Bettenhausen, C., "New York City is Becoming an Unlikely Carbon Capture Hub," *Chemical and Engineering News,* March 15, 2024.
[115] US DOE, "Direct Heating Equipment," accessed October 2, 2024.
[116] US EIA, "Residential Energy Consumption Survey (RECS) 2020," accessed October 24, 2024.

equipment also tends to be used in building types, such as off-grid buildings and seasonal camps, that might otherwise be exempted from the Model Rule due to practical concerns in transitioning to zero-emission options.

- **Equipment Designed to Combust Less Common Fuels:** Space and water heating equipment designed to exclusively combust kerosene, coal, or wood is not covered by Model Rule 1.0 due to Energy Solutions' findings on their very small market share (approximately 2% of Northeast households),[117] application in unique equipment types, or economic non-competitiveness against other heating types. The majority of wood equipment is direct heating equipment (stoves and fireplaces), and thus already not covered by Model Rule 1.0. Central wood furnaces and boilers have a low market prevalence and some equipment types, such as outdoor wood boilers, are already subject to other air pollution control regulations in some jurisdictions.
- **Equipment that Uses Electricity:** Space and water heating equipment that is powered by electricity and does not combust fuel is not covered by the Model Rule. The purpose of the model rule is to set emissions limits to reduce or eliminate on-site NOx and GHG emissions. Electric equipment has no on-site emissions and so needs no emissions limits and is not covered. Emissions from the generation of electricity can and are being addressed through other state regulations.

The following types of equipment are expressly excluded from coverage under Model Rule 1.0:

- **Industrial Equipment:** Equipment designed exclusively for use in manufacturing, testing, or research and development tends to be larger and more specialized, and is excluded from Model Rule 1.0. Future iterations of the Model Rule could include certain commercial and industrial equipment.
- **Recreational Vehicle (RV) Heating Equipment:** RVs are small, temporary residential accommodations that can either transport themselves or be towed.[118] Space and water heaters designed for RV use are excluded from Model Rule 1.0 because they comprise a relatively small portion of the equipment market and often must be sized to meet severe space limitations. Future iterations of the Model Rule could include RV equipment.
- **Pool Water Heaters:** Pool water heaters are designed and used to heat water for swimming pools, hot tubs, spas, and other similar operations.[119] While some California NOx regulations include pool heaters, they are less prevalent in the Northeast where pools are not as common. Pool heaters are excluded from Model Rule 1.0, but may be added in future Model Rule iterations.

[117] *Ibid*.
[118] US Federal Emergency Management Agency, "Recreational Vehicle," last updated July 8, 2020.
[119] US DOE, "Consumer Pool Heaters," accessed October 3, 2024.

Compliance Dates

Model Rule compliance dates consider states' climate goals and market feasibility, and may be adjusted to fit state-specific timelines.

Effective Dates for ULN Standards

ULN standards for water heaters take effect 12 months after rule promulgation. As previously noted, ULN standards for residential and commercial water heaters have been in effect since the 2006-2012 time frame in California,[120] and Utah and Colorado have adopted similar standards since then.[121] NESCAUM determined that it was feasible for these standards to take effect relatively quickly after rule promulgation, given the widespread market availability of qualified ULN water heaters. Qualified product lists maintained by South Coast AQMD include hundreds of qualified products across size categories.[122]

Effective Dates for Zero-NOx and Zero-GHG Standards

Model Rule 1.0 sets zero-emission compliance dates at January 1, 2029 for residential-scale water heaters, furnaces, and boilers for a variety of reasons. First, NESCAUM-commissioned research indicates that a residential zero-emission transition is technically and economically feasible under current market conditions for most scenarios.[123,124] Second, NESCAUM reviewed compliance dates in ZEHES rules adopted by BAAQMD and under development by CARB and South Coast AQMD, and sought to align compliance dates for common equipment types where possible. A January 1, 2029 effective date for zero-emission residential furnaces matches the schedule that BAAQMD has adopted.[125]

Third, 2029 effective dates for zero-emission standards align with states' goals to achieve economy-wide decarbonization or significant GHG emission reductions by 2045 or 2050. As of September 2023, 23 states and the District of Columbia had adopted economy-wide GHG emissions targets.[126] Assuming a 15-year lifespan for boilers and furnaces, any compliance date later than 2029 would fail to retire polluting equipment before 2045.

In addition to furnaces, Model Rule 1.0 sets an effective date of January 1, 2029, for small boilers and water heaters to achieve zero emissions. Model Rule 1.0 takes a different approach

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[120] See footnotes 75-77.
[121] See footnotes 78-79.
[122] See footnote 80.
[123] Booth, K., and Fosberg, C., "Heat Pump Water Heaters in the Northeast and Mid-Atlantic: Costs and Market Trends", June 17, 2024.
[124] Booth, K., et al., "Heat Pumps in the Northeast and Mid-Atlantic: Costs and Market Trends," October 30, 2024.
[125] BAAQMD, Rule 9-6.
[126] Center for Climate and Energy Solutions (C2ES). 2023. US State Greenhouse Gas Emissions Targets. https://www.c2es.org/document/greenhouse-gas-emissions-targets.

from the California AQMDs for boilers, which are rarely used for home heating in California but are a very common type of heating system in many Northeastern states.

For water heaters, the 2029 effective date is later than the 2027 effective date for small storage water heaters with rated heat pump capacity less than 75,000 Btu/hr adopted by BAAQMD and initially proposed by South Coast AQMD and CARB. It is also earlier than the 2031 effective date adopted by BAAQMD for residential instantaneous water heaters with rated heat pump capacity 75,000-200,000 Btu/hr, which BAAQMD combines with larger water heaters and boilers up to 2,000,000 Btu/hr.

Model Rule 1.0 sets the effective date for water heaters at 2029 for two reasons. First, 2029 aligns with DOE's recently finalized energy efficiency standards for water heaters, which will transition much of the residential water heating market from electric resistance to heat pump technology. These federal efficiency standards take effect on May 6, 2029.[127] Second, manufacturers preferred that emissions standards for all residential-type water heaters take effect on the same date. They indicated that an earlier effective date for storage water heaters less than 75,000 Btu/hr might encourage a transition to inefficient electric resistance water heaters or to instantaneous gas water heaters that still produce NOx emissions. Some states may opt to delay compliance dates for water heaters until after the federal efficiency standards take effect on May 6, 2029, while others may prefer to move compliance earlier to achieve net-zero by 2040 targets, or to yield more immediate public health benefits.

Ultimately, states will adopt dates through their own regulatory and stakeholder processes. Given that some stakeholders expressed concerns regarding the January 1, 2029 compliance dates in Model Rule 1.0, it is likely that implementing states will hear similar feedback, and can weigh it against other stakeholder input and state goals.

Consistency Across Equipment and Building Stock:

South Coast AQMD and BAAQMD currently phase in compliance dates for different types of equipment and building types. For example, both BAAQMD and South Coast AQMD have imposed later compliance dates for larger water heating equipment, which is not included in Model Rule 1.0.[128,129] NESCAUM determined that 2029 compliance dates are feasible for the residential-scale equipment covered in Model Rule 1.0, but may consider later compliance dates for other equipment types in future iterations.

NESCAUM also worked with the EESC and Energy Solutions to consider different compliance dates for new construction compared to retrofits. South Coast AQMD has proposed earlier compliance dates for furnaces and water heaters installed in new construction versus existing

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[127] US Federal Register, "Energy Conservation Program: Energy Conservation Standards for Consumer Water Heaters," Department of Energy, May 6, 2024.

[128] BAAQMD, Regulation 9.6.

[129] South Coast AQMD, Rule 1146.2.

buildings. New construction accounts for approximately 3% of total building stock[130] and an even smaller proportion of total building emissions, due to more efficient design and materials. Further, equipment installed in new construction is already governed by energy code requirements. Given the small opportunity for emissions savings and the potential complexity of enforcing requirements that vary based on building type, Model Rule 1.0 keeps compliance dates the same for new construction and existing buildings.

Temporary Leasing and Installation

Many water heater and HVAC installations are emergency replacements and need to be done quickly to provide essential heating, cooling, and hot water services. While many conversions to zero-emission equipment can be done easily, others may involve more complex retrofits such as upgrading electric panels, installing new distribution systems, or addressing space constraints. To bridge the gap for more complex upgrades, Model Rule 1.0 allows for the temporary installation of noncompliant equipment after January 1, 2029, to enable any modifications necessary to install compliant equipment. Under Model Rule 1.0, temporary installations may last up to six months, must be installed by registered providers, and (in the case of water heaters) must comply with Model Rule 1.0 ULN limits. After six months, registered leasing providers must replace the temporary equipment with equipment covered by Model Rule 1.0 that meets the zero-emission limits, or equipment like heat pumps that are not subject to Model Rule 1.0.

California pilots have shown the viability of temporary installations to support HPWH conversions. TECH Clean California funded a Quick Start Grant project in which a plumbing contractor, Barnett Plumbing, offered customers with a failed gas water heater a no-cost, temporary gas water heater installation. This "provided same-day hot water restoration and created sufficient time to complete necessary electrical upgrades for the heat pump water heater installation… Through the heat pump water heater loaner project, Barnett Plumbing increased the rate of customer conversion from gas water heaters to heat pump water heaters from less than one percent to 17.1 percent."[131]

Registered Providers:

Entities that wish to provide temporary installations must apply to be a registered provider with the implementing jurisdiction's environmental protection agency. As written in Model Rule 1.0, a list of registered providers will be made publicly available so that temporary leasing is only performed by registered entities. Registered providers are subject to documentation and record-keeping requirements and may be subject to penalties or fines for noncompliance. Model Rule 1.0 limits temporary installations to registered providers to make it easier for regulators to track and enforce temporary installations. While we do not know exactly how the equipment leasing market would develop, we anticipate that many manufacturers and

[130] US Census, https://www.census.gov/construction/nrc/index.html.
[131] Foster, Benjamin, "Bridging the Gap to Heat Pump Adoption: Water Heater Loaner Program," July 27, 2023.

distributors – who are already subject to the Model Rule's certification and record-keeping requirements (described below) – may become registered providers since they already offer similar financing options to contractors and customers.

Certification, Record-Keeping, and Enforcement

Model Rule 1.0 contains certification, record-keeping, labeling, and enforcement provisions to help states with implementation of ZEHES. Certification requirements ensure that only ULN or zero-emission equipment models are allowed in the jurisdiction's market, record-keeping provisions enable states to track compliance with the regulation, labeling provisions facilitate compliance by distributors, retailers, and contractors with the regulation and support tracking by states, and penalties provide states with mechanisms for enforcement. These requirements only apply to equipment types and sizes covered by Model Rule 1.0.

Certification

Model Rule 1.0 requires that manufacturers apply to the implementing jurisdiction's environmental protection agency for a certification affirming that covered heating equipment is compliant with emissions requirements prior to sale or lease. NESCAUM worked to make Model Rule certification procedures consistent to the extent possible with those utilized by South Coast AQMD and BAAQMD, to decrease administrative complexity for both manufacturers and regulators.

To encourage consistency with California, Model Rule 1.0 allows for methane gas-fired heating equipment to be certified for NOx emissions under South Coast AQMD or BAAQMD testing procedures, or under testing procedures that the implementing jurisdiction finds acceptable. NESCAUM anticipates that most states will opt for an existing California certification to reduce administrative burden.

While California residents predominantly heat their homes with methane gas, residents in the Northeast often combust heating oil or propane – in New England, nearly 40% of households use delivered fuels for home heating.[132] Given this discrepancy in heating equipment types, California air quality management districts have not created NOx emission certification or testing requirements for delivered fuels. In addition, California regulators have not yet created certification and testing requirements for any equipment for GHG emissions. Model Rule 1.0 therefore leaves the adoption of any testing requirements for fuel oil and propane-combusting equipment or GHG emissions to the implementing jurisdiction's environmental protection agency. When applying for certification, manufacturers must provide details on product model and design, rated heat input capacity, and how the product complies with Model Rule emissions limits. If the jurisdiction adopts its own testing requirements for fuel oil or propane equipment or GHG emissions, proof of compliance must include a source test report detailing the emissions testing methods and results obtained from an independent testing laboratory.

[132] Commonwealth of Massachusetts, "How Massachusetts Households Heat Their Homes," accessed October 4, 2024.

Once a product model has been certified, that product can be sold, leased, or installed in the implementing jurisdiction without individual testing for any singular piece of equipment.

Record-Keeping and Labeling Requirements

Model Rule 1.0 requires that both sales and installations of covered equipment meet applicable emissions limits. However, it is structured like a consumer product rule in that record-keeping and labeling requirements generally apply higher up the supply chain, on equipment sales by manufacturers, distributors, and retailers, rather than on installers or building owners. This format is similar to previous consumer product model rules developed by the Ozone Transport Commission (OTC), which forbid sale, rather than purchase, of noncompliant materials.[133] Model Rule 1.0 holds that any manufacturer, refurbisher, distributor, or retailer selling or leasing covered heating equipment in an implementing jurisdiction must maintain sale or lease records for covered equipment for at least five years to demonstrate compliance with emissions standards. While active reporting of sales and leasing is not required under Model Rule 1.0, manufacturers, refurbishers, distributors, and retailers must provide records to the implementing jurisdiction upon request.

Manufacturers, refurbishers, retailers, and distributors are required to collect the following details for recordkeeping of covered equipment:

- Equipment brand name, model number, and serial number
- Date of manufacture or refurbishment
- Emissions certification status
- Date of sale or lease
- Date and destination (recipient and address) of equipment shipment if it is shipped by the regulated entity[134]

Entities temporarily leasing and installing non-compliant equipment under the Temporary Leasing and Installation provision discussed above are also required to maintain records showing compliance with the requirements of that provision, including the six-month limitation on the leasing term.

In addition to record-keeping, Model Rule 1.0 directs that each individual unit of covered equipment offered for sale and use in an implementing jurisdiction must come with a label on its shipping container and on the equipment itself. Shipping container labels must include model and serial number, date of manufacture or refurbishment, and certification status; the equipment nameplate must include those same details, and the maximum heat input capacity.

[133] OTC consumer product rules were widely adopted by Northeast states including DE, MA, MD, NH, NY, and PA. (OTC, "Model Rules and Guidelines – Status of Adoption of OTC Model Rules", May 10, 2023)
[134] This need not be the ultimate installation location, only the next destination to which the equipment is shipped.

Record-keeping and labeling requirements apply to covered equipment types (furnaces, boilers, and water heaters that combust methane gas, oil, or propane). Sales and leases of other types of space and water heating equipment are not subject to record-keeping and labeling requirements.

Enforcement and Penalties

To ensure compliance with emissions limits, environmental protection agencies in implementing jurisdictions may conduct on-site inspections and/or records requests at their discretion. Upon discovering emissions violations, the jurisdiction may levy fines and penalties as provided under state law. While Model Rule 1.0 leaves specification of enforcement parameters to state law, it creates the following framework for issuing fines and penalties:

- Violations will apply to each individual piece of noncompliant equipment sold, leased or installed, with limitations applying to any related series of violations.
- Fines and penalties can be assessed against installers who violate the ZEHES regulation, but not against nonmanagerial employees who may have physically completed the installation.

Based on stakeholder input, NESCAUM recommends that any fines and penalties collected for noncompliance with the regulation be used to support the installation of compliant heating equipment in low-and-moderate income (LMI) households or households in environmental justice communities. However, not all state environmental agencies have the authority to use penalties in this way, and penalty distribution will ultimately be determined state-by-state.

Additionally, some jurisdictions may decide not to include these enforcement and penalty provisions, or to revise them to reflect their own preferred approach.

Extensions and Exemptions

Energy Solutions' analysis of the market and technology options indicated that it will be technically feasible to transition to zero-emission space and water heating in residential-scale applications starting in 2029, as required under Model Rule 1.0. However, in certain retrofit scenarios, installing zero-emission equipment may be expensive and complicated, though technically feasible. Challenging scenarios include:

- **Emergency replacements:** The majority of water heater replacements and approximately one-third of furnace (and likely also residential boiler) replacements are emergency replacements, in which the existing equipment stops working and the customer needs an immediate equipment installation to restore heat or hot water.[135]
- **Distribution system upgrades:** Some zero-emission technologies, such as ducted heat pumps, can use existing hot air ducts and others, such as ductless heat pumps, do not require distribution systems. However, in certain scenarios, installing a preferred

[135] Foster, Benjamin, "Bridging the Gap to Heat Pump Adoption: Water Heater Loaner Program," July 27, 2023.

zero-emission option might require installing a new distribution system or significantly upgrading or modifying an existing distribution system. Section 11 provides information on distribution system costs.

- **Electrical upgrades:** Some buildings, especially older homes, have lower electrical capacity and may need upgrades to panels and wiring to accommodate zero-emission electric technologies. Section 11 provides information on electrical upgrade costs.
- **Weatherization and other building upgrades:** Some homes may need to remediate health and safety problems such as mold and moisture before zero-emission equipment can be installed safely. Additionally, heating technologies cost less to install and operate in homes that have been weatherized, which reduces heating and cooling loads and prevents equipment oversizing. Occasionally, buildings may face space constraints that require rearranging the location of HVAC or water heating equipment.
- **Off-grid buildings:** Homes that are not connected to the electricity grid might be challenged to transition from combustion heating and hot water equipment to zero-emission electric options. However, many of these buildings are seasonal summer camps that rely on direct heating equipment, such as stoves and wall heaters, which are excluded from Model Rule 1.0.

Some of these challenges present temporary obstacles that can be overcome by allowing additional time to transition to a zero-emission option. For these scenarios, Model Rule 1.0 includes a Temporary Leasing and Installation provision allowing for temporary installation of noncompliant equipment for up to six months while building owners conduct necessary building modifications, utility upgrades, and other changes to enable compliant equipment installation (see previous section on Temporary Leasing and Installation).

Other scenarios present an affordability challenge. In particular, installation costs for zero-emission equipment may be very high in cases where significant upgrades are needed to the building envelope, electrical panels and wiring, and/or distribution systems. States and other stakeholders, notably members of NESCAUM's EJ Advisory Group, did not recommend incorporating a permanent "economic hardship" exemption to Model Rule 1.0. A broad exemption like this could create enforcement challenges, and permanently exempting compliance due to economic hardship could leave communities that would most benefit from air pollution reductions out of the transition to zero-emission technologies.

To address affordability challenges, states and stakeholders emphasize that ZEHES should not be implemented as a stand-alone policy, but rather should be paired with robust incentives and technical assistance to help building owners – particularly low-income households – transition to zero-emission technologies. Energy Solutions conducted economic analyses to compare equipment, installation, and operating costs between zero-emission technology and conventional equipment (key findings are reported in Section 11). Energy Solutions found many situations where zero-emission heating equipment is cost-competitive with non-compliant combustion equipment (particularly when comparing propane and fuel oil equipment to heat pumps), and that federal and state incentives can significantly improve cost comparisons in situations where zero-emission equipment is less competitive. Their analysis also indicates that, in some states, reforms to electricity and gas rates may be needed to ensure that customers transitioning to zero-emission options such as heat pumps do not experience higher operating costs. Other implementation considerations for Model Rule 1.0 are discussed in Section 8.

Policymakers can consider allowing for exemptions or additional time extensions on a state-by-state basis after soliciting stakeholder feedback. Potential areas where exemptions or extensions of time may be considered include off-grid installations or needed utility upgrades.

7. STAKEHOLDER INPUT ON MODEL RULE

Environmental Justice Advisory Group Input:

NESCAUM established an Environmental Justice Advisory Group (EJAG) in 2023 to advise and guide building electrification efforts. The EJAG is comprised of ten community, state, and national environmental justice and housing organizations that work in the Northeast and Mid-Atlantic. With support from our consultant Equnival Partners, NESCAUM obtained feedback from EJAG members on Model Rule 1.0 through both a group meeting and individual discussions. EJAG input and concerns included:

Exceptions & Exemptions:

While NESCAUM minimized the number and type of exemptions allowed in Model Rule 1.0, states may choose to incorporate their own exemptions, such as hardship waivers for high-cost installations. In general, EJAG members are concerned that exemptions would be exploited to avoid upgrading equipment in low-and-moderate-income residences and disadvantaged communities. For this reason, multiple EJAG members recommended that any exemptions should be temporary, and that states should accompany exemption approvals with referrals to resources to help residents and building owners overcome the barriers that necessitated the exemption. Based on EJAG feedback, NESCAUM suggests that states require any exemption requests to be accompanied by a plan to reach compliance, and that states should encourage building owners to plan in advance for conversion to zero-emission technologies, rather than waiting until an emergency replacement is needed.

Affordable Housing Compliance Delays:

As states consider exemptions, a member of NESCAUM's EJAG raised the issue of compliance delays for affordable housing. Decarbonizing multifamily housing can require electric panel upgrades and "heavy-ups" to increase electricity service to the building, which are costly and time-intensive. As such, heat pump installations may need to be aligned with recapitalization, when the affordable housing owner can access capital to make system-wide building upgrades and pay for the electric infrastructure upgrades. Electrical upgrades in multifamily housing, such as line extensions, can also require cooperation from utility companies, which can extend timelines beyond the property owner's control. One EJAG member suggested that longer compliance delays beyond the standard six-month delay should be allowed for affordable housing providers who meet certain conditions, such as if they:

- Demonstrate financial barriers to upgrading to a heat pump
- Are nonprofit-owned
- Have affordability restrictions in place
- Commit to replacing the gas system with a heat pump instead of electric resistance
- Submit a timeline for when they expect to be able to install a heat pump
- Justify why the delay is necessary

Beneficial Replacement:

EJAG members expressed concern over the potential for gas heating equipment to be replaced by inefficient electric resistance space and water heaters, which could significantly increase utility bills for residents.

Upcoming DOE efficiency standards for water heaters should mitigate some of this risk by making HPWHs, rather than electric resistance water heaters, the default option for most small electric water heaters installed after 2029. States can also address this concern through complementary policies to ZEHES, such as requirements for affordable housing owners to upgrade to heat pumps over electric resistance, creating energy bill caps for low-and-moderate income residents, increasing incentives to reduce the upfront cost of heat pumps, investing in workforce development to increase competition for heat pump installation contracts and drive down costs, and other policies that discourage electric resistance installations.

Funding:

Given that heat pumps can be more expensive to install than conventional alternatives, EJAG members emphasized the need for additional funding streams to support LMI households with the transition. Funding carveouts for target communities can help ensure that lower-income households are not left behind with increasingly outdated technology and rising utility bills.

Tradeoffs Between Equity and GHG Reduction Goals:

One EJAG member noted that states should be wary of targeting only the lowest-hanging fruit that is easiest and least expensive to decarbonize, as this can lead to inequitable outcomes. States should be aware of and consider the tensions between pursuing equity (which may take more resources) and attaining emission reduction goals.

Manufacturer Feedback

NESCAUM reviewed manufacturer feedback obtained during development of the RAP Model Rule for water heaters[136] and conducted additional manufacturer outreach to inform Model Rule 1.0. Below we provide a synthesis of manufacturer feedback and NESCAUM's response.

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[136]Seidman et al., 2023.

Table 3: Synthesis of Manufacturer Feedback

Manufacturer Comment	Response
DOE's definitions should be used to delineate equipment types. These are the default definitions used nationally and will be easier for market actors to understand and implement.	This feedback, provided by multiple manufacturers, has been incorporated into Model Rule 1.0.
Starting with residential equipment makes sense, since residential equipment is more market-ready than larger categories.	Model Rule 1.0 sets zero-emission limits for residential-scale equipment; future iterations may address commercial and industrial equipment as the market grows.
The Model Rule should only include ULN standards, with jurisdictions evaluating future increases in rule stringency after assessing the market, product availability, and other factors.	After commissioning technical and market cost studies on space and water heating systems, NESCAUM concluded that transitioning to zero-emission technology is generally technically and economically feasible for the size categories covered in Model Rule 1.0.
If the Model Rule must have zero-NOx standards, then it makes sense to only include zero-NOx and strike ULN. Adding ULN requirements when the market is ultimately transitioning to zero-NOx will force manufacturers to undergo burdensome and expensive supply chain changes for a temporary and modest benefit, and could be a distraction from the broader market transition to zero-emission technologies.	NESCAUM included ULN standards for water heaters in Model Rule 1.0 since several states have longstanding ULN standards and qualified product lists, so these technologies are already present in the water heater market and will help states attain near-term improvements in air quality. Model Rule 1.0 does not include ULN standards for furnaces based on input from manufacturers.
The Model Rule's draft size definition for storage water heaters also captures small commercial storage water heaters under 200,000 Btu/hr. The Model Rule should only set zero-emission limits for residential-scale equipment.	The Model Rule is designed to regulate residential-scale equipment utilized in any application, regardless of whether that application is residential or commercial. This caveat notwithstanding, we revised Category 3 water heater definitions to include zero-emission standards only for methane gas storage water heaters up to 105,000 Btu/hr (in addition to instantaneous water heaters up to 200,000 Btu/hr). Given the small number of oil and propane- light commercial storage water heaters, for simplicity's sake we did not adjust the size thresholds for Category 4 water heaters.

Manufacturer Comment	Response
The requirement that manufacturers maintain HVAC and water heater records for five years imposes a burdensomely long timeframe.	Record maintenance by manufacturers will enable states to accurately conduct monitoring, enforcement, and compliance.
Record-keeping and labeling requirements should align as closely as possible with South Coast AQMD requirements.	The labeling and recordkeeping requirements in Model Rule 1.0 are very similar those in South Coast AQMD's proposed Rules 1111 and 1112,[137] and reflect feedback from states.
It should be clarified that manufacturers may bring noncompliant equipment into an implementing state (i.e., in the case of warehouses), as long as they do not sell the equipment within that state.	This provision is made clear by the language, "No person shall sell or offer to sell, or lease or offer to lease, in JURISDICTION *for use* in JURISDICTION," used throughout Model Rule 1.0.
Because manufacturers cannot guarantee that previously certified but newly refurbished equipment complies with NOx certification standards, clarification should be added that refurbishers may not use the "Certification Status" of the original manufactured models and must apply for their own.	Model Rule 1.0 has been adjusted to make clear that it applies to both manufactured and refurbished equipment, and therefore refurbishers must also request certification.
If Category 1 and 2 water heaters have different compliance dates, customers may switch from one high-emissions heater to another, rather than to zero-emissions equipment.	Category 1 and 2 water heaters have the same compliance dates in Model Rule 1.0 to avoid creating this loophole.
A January 2029 compliance date for water heaters is too early, particularly given that the new DOE efficiency standards for water heaters will not take effect until May of 2029. Failing to align compliance timelines with DOE could result in significant stockpiling of electric resistance equipment before the DOE standard takes effect.	Model Rule 1.0 is designed to align with the most stringent state climate goals of net-zero emissions by 2045. To achieve this net-zero deadline, states need to begin phasing out emissions-producing equipment by 2029.

[137] South Coast AQMD, "Proposed Amended Rules (PAR) 1111 and 1121," accessed October 25, 2024.

Manufacturer Comment	Response
Replacement of gas-fired heating equipment with electric equipment may not provide desired emissions reductions if occurring in a region where electricity generation is not clean.	A National Renewable Energy Laboratory (NREL) study found that transitioning to air source heat pumps provides lifetime emissions reductions in all contiguous US states regardless of grid carbon-intensity scenario.[138] An RMI analysis using likewise found 39-91% reductions in operational emissions from converting gas water heaters to HPWHs in all contiguous US states.[139]
There should be separate requirements for equipment installed in new construction versus existing buildings.	NESCAUM, RAP, and Energy Solutions considered this issue. Given that new construction comprises a very small proportion of buildings, and that different requirements would create additional complexity for compliance and enforcement, Model Rule 1.0 does not differentiate between new construction and existing buildings.
Boilers should be addressed within this Model Rule, or a boiler Model Rule should be created with aligned compliance dates.	NESCAUM has included Category 1 boilers in Model Rule 1.0 with aligned compliance dates; larger boilers may be addressed in later phases of the rule.
Emission limits should apply to equipment manufactured after the compliance date, not sold after the compliance date. Allowing equipment manufactured before the compliance date to be stocked and sold after the compliance date will reduce supply chain disruptions.	Model Rule 1.0 incorporates this recommendation, which is consistent with the approach in BAAQMD's ZEHES regulation.

[138] Wilson et al. (2024), "Heat pumps for all? Distributions of the costs and benefits of residential air-source heat pumps in the United Statesv", *Joule* 8(4):1000-1035.
[139] Tan, L. & Teener, J., "Now Is the Time to Go All In on Heat Pumps", RMI, July 6, 2023.

8. IMPLEMENTATION CONSIDERATIONS

Community Engagement Best Practices:

States should engage in targeted stakeholder and community outreach to ensure an inclusive process for drafting an equipment emissions rule. WE ACT for Environmental Justice (WE ACT) released a Community Engagement Brief that details how governments can successfully partner with communities to design equitable policies.[140] States may wish to consult this and other stakeholder engagement guides as they design strategies for community outreach. Essential best practices highlighted in WE ACT's report include:

- **Identify all communities that might be impacted by a policy:** Create accessible platforms for communities to identify themselves as environmental justice (EJ) communities, and use EJ screening tools like US EPA's EJSCREEN to identify areas where people may be disproportionately impacted by environmental burdens.
- **Create a 'cohesive framework' for outreach:** Open communication with local communities early, utilize a variety of engagement strategies including community meetings, focus groups, advisory boards, and partnerships with community-based organizations, and develop a system of values and principles for collaboration.
- **Make community participation as easy as possible:** Schedule community meetings at convenient times and locations for community members, provide translation services and childcare, financially compensate individuals and participating organizations for their time, use multiple types of media in outreach, and give advance notice of public comment periods.
- **Be transparent regarding all community engagement exchanges:** Document and publish all interactions in a timely way, be clear about the outcomes of community engagement including why or why not recommendations were included in the final project, and properly credit those whose ideas were used.

Another best practice for community engagement that emerged through meetings with NESCAUM's EJAG was to pair discussions of ZEHES design and implementation with information and input-gathering on financial and technical assistance available to help LMI households, affordable housing providers, and others with limited financial means transition to zero-emission technologies. EJAG members also emphasized that states should specifically consult housing stakeholders during rule outreach, including affordable housing providers, housing owners, and tenants for both single and multi-family residences.

Case Study in Stakeholder Engagement: Washington, DC BEPS Task Force

The Washington, DC Department of Energy and Environment (DOEE) established a stakeholder Task Force to advise the development and implementation of its Building Energy Performance

[140] WE ACT for Environmental Justice, "Community Engagement Brief," September 23, 2022.

Standards (BEPS).[141] DC's BEPS Task Force process serves as a case study for the type of robust stakeholder engagement that states might consider when pursuing ZEHES adoption.

The BEPS Task Force consisted of stakeholders from a variety of backgrounds, including (but not limited to):

- Commercial building representative
- Rent-controlled apartment building representative
- Affordable housing developer
- Affordable housing operator
- Energy efficiency nonprofit
- Department of Housing & Community Development staff
- Green Finance Authority representative
- Energy utility representative

The BEPS Task force has met biweekly since 2019 to discuss BEPS program implementation and enforcement, resulting in a public report summarizing Task Force discussions and recommendations for the BEPS rule.[142] Meetings were open to the public, with meeting agenda, notes, slides, and video recordings posted for public access on the BEPS Task Force website. Through the Task Force, DOEE gathered recommendations from a variety of stakeholders who would be directly impacted by the BEPS rule, and also created more transparency over the considerations and decisions made during the rulemaking process.

In addition to the BEPS Task Force, DOEE partnered with National Housing Trust to engage frontline communities in the design of building electrification programs.[143] Their engagement model involved extensive partnership with community-based organizations (CBOs), and outreach targeted toward two affordable multifamily housing buildings. Engagement began with 'Power on the Block' events advertised through door knocking, event fliers, and communication through building service coordinators, which functioned as neighborhood block parties with information tables staffed by local community groups and an electrification team. At these events, the team recruited participants for small group discussions facilitated by CBOs, where residents voiced energy and climate change concerns, discussed the benefits of electrification, and shared information that DOEE should include (and subsequently did include) in their clean energy plan. The positive results of this case study can serve as a model for other jurisdictions looking to engage in similar work.

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[141] Washington, D.C. Department of Energy & Environment (DOEE), "BEPS Task Force," accessed October 4, 2024.
[142] Building Energy Performance Standards Task Force, "Recommendations for Rulemaking," October 15, 2020.
[143] McCullough, et al. (2024), "Power on the Block: Empowering Residents to Impact Community Change Through Electrification and Decarbonization," ACEEE Summer Study on Energy Efficiency in Buildings.

Program Implementation

States and other stakeholders recognize that ZEHES policies should not be implemented in a vacuum; they should be accompanied by other policies to support the market transition to zero-emission buildings and equipment. A 2024 policy brief co-authored by NESCAUM, RAP, and the Northeast Energy Efficiency Partnerships (NEEP) describes a comprehensive, state-based approach to building decarbonization, focusing on four policy areas:[144]

- Equity and workforce investments address housing and workforce inequities by increasing access to opportunities for historically marginalized communities and ensuring that the energy transition is just and inclusive.
- Carbon reduction obligations set performance requirements for obligated parties, such as energy providers, to reduce carbon emissions or install clean heating systems.
- Codes and standards like ZEHES establish a clear timetable for improving the emissions performance of buildings and equipment, spurring changes in the market.
- Utility planning and regulation sets mandates and frameworks to ensure that utility investment, rates, and programs align with building decarbonization goals.

Incentives and financing are particularly important to help building owners afford the higher upfront costs of many zero-emission technologies. While a federal tax credit is effective for some heat pumps installed through 2032,[145] states should strongly consider implementing incentive programs alongside ZEHES adoption. Strategies might include:

- Midstream incentives to wholesale distributors and retailers to defray any additional costs associated with ZEHES compliance;
- Expanded, easy-to-access federal, state, local, and utility incentives and tax credits for heat pumps, as well as associated upgrades such as electric panels and wiring;
- Inclusive financing (on-bill tariffs) that enables building owners to finance upgrades on their utility bills and pay for them, in whole or in part, out of the energy cost savings;
- One-stop-shop home upgrade hubs to provide wraparound financial and technical assistance to low-income households and affordable housing providers; and
- Additional upfront financial assistance for LMI households who may not have the upfront capital to invest in zero-emission technology and wait to receive the tax credit.

Many states may also consider reforms to electric and methane gas utility rates to ensure that customers that transition to zero-emission electric technologies do not face higher energy burdens. Options include establishing heat pump-friendly electric rate designs and undertaking “future of gas” planning.

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[144] NEEP, NESCAUM, and RAP, “Decarbonizing Buildings: How States Can Set the Table for Success, June 2024.

[145] US EPA ENERGY STAR, “Air Source Heat Pumps Tax Credit,” accessed October 4, 2024.

9. EMISSIONS REDUCTIONS

Heat pumps are a leading zero-emission technology and are likely to grow in market share after ZEHES implementation. Because they do not combust fuel, heat pumps do not directly emit air pollution while operating and will therefore improve local air quality.[146] While a common concern regarding electricity-based heat is that pollution will simply shift from on-site to power plant emissions, recent studies indicate that every state would see GHG emissions reductions if heat pumps were widely adopted – even under multiple electricity decarbonization scenarios.[147,148] Many NESCAUM member states have set targets for net-zero electricity by 2030-2045,[149] as well as corresponding goals for building electrification as a key decarbonization pathway.[150]

NESCAUM conducted a study on the emissions reduction potential associated with residential electrification for states in the Ozone Transport Commission (OTC) region, "Residential Building Electrification in the Northeast and Mid-Atlantic: Criteria Pollutant and Greenhouse Gas Reduction Potential" ("Emissions Reduction Potential Report").[151] The study estimates state-level changes in GHG and air pollutant emissions if the currently installed base of space and water heating equipment were replaced with high-efficiency electric heat pumps. The study does not specifically model the impacts of adopting Model Rule 1.0 or any other ZEHES regulation. Rather, it illustrates the magnitude of emissions reduction that could be achieved in each OTC state if all homes transitioned to zero-emission appliances.

The study involved the following steps to assess changes in NOx, PM2.5, CO2, and SO2 under several electrification scenarios:

1. Utilize NREL's 2022 ResStock[152] tool to obtain energy consumption outputs (in kWh) for each state under four different scenarios:[153]
    a. **Baseline:** Building appliance characteristics in the housing stock in 2018.

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[146] IEA 2022.
[147] Wilson et al. (2024), "Heat pumps for all? Distributions of the costs and benefits of residential air-source heat pumps in the United States", *Joule* 8(4):1000-1035.
[148] Tan, L. & Teener, J., "Now Is the Time to Go All In on Heat Pumps", RMI, July 6, 2023.
[149] Maryland Department of the Environment, "Maryland's Climate Pollution Reduction Plan", December 28, 2023; State of Rhode Island, "Governor's Climate Priorities", August 23, 2023; New York State Energy Research & Development Authority, "Greenhouse Gas Emissions Reductions", accessed June 27, 2024; Maine Governor's Energy Office, "Maine Energy Plan: Pathway to 2040", accessed June 27, 2024.
[150] State of Massachusetts, "Massachusetts Clean Energy and Climate Plan for 2025 and 2030," June 30, 2022; Maryland Commission on Climate Change, "Building Energy Transition Plan," November 2021; Office of Governor Janet T. Mills, "After Maine Surpasses 100,000 Heat Pump Goal Two Years Ahead of Schedule, Governor Mills Sets New, Ambitious Target," July 21, 2023.
[151] NESCAUM, "Residential Building Electrification in the Northeast and Mid-Atlantic: Criteria Pollutant and Greenhouse Gas Reduction Potential", August 2023.
[152] NREL, "ResStock Analysis Tool", accessed July 3, 2024.
[153] NREL, "End-Use Savings Shapes: Residential Round 1 Technical Documentation and Measure Applicability Logic," accessed September 18, 2024.

   b. **Heat Pump Water Heaters:** Assumes all water heaters are converted to heat pump technology except for electric tankless water heaters.
   c. **Air-Source Heat Pumps**: Assumes all heating systems – including those using electric resistance – and air conditioners are converted to high-efficiency, variable speed ducted or ductless mini-split heat pumps.
   d. **Whole Home Electrification:** Combines HPWH and ASHP scenarios with heat pump dryers and electric oven ranges for all households; does not include any weatherization or other building envelope measures.
2. Convert ResStock energy consumption outputs from kWh to fuel volumes and apply EPA's AP-42 emission factors[154] to estimate pounds of air pollutant per gallon or million cubic feet (mmcf) of fossil fuel used for heating.
3. Estimate power plant emissions from electricity consumption for each scenario using EPA's eGRID[155] and three regional Independent System Operator (ISO) emission factors for PM2.5, NOx, and SO2;[156] estimates were made using emissions factors based on energy mixes for the current grid and an anticipated future grid (90% emissions reductions compared to 2023 by 2045, based on OTC state decarbonization goals).

NESCAUM calculated state-by-state net annual emissions reductions that would be achieved for each electrification scenario under current and future energy grids, including changes to on-site and power plant-related emissions. Emissions reductions do not account for avoided emissions from the production, refining, and delivery of combustion fuels. Virginia, Maryland, Delaware, and Washington, DC showed decreases in overall electricity consumption after converting space heating to heat pumps due to the high prevalence of air conditioning and inefficient electric resistance heating in the baseline in those jurisdictions.

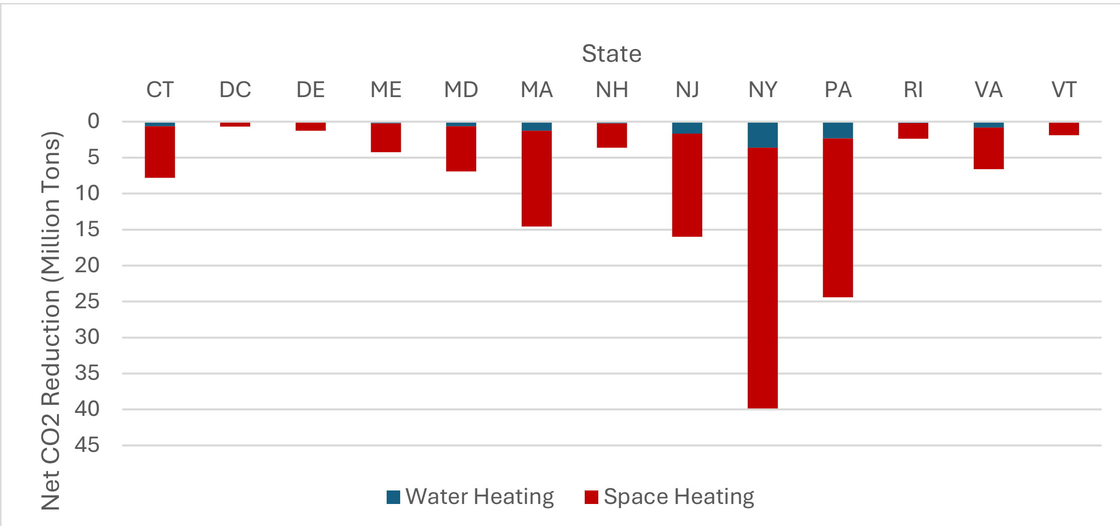
Figures 1 and 2 illustrate emissions reduction potential under space and water heating electrification scenarios – the two scenarios most relevant to Model Rule 1.0. Figures 1 and 2 highlight emissions reductions under a future grid scenario to demonstrate the annual emissions reductions if space and water heating were fully converted to heat pumps. The vast majority of emissions savings come from reductions in on-site fossil fuel combustion; the full report shows that all states experienced emissions reductions under both current and future energy grid scenarios.[157]

Results show that space heating electrification yields nearly ten times the emissions reductions as water heating. Variation in reductions potential is due to factors such as population size, state grid emissions, and proportion of electric resistance heaters. New York, New Jersey, and Pennsylvania have the greatest emissions reduction potential for CO2 and

[154] US EPA, "AP-42: Compilation of Air Emissions Factors from Stationary Sources," last updated August 15, 2024.
[155] US EPA, "Emissions & Generation Resource Integrated Database (eGRID)," last updated July 24, 2024.
[156] ISO New England, ISO New York, Pennsylvania, New Jersey, Maryland (PJM).
[157] NESCAUM, "Emissions Reduction Potential Report."

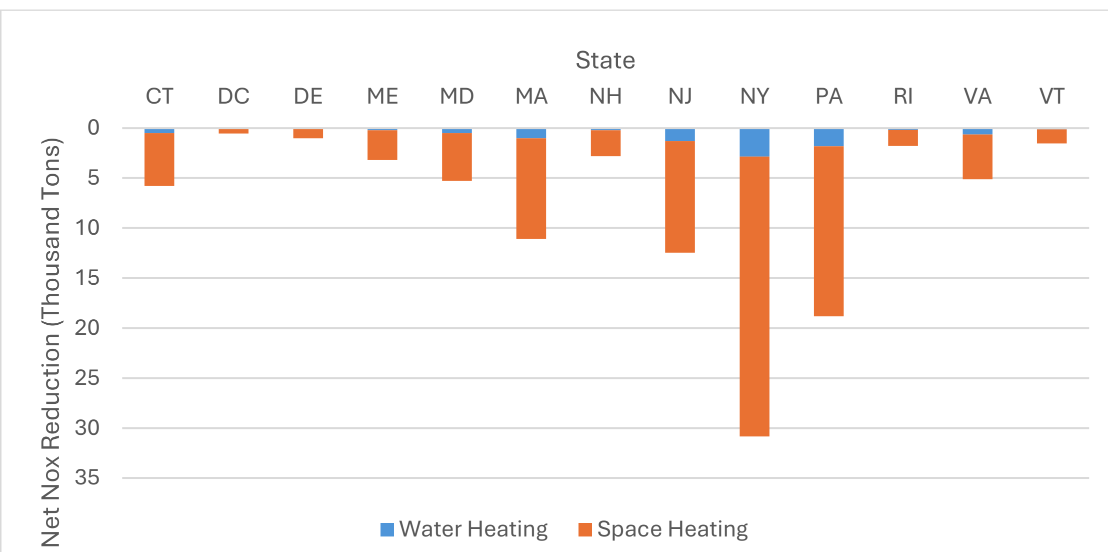
NOx, while Washington, DC and Delaware have the lowest emissions reduction potential, because of their small population sizes. If every state in the OTC completely converted to zero-emission heat pump technology for residential space and water heating, for example by implementing a ZEHES regulation until the entire stock of space and water heaters turns over, the Northeast and Mid-Atlantic region would avoid approximately 130 million tons of CO2 and 100,000 tons of NOx each year.

Figure 1. State-by-State Net Annual CO2 Reductions Under Water and Space Heating Electrification Scenarios and a Future Electricity Grid*



* Estimated emissions reductions associated with electrification of space and water heating under a future grid (90% reduced emissions by 2045). For raw numbers, refer to the Emissions Reduction Potential Report.

Figure 2. State-by-State Net Annual NOx Reductions Under Water and Space Heating Electrification Scenarios and a Future Electricity Grid*



*Estimated emissions reductions associated with electrification of space and water heating under a future grid (90% reduced emissions by 2045). For raw numbers, refer to the Emissions Reduction Potential Report.

NESCAUM also modeled the emissions reduction potential for a simplified phase-in scenario where all homes electrify gradually over a 15-year period. The model assumes a linear rate of equipment turnover from 2030-2045, alongside linear electricity decarbonization to 90% reduced grid emissions (compared to 2023) by 2045. Figures 3 and 4 show annual emissions reduction potential cumulative across the Ozone Transport Commission region (OTR) in this phase-out scenario.

Figure 3. Annual CO2 Reductions in the OTR Assuming Replacement of Space and Water Heating Equipment at End of Useful Life

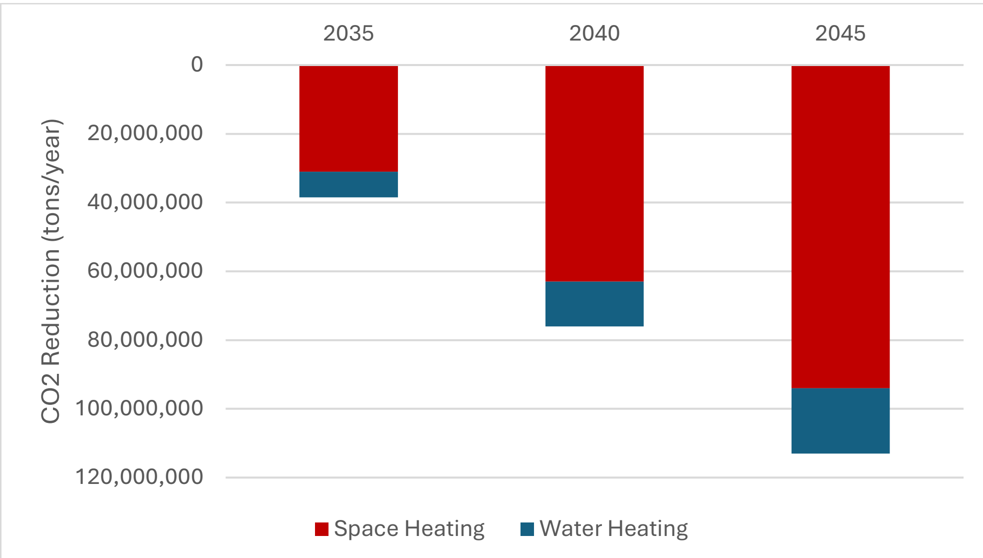
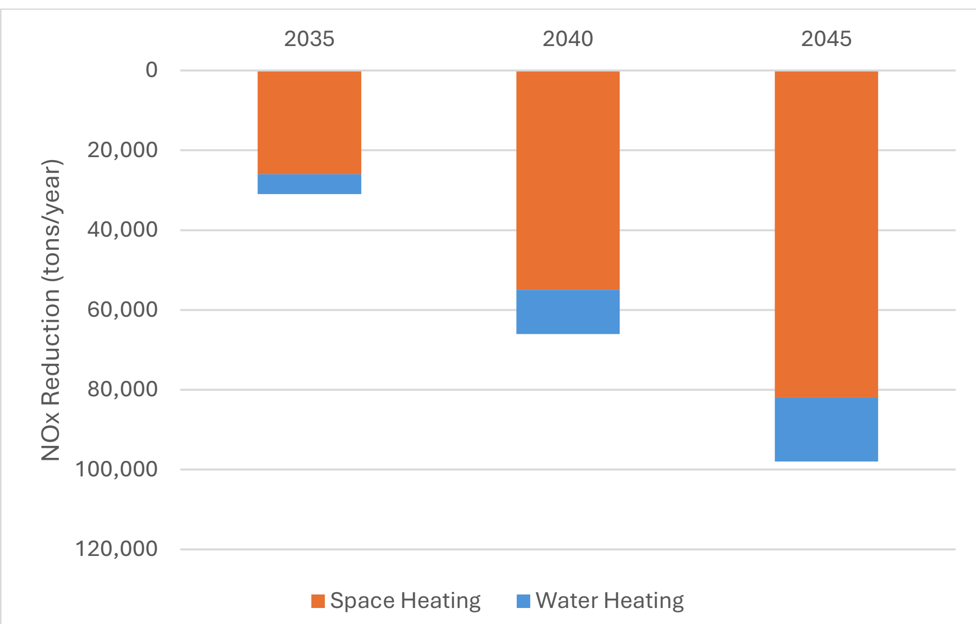


Figure 4. Annual NOx Reductions in the OTR Assuming Replacement of Space and Water Heating Equipment at End of Useful Life



Based on these estimates, a linear phase-in of electric space and water heating in the OTR starting in 2030 could save around 30,000 tons of NOx and nearly 40,000,000 tons of CO2 each year by 2035, with annual reductions significantly increasing in magnitude until full electrification.

10. HEALTH IMPACTS SCREENING

After estimating emissions reductions from space and water heating electrification, NESCAUM used the EPA Co-Benefits Risk Assessment Health Impacts Screening & Mapping Tool (COBRA)[158] to translate those reductions into potential health benefits.

COBRA was developed by EPA to help states and municipalities explore the health impacts and associated monetary benefits of clean energy programs.[159] NESCAUM used COBRA 4.1, which models changes in primary PM2.5 emissions and secondary PM2.5 formation,[160] and converts those changes to health endpoints and associated monetary sums.[161] Data sources for economic values include cost of treatment for illnesses, hospital charges, median annual earnings lost due to illness, and the value of a statistical life.[162] COBRA is designed for use as a screening tool[163] and has been applied in multiple peer-reviewed studies to estimate the potential impacts of clean energy policies.[164]

NESCAUM ran state-by-state COBRA models for the same emissions scenarios as the Emissions Reduction Potential Report: water heating electrification, space heating electrification, and whole-home electrification. We aggregated health benefits from 2030-2045, assuming state-by-state linear adoption of clean energy to 90% reduction in electricity emissions by 2045 based on OTC state goals to reach net-zero by 2045-2050, and linear phase-in of electrification through 2045 (as shown for the OTR in Figures 3 and 4). As such, NESCAUM's COBRA analysis provides a rough estimate of the total health benefits

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[158] US EPA, "Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)", last updated April 24, 2024.
[159] US Environmental Protection Agency, "What is COBRA?", April 23, 2024.
[160] US Environmental Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA): Version 5.1", June 2024.
[161] *Ibid*.
[162] US Environmental Protection Agency, "Estimating the Co-Benefits of Clean Energy Policies", accessed June 28, 2024.
[163] US EPA, "Why Use COBRA?", August 24, 2024.
[164] Thomson, V., et al. (2018), "Coal-fired power plant regulatory rollback in the United States: Implications for local and regional public health", *Energy Policy* 123: 558-568; Thomson, V., et al. (2018), "Coal-fired power plant regulatory rollback in the United States: Implications for local and regional public health", *Energy Policy* 123: 558-568; Hou, L., et al. (2016), "Public Health Impact and Economic Costs of Volkswagen's Lack of Compliance with the United States' Emission Standards", *Int. J. Environ. Res. Public Health* 13(9): 891; Mailloux, N., et al. (2022), "Nationwide and Regional PM2.5-Related Air Quality Health Benefits From the Removal of Energy-Related Emissions in the United States", *GeoHealth* 6(5): e2022GH000603.

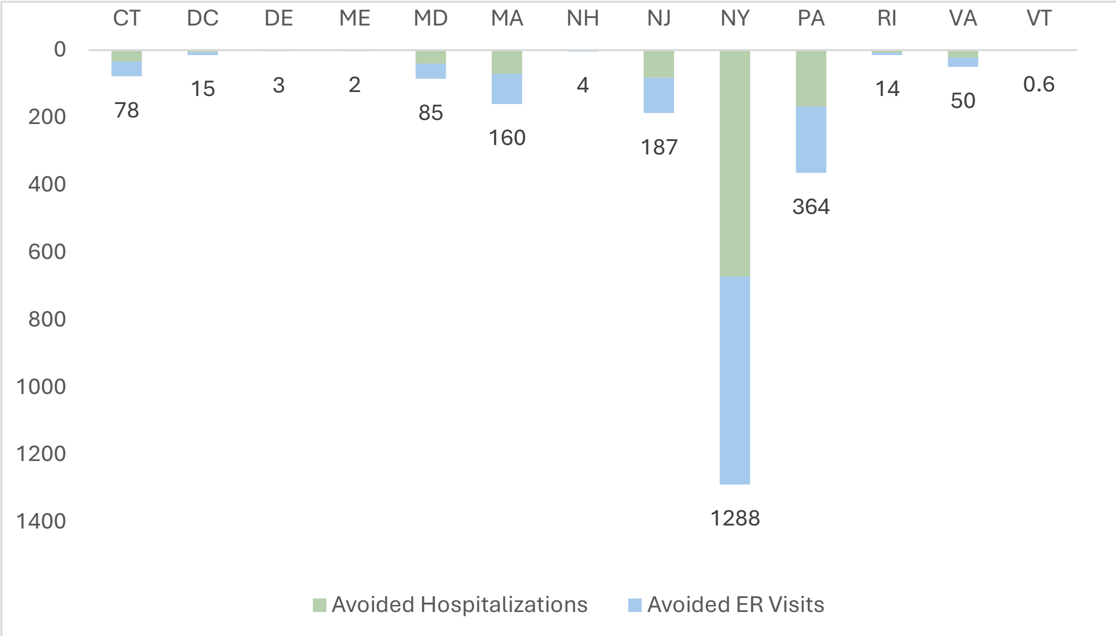
accumulated over a 15-year linear transition from current space and water heating equipment to 100% heat pump technology.

Because the version of COBRA used in NESCAUM's analysis only accounts for secondary PM2.5 formation, we were not able to estimate the health benefits associated with reducing secondary ozone formation. As such, our results represent a conservative estimate of potential health benefits from electrification. In the future, NESCAUM plans to rerun the analysis with both a newly released COBRA 5.0 model that includes ozone impacts, as well as recent updates to EPA's AP-42 emissions factors.[165]

Figures 5 through 8 show COBRA modeling results for cumulative avoided premature deaths, cardiovascular and respiratory-related emergency room visits, hospitalizations, and work loss days over the 2030-2045 period. COBRA provides a high and low estimate based on the literature for mortality, so our mortality and cost estimates show a range of benefits for each state. NESCAUM's estimates combine avoided health incidents associated with both space and water heating and assume that residential buildings in each state have fully electrified space and water heating by 2045. Health benefit potential is driven by factors including population size, age, and density. All states showed some amount of health improvement and associated economic value from electrification. New York, which could experience the greatest benefit, could avoid up to 4,000 premature deaths and $47 billion in associated monetary benefit; Vermont, with the smallest population, yielded the smallest benefit, but still achieves $21-47 million worth of estimated economic health value from 2030-2045. See Appendix B for full COBRA result tables for each OTC state.

[165] US EPA, "AP-42: Compilation of Air Emissions Factors from Stationary Sources," last updated October 18, 2024.

Figure 5. State number of emergency incidents avoided from 2030-2045 through space and water heating electrification*



*Data labels indicate total avoided incidents (sum of hospitalizations and ER visits)

Figure 6. State number of work loss days avoided from 2030-2045 through space and water heating electrification

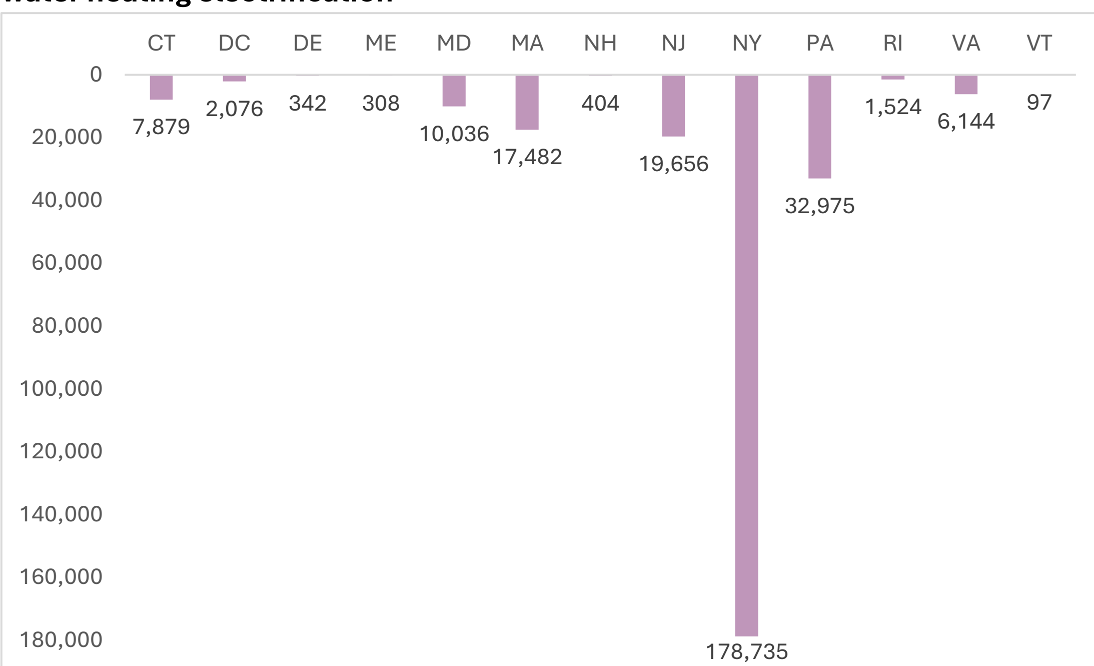
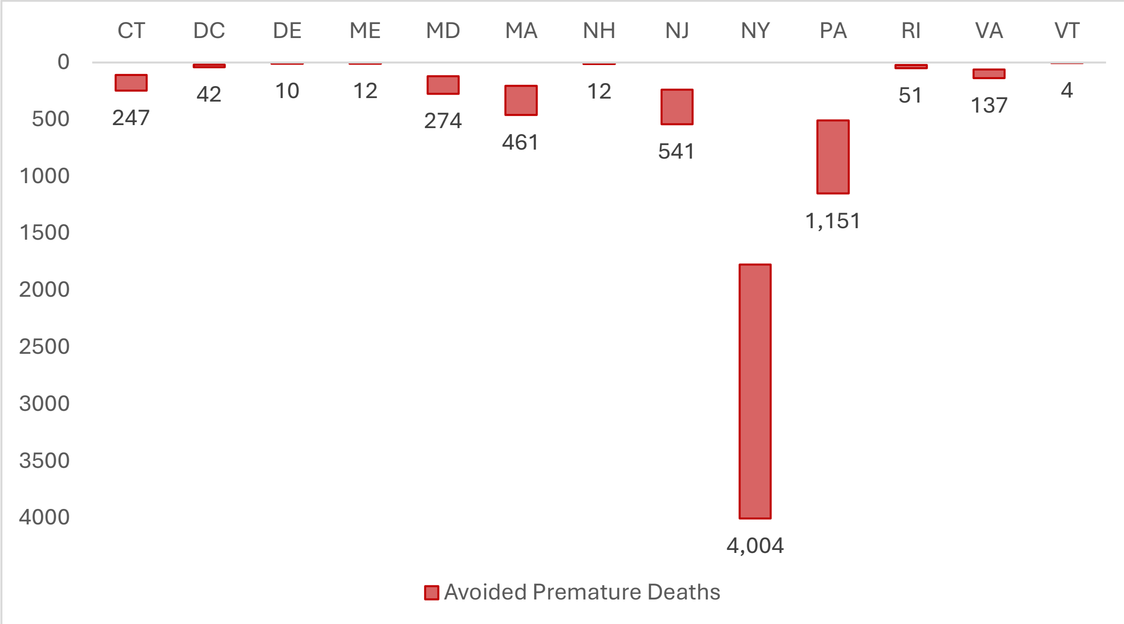
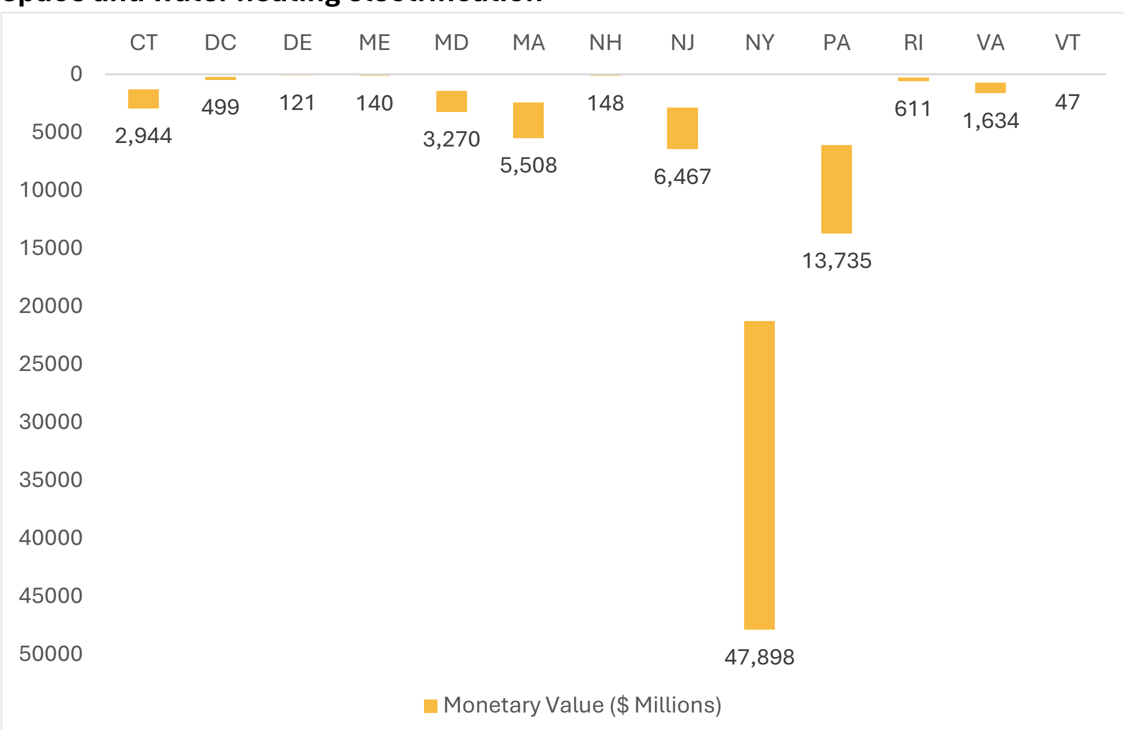


Figure 7. State ranges for number of deaths avoided from 2030-2045 through space and water heating electrification*



*Data labels show maximum number of avoided premature deaths.

Figure 8. State monetary value ranges for avoided health harms from 2030-2045 through space and water heating electrification*



*Data labels show maximum monetary value.

11. COST ANALYSIS

While zero-emission technologies like ASHPs and HPWHs may cost less to operate than conventional technology, they are typically more expensive upfront than conventional HVAC and water heating equipment. Additionally, upgrading to zero-emission technologies can involve other home upgrades that significantly increase installation costs, such as electric panel upgrades to accommodate increased load. NESCAUM commissioned two economic and market analyses to assess installation and operating costs and market trends for water heater and HVAC equipment installations in the Northeast and Mid-Atlantic.

Heat Pump Water Heaters:

Energy Solutions conducted a study assessing the cost impacts and market trends associated with water heater installations in the Northeast and Mid-Atlantic.[166] Energy Solutions used data from the US Department of Energy (DOE), New Buildings Institute, the US Energy Information Agency (EIA), and manufacturer interviews to analyze average equipment, labor, and operating costs associated with different types of water heaters.

Equipment assessed included methane gas storage, methane gas tankless, propane storage, fuel oil storage, electric resistance storage, electric 120V HPWHs, and electric 240V HPWHs.[167] For OTC states, Energy Solutions then generated state-by-state estimates of total installation (equipment plus labor) and operating costs for each equipment type, and compiled state and federal incentives currently available for HPWH installations.

Installation and Operating Costs:

Tables 4 and 5 show the total installation and operating costs estimated by Energy Solutions for water heaters in each state. These costs are best estimates and are subject to change over time. Overall, HPWHs are more expensive upfront than all conventional equipment except for fuel oil storage water heaters, with panel upgrades adding an additional ~$2,000 in installation costs for 240-volt HPWHs, when needed. With a 30% federal tax credit[168] and the minimum available rebate available in each state, HPWH installation costs approach parity with gas tankless water heaters, but remain significantly higher than gas storage, electric resistance, and propane water heaters.

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166 Booth, K., and Fosberg, C., "Heat Pump Water Heaters in the Northeast and Mid-Atlantic: Costs and Market Trends", June 17, 2024.
167 Booth 2024.
168 ENERGY STAR, "Heat Pump Water Heaters Tax Credit," Accessed October 24, 2024.

Table 4. State-by-State Total Installation Cost for Water Heating Equipment*

State	Methane Gas & Propane Storage	Methane Gas Tankless	Electric Resistance Storage	Fuel Oil Storage	120V HPWH		240V HPWH		
					No Incentive	With Incentive	With Panel Upgrade	No Panel Upgrade	No Panel Upgrade with Incentive
CT	$912	$1,278	$920	$3,254	$3,473	$1,681	$5,926	$3,321	$1,575
DC	$899	$1,255	$913	$3,254	$3,486	$1,740	$5,723	$3,276	$1,593
DE	$835	$1,154	$859	$3,116	$3,363	$1,654	$5,058	$3,042	$1,429
ME	$791	$1,093	$814	$2,954	$3,189	$1,282	$4,793	$2,884	$1,069
MD	$796	$1,097	$821	$2,990	$3,233	$1,563	$4,764	$2,899	$1,329
MA	$927	$1,303	$932	$3,282	$3,495	$1,697	$6,100	$3,377	$1,614
NH	$822	$1,139	$842	$3,040	$3,274	$1,542	$5,052	$2,995	$1,347
NJ	$973	$1,375	$970	$3,382	$3,584	$1,759	$6,568	$3,543	$1,730
NY	$1,072	$1,529	$1,056	$3,618	$3,804	$1,963	$7,533	$3,904	$2,033
PA	$916	$1,286	$922	$3,253	$3,468	$2,078	$5,997	$3,337	$1,986
RI	$901	$1,261	$912	$3,240	$3,464	$2,275	$5,798	$3,284	$2,149
VT	$783	$1,081	$807	$2,933	$3,168	$1,918	$4,719	$2,854	$1,698
VA	$756	$1,035	$788	$2,899	$3,149	$1,804	$4,375	$2,756	$1,529

*Costs include equipment and labor. Sliding scale of green (least expensive) to red (most expensive).

The cost calculus changes when looking at operating costs. Due to their higher energy efficiency, HPWHs are less expensive to operate on average in every state, compared to every type of baseline water heating equipment included in the analysis. Table 5 shows annual operating costs for water heating equipment, as calculated by Energy Solutions.

Table 5. State-by-State Annual Operating Costs for Water Heating Equipment*

State	Methane Gas Storage	Methane Gas Tankless	Electric Resistance Storage	Propane Storage	Fuel Oil Storage	120V HPWH	240V HPWH
CT	$289	$207	$553	$668	$500	$159	$152
DE	$214	$154	$288	$559	$502	$83	$79
DC	$228	$163	$336	$532	$460	$97	$92
ME	$365	$261	$471	$662	$544	$136	$129
MD	$246	$176	$319	$564	$488	$92	$88
MA	$327	$234	$585	$643	$519	$168	$161
NH	$351	$251	$569	$729	$562	$164	$156
NJ	$187	$134	$400	$570	$508	$115	$110
NY	$272	$195	$515	$640	$562	$148	$141
PA	$237	$170	$304	$531	$497	$87	$83
RI	$283	$203	$551	$659	$496	$158	$151
VT	$269	$192	$543	$679	$551	$156	$149
VA	$231	$166	$252	$545	$458	$72	$69

*Sliding scale of green (least expensive) to red (most expensive).

Net Present Value (NPV):

Despite higher upfront costs, the average 240-volt HPWH can save customers money over its lifetime depending on the equipment type it replaces (Table 6). NESCAUM utilized Energy Solutions' installation and cost estimates to calculate the net present value of purchasing a HPWH instead of a conventional water heater. We applied a 2% discount rate[169,170] and assumed a 12-year lifespan[171] for all water heating equipment types using the following formula:

$$Net\ Present\ Value = \sum \frac{Annual\ Operating\ Savings}{(1 + Discount\ Rate)^t} - Initial\ Investment$$

Where:

- Annual Operating Savings = Operating savings (or costs) of running a HPWH instead of a conventional water heater
- Discount Rate = 2%
- Initial Investment = Installation cost difference between a HPWH and a conventional water heater
- t = Year after installation

These calculations are inherently limited by the assumptions used by Energy Solutions to estimate state-by-state installation and operating costs, including but not limited to groundwater temperature, fuel prices, and heating loads.[172] In particular, our calculations for lifetime operating savings do not include potential changes in electricity or methane gas prices over time. As such, we do not account for future increases in heat pump operating cost savings due to potential rises in methane gas prices as the gas customer base declines over time.[173] Additionally, this analysis does not account for incentives, which could vary over time.

With these caveats, NESCAUM found that the average HPWH without electrical upgrades provides positive net present value in all states when replacing oil and propane water heaters, and in all states except Delaware, Pennsylvania, and Rhode Island when replacing electric resistance water heaters. A HPWH could save customers around $3,000 to $4,000 over its lifetime compared to a fuel oil water heater, and around $400 to $2,000 compared to an electric resistance water heater. However, with current fuel prices, HPWHs generally cost more over their lifetimes compared to methane gas water heaters. Our estimates only show lifetime

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[169] Based on White House Office of Management & Budget recommended annual discount rate of 2% "to compare costs and benefits that are experienced at different points in time".
[170] US EPA, "Supplementary Material for the Regulatory Impact Analysis for the Final Rulemaking, 'Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review'", November 2023.
[171] NREL, "National Residential Efficiency Measure Database Lifetime of Heat Pump Measures," accessed October 28, 2024.
[172] Booth et al. 2024, "Heat Pump Water Heaters in the Northeast and Mid-Atlantic".
[173] Nadel, S. (2023), "Impact of Electrification and Decarbonization on Gas Distribution Costs," ACEEE.

savings for HPWHs compared to gas storage water heaters in Maine. However, cost differences remain relatively low, with lifetime HPWH costs relative to methane gas water heaters remaining below $2,000 in all states. Currently available federal and state incentives can close this gap in most scenarios.[174]

Table 6: 12-Year Net Present Value of Purchasing a 240-Volt Heat Pump Water Heater (No Electrical Upgrade, No Incentives) Compared to Baseline Water Heaters*

State	Methane Gas Storage Water Heater	Methane Gas Tankless Water Heater	Electric Resistance Storage Water Heater	Propane Storage Water Heater	Fuel Oil Storage Water Heater
CT	-$960	-$1,461	$1,840	$3,048	$3,613
DE	-$632	-$1,228	-$153	$2,699	$4,199
DC	-$769	-$1,137	$397	$2,446	$4,184
ME	$403	-$395	$1,547	$3,544	$3,604
MD	-$432	-$871	$365	$2,931	$4,072
MA	-$694	-$1,302	$2,039	$2,647	$3,975
NH	-$111	-$851	$2,215	$3,887	$3,478
NJ	-$1,756	-$1,914	$494	$2,295	$4,007
NY	-$1,447	-$1,804	$1,107	$2,445	$3,970
PA	-$792	-$1,131	-$78	$2,317	$4,163
RI	-$987	-$1,473	$1,858	$2,989	$4,112
VT	-$802	-$1,318	$2,120	$3,534	$3,339
VA	-$287	-$695	-$33	$3,034	$3,927

*Calculations assume a 12-year equipment lifespan, 2% discount rate, and 2022-2023 EIA state average fuel prices. Green represents highest savings from HPWHs, red represents net loss compared to using alternative equipment. No incentives are included in this analysis.

Heat Pump Space Heaters:

The cost calculus for heat pump space heaters is more complex than for HPWHs due to the greater number of available HVAC technologies and comparison permutations. Assuming current fuel and electricity prices, heat pumps installed without incentives are likely to save customers money over their lifetime compared to oil and propane heating but cost more over their lifetime compared to methane gas heating. Heat pumps become more cost-effective when adding the installation and operating costs of central AC, since in many cases heat pump retrofits can involve going from two separate systems (a furnace plus an AC) to a single piece of equipment that provides both heating and cooling. Future changes in methane gas and electricity rates could significantly impact this operating cost analysis.

[174] For example, an RMI report found cost savings under all replacement scenarios when accounting for incentives in Maryland (RMI, "Heat Pumps Can Lower Energy Bills in Maryland Today," June 4, 2024).

NESCAUM commissioned a cost study for common residential HVAC system types in Northeast and Mid-Atlantic states from Energy Solutions. Energy Solutions utilized publicly available data sources to estimate average installation and operating costs for several different heat pump space heater installations compared to conventional equipment.[175] They also conducted market interviews with manufacturers, distributors, and contractors to understand current and future market trends for residential heat pumps.

The cost analysis looked at systems that provide whole-home heating without the need for backup or supplemental heat. Home heating loads vary based on size, vintage, and climate zone, so real-world installations of heat pumps may use a variety of system configurations and combinations to meet heating loads. For consistency and comparison across equipment types, all equipment costs were normalized to an energy output of 65,000 Btu/h to facilitate fair comparisons. Equipment types assessed in Energy Solutions' analysis include:

Baseline HVAC Equipment

- Furnace: Ducted air system powered by methane gas, fuel oil, or propane.
- Boiler: Hydronic heating system that distributes warm water, powered by methane gas, propane, or fuel oil.
- Electric Resistance Heater: Electric resistance-based heat transmitting warmth through a baseboard distribution system.
- Air Conditioner: Split unitary central AC that distributes cooling via ductwork.

Heat Pump Space Heaters

- Split Unitary Heat Pump: Ducted heat pump with an outdoor condensing unit and indoor air handler.
- Packaged Unitary Heat Pump: Ducted heat pump with outdoor condensing unit and integrated air handler.
- Ducted Mini-Split Heat Pump: Ducted single-zone heat pump with a slim-profile condensing unit.
- Ductless Multi-Split Heat Pump: Ductless three-zone heat pump with a slim-profile condensing unit and multiple indoor evaporators.
- Air-to-Water Heat Pump: Heat pump that distributes warm water through low-temperature hydronic distribution system.

Energy Solutions did not consider cold-climate heat pumps in their analysis; these results reflect standard-efficiency heat pumps. While cold-climate heat pumps can cost more upfront

[175] Booth, K., et al., "Heat Pumps in the Northeast and Mid-Atlantic: Costs and Market Trends," October 30, 2024.

than standard-efficiency heat pumps, they operate more efficiently at cold temperatures and could yield greater lifetime savings for customers living in colder states.[176]

Energy Solutions' analysis also considered the impact of distribution system installations (e.g., new ductwork), electricity panel upgrades, and AC installation and operation on overall costs. On average, when needed, electrical panel upgrades increased heat pump installation costs by $2,400 and ductwork increased installation costs by $4,500. The full report details state-by-state cost estimates for all these permutations (and includes an Operating Cost Calculator where users can generate operating cost estimates for specific heating scenarios).

In this section, NESCAUM summarizes average state-by-state results for common heating scenarios in the Northeast and Mid-Atlantic.

Installation and Operating Costs:

Tables 7 and 8 show average installation (equipment and labor combined) and operating costs for fossil fuel-based furnaces and boilers, electric resistance baseboard heaters, and one type of each of ductless and ducted heat pumps. We selected a 3-zone multi-split as the ductless option to highlight, given that most whole-home heating retrofits will require multiple zones, and because this represents a more conservative approach than a single-zone multi-split. We selected a ducted split unitary heat pump as the central heating option, as they are much more common than packaged unitary heat pumps in residential homes.[177]

Installation and operating costs are shown for heating systems plus central AC, as costs associated with a single furnace would not be an apples-to-apples comparison given heat pumps' ability to provide both heating and cooling. Cooling capacity in homes is becoming an increasingly urgent comfort and health requirement as the Northeast experiences rising summer heat due to climate change.[178]

Table 7 shows installation costs for each baseline equipment type with central AC (see Appendix C for tables without central AC), and ASHP installation costs with and without panel upgrades (residents with sufficient panel capacity or who have already upgraded their panel for a HPWH will not need this step). In this table, we assume pre-existing compatible distribution systems, so the cost of installing ductwork or a hydronic distribution system is not included. Results show that 3-zone ductless multi-splits are the most expensive to install by far, ranging from around $16,400-$22,000 with panel upgrades in all states. While fossil fuel-based furnaces and boilers are the cheapest to install overall and cost less than $10,000 in every state (with AC), ducted heat pump systems can become cost-competitive when accounting for federal and state incentives.

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[176] Wilson et al. (2024), "Heat Pumps for All? Distributions of the costs and benefits of residential air-source heat pumps in the United States," *Joule* 8, 1000-1035.
[177] Booth 2024, "Heat Pumps in the Northeast and Mid-Atlantic, Costs and Market Trends".
[178] US EPA, "Climate Impacts in the Northeast," accessed October 28, 2024.

Table 7. State-by-State Total Installation Costs for Select Space Heating Equipment With AC, Assuming Compatible Distribution Systems (No Incentives)*

State	Ducted Methane Gas or Propane Furnace	Hydronic Methane Gas or Propane Boiler	Hydronic Oil Boiler	Electric Resistance	Ducted Split Unitary HP (Panel Upgrade)	Ducted Split Unitary HP (No Panel Upgrade)	3-Zone Ductless Minisplit (Panel Upgrade)	3-Zone Ductless Minisplit (No Panel Upgrade)
CT	$8,255	$8,133	$8,067	$10,750	$12,317	$9,605	$19,074	$16,463
DC	$7,558	$7,457	$7,409	$9,905	$11,348	$9,263	$17,469	$15,383
DE	$8,145	$8,027	$7,966	$10,626	$12,174	$9,618	$18,587	$16,337
ME	$7,379	$7,280	$7,234	$9,672	$11,080	$9,056	$17,051	$15,026
MD	$7,355	$7,259	$7,216	$9,655	$11,061	$9,138	$16,974	$15,051
MA	$8,325	$8,198	$8,128	$10,821	$12,398	$9,530	$19,367	$16,500
NH	$7,547	$7,444	$7,395	$9,883	$11,322	$9,192	$17,452	$15,322
NJ	$8,637	$8,499	$8,420	$11,193	$12,826	$9,641	$20,140	$16,955
NY	$9,388	$9,230	$9,133	$12,115	$13,883	$10,087	$21,967	$18,171
PA	$8,159	$8,038	$7,970	$10,620	$12,168	$9,448	$18,962	$16,242
RI	$8,233	$8,113	$8,048	$10,731	$12,294	$9,644	$19,112	$16,462
VT	$7,395	$7,295	$7,249	$9,690	$11,101	$9,049	$17,094	$15,042
VA	$7,140	$7,051	$7,015	$9,401	$10,768	$9,072	$16,440	$14,743

*Total installation costs include AC installation, assume an existing compatible distribution system, and exclude incentives. Red represents higher total installation costs, green represents lower total installation costs.

Table 8 shows average annual operating costs for the same equipment types featured in Table 7. Operating costs for ASHPs are lower than oil, propane, and electric resistance alternatives in every state, regardless of AC use. With current electricity and gas rates, heat pumps reach price parity with methane gas furnaces and boilers in a handful of jurisdictions (Washington DC, Maryland, Pennsylvania, and Virginia), but remain generally more expensive to operate in other states. Table 8 represents a snapshot in time dependent on current electricity and methane gas prices, and these differences may change as energy prices evolve.

Table 8. State-by-State Average Annual Operating Costs for Select Space Heating Equipment Plus Central AC*

State	Methane Gas Furnace & Boiler	Oil Boiler	Propane Furnace & Boiler	Electric Resistance	3-Zone Ductless Minisplit	Ducted Split Unitary HP
CT	$1,658	$2,674	$2,955	$4,768	$2,100	$2,375
DC	$1,646	$2,834	$2,759	$2,679	$1,244	$1,406
DE	$1,139	$3,019	$2,838	$2,740	$1,229	$1,390
ME	$1,954	$4,057	$4,142	$6,910	$2,843	$3,220
MD	$1,683	$2,677	$2,605	$2,701	$1,229	$1,389
MA	$2,440	$3,575	$3,706	$6,663	$2,825	$3,197
NH	$1,384	$3,022	$3,269	$5,604	$2,351	$2,662
NJ	$1,209	$2,494	$2,364	$2,968	$1,310	$1,482
NY	$1,537	$2,759	$2,647	$4,414	$1,885	$2,134
PA	$1,799	$2,917	$2,654	$3,325	$1,531	$1,729
RI	$1,828	$3,567	$3,919	$5,858	$2,612	$2,953
VT	$1,655	$4,114	$4,251	$6,168	$2,579	$2,920
VA	$1,470	$2,794	$2,787	$2,766	$1,216	$1,376

*Annual operating costs including AC operation. Red represents higher annual operating costs, green represents lower annual operating costs.

Net Present Value:

Similar to our analysis for HPWHs, NESCAUM used Energy Solutions' installation and operating cost results to estimate the lifetime value of installing heat pumps compared to conventional space heaters with AC (See Appendix C for net present value without AC). To calculate the net present value of a heat pump investment, NESCAUM assumed a 2% discount rate, 15-year equipment lifespans,[179] no electrical upgrades or ductwork, and no incentives. We specifically analyze the lifetime value of installing a ducted split unitary heat pump compared to methane gas and propane furnaces, and ductless multi-splits compared to boilers and electric resistance heaters. These comparisons link heat pump types to their compatible distribution systems.

Table 9 shows the net present value of installing and operating ASHPs instead of conventional space heaters with AC. Under the AC scenario, heat pumps generate positive net present values ranging from around $695 to almost $47,000 in nearly every state when replacing propane, oil, and electric resistance space heaters (oil boilers in Connecticut being the exception). While installing a heat pump system instead of a gas furnace yields net losses in most states even accounting for AC use, the swap generates net savings in DC and Maryland, and approaches cost parity in Pennsylvania and Virginia. New England states with the highest

[179] New Jersey Board of Utilities, "New Jersey 2023 Triennial Technical Reference Manual," April 3, 2023.

heating loads and lowest cooling demands have the least favorable cost proposition for heat pumps. These deficits may point to a limitation in Energy Solutions' analysis regarding the omission of cold-climate heat pumps from analysis. Higher-efficiency cold-climate heat pumps may improve operating costs in these states and improve the lifetime value of heat pump systems relative to methane gas. Incentive programs can also help shift the economic calculus in favor of heat pumps, as could future changes in methane gas and electricity prices.

Table 9. 15-Year Net Present Value of Installing Heat Pump Space Heating Systems Compared to Baseline Space Heaters With AC, Assuming Compatible Distribution Systems*

Measure Case	Ducted Split Unitary Heat Pump		3-Zone Ductless Multi-Split			
Base Case	Methane Gas Furnace	Propane Furnace	Methane Gas Boiler	Oil Boiler	Propane Boiler	Electric Resistance
CT	-$10,563	$6,103	-$14,010	-$1,021	$2,656	$28,569
DC	$1,379	$15,680	-$2,761	$12,457	$11,540	$12,961
DE	-$4,698	$17,133	-$9,466	$14,629	$12,365	$13,704
ME	-$17,944	$10,170	-$19,169	$7,807	$8,945	$46,904
MD	$1,995	$13,842	-$1,959	$10,770	$9,888	$13,519
MA	-$10,932	$5,335	-$13,249	$1,265	$3,018	$43,636
NH	-$18,066	$6,155	-$20,303	$695	$3,918	$36,360
NJ	-$4,512	$10,329	-$9,753	$6,678	$5,088	$15,542
NY	-$8,370	$5,893	-$13,413	$2,192	$850	$26,440
PA	-$390	$10,597	-$4,761	$9,537	$6,225	$17,430
RI	-$15,866	$11,001	-$18,423	$3,857	$8,445	$35,977
VT	-$17,908	$15,448	-$19,620	$11,930	$13,737	$40,764
VA	-$724	$16,198	-$4,428	$12,548	$12,495	$14,574

*NPV assumes a 15-year equipment lifespan, 2% discount rate, existing compatible distribution systems, no electrical upgrades or ductwork, no incentives, and AC installation and operation. Red represents negative NPV (lifetime economic loss from installing and operating a heat pump system instead of baseline equipment), green represents positive NPV (lifetime economic savings from installing and operating a heat pump system instead of baseline equipment).

12. Cost/Ton Analysis

NESCAUM estimated the incremental cost per ton of NOx and CO2 emissions that could be avoided by conversion to zero-emission technology using a combination of inputs from Energy Solutions' report and NESCAUM's Emission Reduction Potential report. Like the other analyses, we conducted this analysis state-by-state to help inform state agency decision-making regarding Model Rule 1.0 implementation. While we included electric resistance heaters in the cost analyses summarized in Section 11, we exclude them from the following cost-effectiveness analysis. States may find the economics around electric resistance installation and operating costs useful from the perspective of program implementation, given that electric resistance space and water heaters are present in many homes. However, given that cost-effectiveness analysis is a regulatory tool and Model Rule 1.0 does not regulate electric resistance heaters, we do not include it as a cost/ton measure.

Water Heating Cost-Effectiveness

We first conducted cost/ton analysis for conversion from combustion water heaters to HPWHs, a common zero-emission technology that might be installed if a ZEHES regulation like Model Rule 1.0 were in effect. This analysis is based on currently available data and is subject to change over time – for example as EPA updates emission factors or as electricity and fuel costs change over time.

We utilized the following data inputs for our cost/ton analysis:

- EPA Wagon Wheel[180] emissions factors for fuels
- NREL 2023 Standard Scenarios[181] ("Mid-Case 95% by 2050 Decarbonization") for future electricity grid emissions
- Annual energy consumption by equipment type in MMBtu (calculated by Energy Solutions)[182]
- Operating and installation costs by equipment type (calculated by Energy Solutions)[183]

We calculated annual emissions for emissions-based (baseline) water heaters by converting US EPA Wagon Wheel emissions factors for fuel combustion from pounds per 1,000 gallons (or mmcf) of fuel to tons per MMBtu using EIA conversion units.[184] We calculated annual emissions for zero-emission HPWHs by converting NREL Standard Scenarios electricity grid emissions factors (g or kg/MWh) to tons per MMBtu. Given that Model Rule 1.0 provisions do not take effect until 2029, and that NREL provides grid emissions estimates for even years, we averaged NREL grid emissions factors (provided every other year) from 2030-2042 to develop mid-level estimates of what electricity grid emissions could look like over the 12-year lifetime of a HPWH installed under Model Rule 1.0.

We multiplied emissions per equipment type (tons per MMBtu) by annual energy consumption (in MMBtu) converted from Energy Solution's HPWH report to get annual emissions for each water heater type. We estimated lifetime emissions for each equipment type by multiplying

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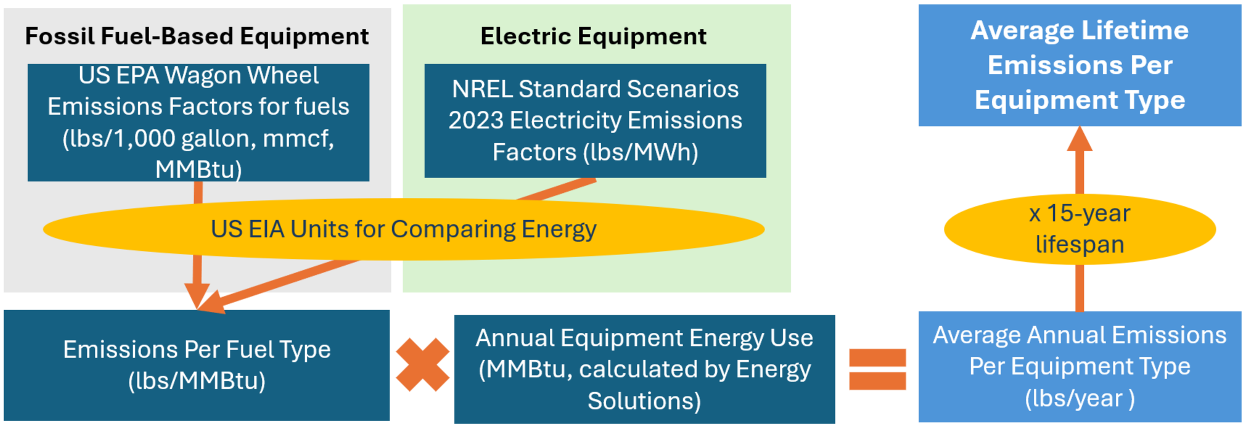
[180] US EPA, "Wagon Wheel 2020, v7 Final" in 2020 NEI Supporting Data Tables and Summaries, last updated October 4, 2024.
[181] Gagnon, P., Pham, A., Cole, W.,"2023 Standard Scenario Report A U.S. Electricity Sector Outlook," National Renewable Laboratory (NREL) Technical Report, NREL/TP-6A40-87724, Revised January 2024.
[182] Booth, K., and Fosberg, C., "Heat Pump Water Heaters in the Northeast and Mid-Atlantic, Costs and Market Trends".
[183] *Ibid*.
[184] US EIA, "Units for Comparing Energy," June 1, 2023.

annual emissions by an estimated water heater equipment lifespan of 12 years. See Figure 9 for an illustration of these calculations.

Figure 9. Graphical representation of water heater average lifetime emissions calculations



NESCAUM used lifetime emissions estimates per equipment type in conjunction with the installation and operating costs calculated by Energy Solutions to estimate incremental lifetime cost per ton. We adapted the incremental cost per ton formula detailed in South Coast AQMD's staff report[185] to calculate incremental cost-effectiveness as a function of incremental difference in lifetime cost between baseline vs. heat pump equipment (i.e., net present value of installing a HPWH over baseline equipment) divided by the difference in lifetime emissions for baseline vs. heat pump equipment:

$$I-CE\left(\frac{\$}{tons\ reduced}\right)=\frac{Incremental\ Difference\ in\ Cost\ (Net\ Present\ Value)}{Incremental\ Difference\ in\ Emissions\ (Lifetime\ Emissions\ Reductions)}$$

Where I-CE = Incremental Cost-Effectiveness

For incremental cost-effectiveness, NESCAUM calculated the net present value of installing and operating a HPWH instead of a baseline water heater without taking incentives into account. We used incremental costs because customers will need to install a water heater at time of replacement and are choosing between a baseline water heater and a HPWH. We omitted incentives to generate a more accurate assessment of the 'true' cost-effectiveness of the transition.

Without incentives (and assuming no panel upgrades), HPWHs generally yield significant savings per ton of NOx reduced compared to propane and fuel oil water heaters. In other words, there is no incremental cost of switching from these technologies to HPWHs in most states. Incremental cost per ton of NOx reduction associated with switching from methane gas

[185] South Coast AQMD, "Preliminary Staff Report for Proposed Amended Rule 111 and Proposed Amended Rule 1121," September 2024.

appliances to HPWHs is generally less favorable, ranging from around -$41,500/ton (cost savings) in Maine to over $330,000/ton in New Jersey (Table 10).[186]

Incremental cost-effectiveness for NOx has a wide range across states and equipment types due to relatively small amounts of NOx saved per HPWH, and therefore the large number of water heaters required to reach one ton of NOx reduction. The primary NAAQS for NO2 is a 53 ppb annual mean[187] (for reference, ambient CO2 concentrations are at 419,300 ppb[188]), so even a small reduction in NOx emissions can have a meaningful impact on ambient NOx levels.[189]

Table 10. Incremental Cost ($1000/ton) of NOx Emissions Reductions for HPWHs*

Cost ($1,000) per Ton of NOx Reduction Associated with Installing and Operating a 240-Volt HPWH Instead of a Combustion Water Heater				
NOx	Methane Gas Storage	Methane Gas Tankless	Propane Storage	Fuel Oil
CT	$120.0	$268.4	-$225.9	-$340.3
DE	$79.3	$216.0	-$208.8	-$426.3
DC	$115.9	$255.1	-$214.8	-$442.4
ME	-$41.5	$57.4	-$223.7	-$351.2
MD	$61.5	$183.8	-$243.3	-$456.5
MA	$87.0	$240.1	-$195.5	-$344.3
NH	$11.6	$124.0	-$250.5	-$346.9
NJ	$215.8	$333.4	-$172.2	-$381.3
NY	$166.2	$298.9	-$168.7	-$361.4
PA	$97.3	$202.6	-$169.5	-$398.4
RI	$115.1	$242.6	-$213.5	-$321.2
VT	$82.2	$188.8	-$223.9	-$341.7
VA	$36.2	$123.4	-$235.0	-$411.8

*Reflects the incremental cost of reducing one ton of NOx emissions by installing and operating a 240-volt HPWH instead of baseline equipment, without factoring in incentives. Red (positive numbers) represents the cost per ton of NOx reduction from installing HPWHs; green (negative numbers) represents savings per ton of NOX reduction from installing HPWHs. Savings occur when lifetime installation and operating costs (NPV) are cheaper for HPWHs than for baseline equipment.

Incremental cost-effectiveness for CO2 followed similar patterns, although with significantly less dramatic costs and savings, due to the greater number of pounds of CO2 saved per water heater compared to NOx. CO2-related cost savings peaked at around $329 saved per ton of CO2 reduced for a 240-volt HPWH replacing fuel oil water heater in Vermont. Cost per ton of

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[187] US EPA, "NAAQS Table," last updated February 7, 2024.
[188] US National Oceanic & Atmospheric Administration (NOAA), "Climate Change: Atmospheric Carbon Dioxide," April 9, 2024.

CO2 emissions was highest at $254/ton in New Jersey when comparing a 240-volt HPWH to a methane gas tankless water heater and was below $215/ton for all equipment in all other states.

Table 11. Incremental Cost-Effectiveness ($/ton) for CO2 Emissions Reductions Associated with Heat Pump Water Heating*

Cost ($) per Ton of CO2 Reduction Associated with Installing a 240-Volt HPWH Instead of Baseline Equipment				
CO2	Methane Gas Storage	Methane Gas Tankless	Propane Storage	Fuel Oil
CT	$123	$187	-$202	-$258
DC	$87	$168	-$195	-$343
DE	$110	$162	-$185	-$320
ME	-$45	$44	-$208	-$281
MD	$58	$117	-$210	-$331
MA	$85	$160	-$172	-$256
NH	$13	$98	-$236	-$281
NJ	$233	$254	-$160	-$303
NY	$170	$212	-$152	-$277
PA	$100	$143	-$153	-$305
RI	$123	$184	-$197	-$255
VT	$90	$147	-$209	-$275
VA	$39	$95	-$219	-$329

*Reflects the incremental cost of reducing one ton of CO2 emissions by installing and operating a 240-volt HPWH instead of baseline equipment, without factoring in incentives. Red (positive numbers) represents the cost per ton of CO2 reduction from installing HPWHs; green (negative numbers) represents savings per ton of CO2 reduction from installing HPWHs. Savings occur when lifetime installation and operating costs (NPV) are cheaper for HPWHs than for baseline equipment.

Space Heating Cost-Effectiveness

Utilizing the same methods as we used for HPWHs, NESCAUM estimated the cost per ton of emissions reduction associated with zero-emission space heating, assuming a 15-year lifespan instead of for net present value and grid emissions assumptions. We assumed inclusion of AC installation and operation costs to create a more compatible comparison between heat pumps and baseline space heating technology (see Appendix C for cost/ton without AC). As with net present value, we found that heat pumps performed worse economically when compared to methane gas-fired equipment (Table 12). When replacing delivered fuel space heaters and AC, heat pumps yielded cost savings (or no incremental cost/ton) in every scenario, reaching as high as $281,000 per ton of NOx reduced. While Maryland and Washington, DC still experienced cost savings per ton of NOx reduction when replacing gas furnaces, methane gas incremental costs were generally more costly in other states, with Connecticut and New Hampshire exceeding $400,000 per ton of NOx reduced by replacing methane gas hydronic boilers.

Table 12. Incremental Cost-Effectiveness ($1000/ton) for NOx Emissions Reductions Associated with Heat Pump Space Heaters with AC*

Cost per Ton of NOx Reductions Associated with Installing Heat Pump Space Heating Instead of Baseline Equipment					
NOx	Split Unitary HP		3-Zone Multi-Split		
	Methane Gas Furnace	Propane Furnace	Gas Hydronic Boiler	Oil Hydronic Boiler	Propane Hydronic Boiler
CT	$334	-$105	$422	$18	-$45
DC	-$48	-$281	$89	-$226	-$199
DE	$103	-$231	$208	-$206	-$167
ME	$255	-$87	$270	-$70	-$76
MD	-$72	-$260	$66	-$205	-$178
MA	$188	-$56	$227	-$14	-$32
NH	$360	-$76	$404	-$9	-$48
NJ	$126	-$173	$269	-$116	-$84
NY	$228	-$92	$355	-$35	-$13
PA	$11	-$160	$123	-$147	-$92
RI	$301	-$126	$346	-$46	-$96
VT	$248	-$132	$272	-$107	-$118
VA	$16	-$217	$97	-$175	-$166

*Reflects the incremental cost of reducing one ton of NOx emissions by installing and operating heat pump space heaters instead of baseline equipment, including AC installation and operation, and assuming compatible distribution systems during installation. Red (positive numbers) represents the cost per ton of NOx reduction from installing heat pump space heaters; green (negative numbers) represents savings per ton of NOx reduction from installing heat pump space heaters. Savings occur when lifetime installation and operating costs (NPV) are cheaper for heat pumps than for baseline equipment.

Cost-effectiveness for heat pump space heaters and CO2 emissions reductions followed the same pattern, with savings associated with switching from propane and oil heating, and higher costs associated with switching from methane gas. However, unlike NOx incremental cost-effectiveness, all costs for CO2 fall below $325 per ton of CO2 for even the most expensive switches. This price difference compared to the cost of reducing each ton of NOx is due to the significantly higher quantities of CO2 saved by each heat pump installation compared to NOx. See Appendix C for cost/ton when AC is excluded.

Table 13. Incremental Cost-Effectiveness ($/ton) for CO2 Emissions Reductions Associated with Heat Pump Space Heaters with AC*

Cost per Ton of CO2 Reduction Associated with Installing Heat Pump Space Heating Instead of Baseline Equipment					
CO2	Split Unitary HP		3-Zone Multi-Split		
	Methane Gas Furnace	Propane Furnace	Gas Hydronic Boiler	Oil Hydronic Boiler	Propane Hydronic Boiler
CT	$207	-$87	$271	$13	-$38
DC	-$25	-$210	$50	-$150	-$155
DE	$80	-$216	$162	-$166	-$156
ME	$193	-$80	$205	-$55	-$70
MD	-$38	-$194	$37	-$135	-$138
MA	$148	-$53	$179	-$11	-$30
NH	$287	-$72	$321	-$7	-$46
NJ	$94	-$158	$203	-$91	-$78
NY	$151	-$78	$241	-$26	-$11
PA	$7	-$136	$83	-$109	-$79
RI	$223	-$114	$258	-$36	-$87
VT	$193	-$123	$211	-$86	-$110
VA	$12	-$200	$74	-$139	-$154

*Reflects the incremental cost of reducing one ton of CO2 emissions by installing and operating heat pump space heaters instead of baseline equipment, including AC installation and operation, and assuming existing compatible distribution systems during installation. Red (positive numbers) represents the cost per ton of CO2 reduction from installing heat pump space heaters; green (negative numbers) represents savings per ton of CO2 reduction from installing heat pump space heaters. Savings occur when lifetime installation and operating costs (NPV) are cheaper for heat pumps than for baseline equipment.

The wide variance in costs or savings per ton of NOx emissions, depending on the HPWH and ASHP installation scenario and the type of equipment being replaced, makes it challenging to compare the cost-effectiveness of ZEHES regulations to other strategies designed to control NOx and GHG emissions. Thresholds for 'acceptable' levels of cost-effectiveness vary widely across jurisdictions based on different cost tolerances, methods for calculating cost-effectiveness, technologies being considered, and other factors. The OTC has previously estimated that the cost-effectiveness of NOx controls ranged from $2,700 to $21,000 per ton of NOx reduced for large-scale boilers[190] and from $3,000 to $6,200 per ton of NOx reduced for municipal waste combustors.[191] The US EPA has set a NOx fee of $12,476.67 per ton for major stationary source operators that fail to meet the NAAQS,[192] while South Coast AQMD – in a

[190]Ozone Transport Commission (OTC) and Lake Michigan Air Directors Consortium (LADCO), "Evaluation of Control Option for Industrial, Commercial, and Institutional Boilers," May 2010.
[191] OTC, "Municipal Waste Combustor Workgroup Report," revised May 2023.
[192] US EPA, Office of Air Quality Planning & Standards, "Clean Air Act Section 185 Fee Rates Effective for Calendar Year 2024," October 16, 2024.

region with the worst ozone pollution in the country – has set a significantly higher cost-effectiveness threshold of $325,000 per ton of NOx emissions reductions for their regulations.[193] Costs per ton of GHG emissions can be compared to the Social Cost of Carbon (SCC). EPA recently increased the SCC, which is used for federal regulatory analysis, to $190 per ton.[194] While these represent a wide range of cost/ton estimates, they can provide some context for interpreting the cost-effectiveness values provided in this TSD.

13. CONCLUSION

Model Rule 1.0, NOx and GHG Emissions Standards for Space and Water Heaters, provides a template that state agencies can use to design ZEHES regulations. Model Rule 1.0 specifically targets NOx and GHG emissions from residential-scale space and water heating equipment, requiring that polluting equipment be replaced with zero-emission alternatives at the end of useful life. By implementing the Model Rule, states can improve air quality and address climate change by accelerating the transition to zero-emission buildings.

[193] South Coast AQMD, "Preliminary Staff Report."
[194] EPA, "EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances," November 2023.

APPENDIX

APPENDIX A. Table of Model Rule 1.0 Definitions and Sources

Appendix A shows definitions used in the Model Rule and sources on which they are based. Note that "Source" does not necessarily mean that the word-for-word definition has been used from that source, rather that we have based our definition on or borrowed language from the listed source(s).

Term	Definition in Model Rule	Source
Boiler	A boiler with a rated heat input capacity of less than 300,000 Btu per hour that is designed to: (a) Use only single-phase electric current, or single-phase electric current or DC current; (b) Be the principal heating source for the living space of a residence; and (c) Either supply low pressure steam and operate at or below 15 pounds per square inch gauge (psig) steam pressure or supply hot water and operate at or below 160 psig water pressure and 250 °F water temperature.	US DOE definition in 10 CFR 430.2
British Thermal Unit (Btu)	The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit	US Department of Energy (DOE) definition in 10 CFR 430.2
CO_2 Equivalent (CO_2e)	The amount of carbon dioxide by weight emitted into the atmosphere that would produce the same global warming potential impact as a given weight of a greenhouse gas	California Air Resources Board (CARB) Glossary of Terms
Circulating Water Heater	Storage type water heater that: (a) Does not have an operational scheme in which the burner or heating element initiates or terminates heating based on sensing flow; (b) Has a water temperature sensor located at the inlet or the outlet of the water heater or in a separate storage tank that is the primary means of initiating and terminating heating; and (c) Must be used in combination with a recirculating pump and either a separate storage tank or water circulation loop to achieve the water flow and temperature conditions recommended in the manufacturer's installation and operation instructions.	US DOE definition in 10 CFR 430.2

Term	Definition in Model Rule	Source
Flow-activated instantaneous type water heater	An instantaneous type water heater that activates the burner or heating element only if heated water is drawn from the unit	US DOE definition in 10 CFR 430.2
Forced air central furnace	A furnace designed to supply heat generated by combustion of fuel, transferred to the air within a casing by conduction through heat exchange surfaces, and circulated through the duct system by means of a fan or blower	US DOE definition in 10 CFR 430.2
Furnace	A product that is designed to supply heated air through a system of ducts for space heating applications, including, but not limited to a forced air central furnace or gravity central furnace	US DOE definition in 10 CFR 430.2
Gravity Central Furnace	A furnace that depends primarily on natural convection for circulation of heated air and is designed to be used in conjunction with a system of ducts	US DOE definition in 10 CFR 430.2
Heat Input	The heat of combustion released by fuels burned in a water heater, boiler, or furnace based on the higher heating value of fuel and does not include the enthalpy of incoming combustion air	BAAQMD definition in Rule 6, §9-6-204 and South Coast AQMD definition in Rule 1121, par. (b)(3)
Heat Output (for water heaters)	Rated heat input capacity multiplied by the ratio of energy delivered to the water to energy content of the fuel consumed	BAAQMD definition in Rule 6, §9-6-205 and 10 CFR Part 430, Subpart B, Appendix E, §1.11
Heat Output (for furnaces)	The product of the furnace's heat input multiplied by its annual fuel utilization efficiency under 10 CFR Part 430, Subpart B, Appendix N, §10.1	BAAQMD definitions in Rule 4, §9-4-200 and South Coast AQMD definitions in Rule 1111, par. (b)(1)
Heating Oil	A distillate fuel oil that has distillation temperatures of 400 degrees Fahrenheit (204 degrees Celsius) at the 10-percent recovery point and 640 degrees Fahrenheit (338 degrees Celsius) at the 90-percent recovery point and meets the specifications defined in ASTM Specification D396-71 (2021)	USEIA glossary ("No. 2 fuel oil") and USDOE definition in 10 CFR §430.2 ("oil")
Instantaneous type water heater	A water heater that contains no more than one gallon of stored water per 4,000 Btu per hour of rated heat input capacity, including, but not limited to, a combination boiler, flow-activated instantaneous water heater, hot	US DOE definitions in 10 CFR 430.2

Term	Definition in Model Rule	Source
	water supply boiler, or storage-type instantaneous water heater	
Manufacturer	A person that produces, assembles, or imports a water heater, boiler, or furnace for sale	US DOE definitions of "manufacture" and manufacturer" in 10 CFR 431.2
Methane Gas	A mixture of gaseous hydrocarbons containing at least 80 percent CH_4 by volume as determined according to Standard Method ASTM D1945 (2020)	BAAQMD definition of "natural gas" in Rule 6, §9-6-208
Propane	A hydrocarbon whose chemical composition is predominantly C_3H_8, whether recovered from pipeline gas or crude oil	US DOE definition in 10 CFR 430.02
Rated heat input capacity	The maximum rate at which equipment is rated to use energy as specified on the nameplate of the equipment	US DOE definition in 10 CFR 431.101
Recreational vehicle	A multipurpose passenger vehicle with motive power, or a trailer designed to be drawn by a vehicle with motive power by means of a bumper, frame or fifth wheel hitch, that is designed to provide temporary residential accommodations with the presence of at least four of the following: (a) Cooking facilities; (b) Refrigeration or ice box; (c) Self-contained toilet; (d) Heating or air conditioning; (e) Potable water supply system with faucet and sink; and (f) Separate 110-125 volt electrical power supply or heating oil or propane supply.	National Highway Traffic Safety Administration, US Department of Transportation definitions of "motor home" and "recreational vehicle trailer" in 49 CFR 571.3
Storage-type instantaneous water heater	An instantaneous type water heater that includes a storage tank with a rated storage volume greater than or equal to 10 gallons	US DOE definition in 10 CFR 431.102
Storage type water heater	A water heater that heats and stores water at a thermostatically controlled temperature, including, but not limited to, a circulating water heater	US DOE definitions in 10 CFR 430.2
Water heater	A product that is designed to heat potable water for use outside the heater upon demand	US DOE definition in 10 CFR 430.2
Hot water supply boiler	A product that: (a) Is shipped complete with heating and mechanical draft equipment and automatic controls, (b) Has a rated heat input of 300,000-12,500,000 Btu/hr and at least 4,000 Btu/hr per gallon of stored water,	US DOE definition in 10 CFR 431.102

Term	Definition in Model Rule	Source
	(c) Is suitable for heating potable water, (d) Either has the ability to heat potable water for purposes other than space heating, or the manufacturer's product information indicate that the boiler's intended uses include purposes other than space heating	

APPENDIX B. COBRA Analysis Tables

Table B1. Space Heating Electrification: Cumulative State-by-State Health Impact Potential 2030-2045

State	Number of Premature Deaths Low Estimate	Number of Premature Deaths High Estimate	Number of Avoided Hospitalizations	Number of Avoided ER Visits	Number of Avoided Work Loss Days	Monetary Value Low Estimate ($ Millions)	Monetary Value High Estimate ($ Millions)
CT	98	222	30.5	39.2	7092	1176	2650
DC	15	34	5.3	6.8	1713	183	412
DE	4	8	1.3	1.3	273	43	97
ME	5	10	1.8	0.3	275	55	125
MD	104	234	34.4	38.6	8591	1240	2797
MA	183	414	63.9	79.1	15713	2193	4946
NH	5	11	1.6	2.1	359	58	131
NJ	181	409	62.2	78.9	14814	2168	4889
NY	1589	3589	602.3	552.3	160203	19057	42931
PA	439	993	146.0	168.7	28444	5252	11847
RI	20	46	6.9	5.8	1355	241	544
VA	48	108	17.6	21.5	4834	572	1290
VT	2	3	0.4	0.2	81	18	41

Table B2. Water Heating Electrification: Cumulative State-by-State Health Impact Potential 2030-2045

State	Number of Premature Deaths Low Estimate	Number of Premature Deaths High Estimate	Number of Avoided Hospitalizations	Number of Avoided ER Visits	Number of Avoided Work Loss Days	Monetary Value Low Estimate ($ Millions)	Monetary Value High Estimate ($ Millions)
CT	11	25	3.4	4.4	787	130	294
DC	3	7	1.1	1.4	363	39	87
DE	1	2	0.3	0.3	69	11	24
ME	1	1	0.2	0.0	33	6	15
MD	18	40	5.8	6.5	1445	210	473
MA	21	47	7.3	9.2	1769	249	562
NH	1	1	0.2	0.3	45	7	17
NJ	59	132	20.1	25.7	4842	700	1578
NY	184	415	69.7	64.0	18532	2204	4967
PA	70	158	21.8	27.1	4531	837	1888
RI	3	6	0.9	0.7	169	30	67
VA	13	29	4.7	5.8	1310	152	344
VT	0	1	0.0	0.0	16	3	6

APPENDIX C. Additional Cost Tables

Table C1. Total Installation Costs for Select Space Heating Equipment Without AC, Assuming Compatible Distribution System*

State	Ducted Methane Gas/Propane Furnace	Methane Gas/Propane Boiler	Oil Boiler	Electric Resistance	Ducted Split Unitary HP (Panel Upgrade)	Ducted Split Unitary HP (No Panel Upgrade)	3-Zone Ductless Minisplit (Panel Upgrade)	3-Zone Ductless Minisplit (No Panel Upgrade)
CT	$3,941	$3,753	$3,686	$6,371	$12,317	$9,605	$19,074	$16,463
DC	$3,543	$3,391	$3,344	$5,840	$11,348	$9,263	$17,469	$15,383
DE	$3,869	$3,690	$3,628	$6,288	$12,174	$9,618	$18,587	$16,337
ME	$3,457	$3,310	$3,263	$5,701	$11,080	$9,056	$17,051	$15,026
MD	$3,430	$3,288	$3,245	$5,685	$11,061	$9,138	$16,974	$15,051
MA	$3,996	$3,800	$3,729	$6,422	$12,398	$9,530	$19,367	$16,500
NH	$3,545	$3,392	$3,343	$5,831	$11,322	$9,192	$17,452	$15,322
NJ	$4,180	$3,966	$3,886	$6,660	$12,826	$9,641	$20,140	$16,955
NY	$4,599	$4,349	$4,251	$7,234	$13,883	$10,087	$21,967	$18,171
PA	$3,902	$3,714	$3,647	$6,296	$12,168	$9,448	$18,962	$16,242
RI	$3,921	$3,737	$3,673	$6,355	$12,294	$9,644	$19,112	$16,462
VT	$3,468	$3,319	$3,272	$5,714	$11,101	$9,049	$17,094	$15,042
VA	$3,302	$3,173	$3,136	$5,522	$10,768	$9,072	$16,440	$14,743

*Total installation costs without AC, assuming existing compatible distribution system. Red represents higher total installation costs, green represents lower total installation costs.

Table C2. Total Operating Costs for Select Space Heating Equipment Without AC*

State	Methane Gas/Propane Boiler	Oil Boiler	Propane Furnace & Boiler	Electric Resistance	3-Zone Ductless Minisplit	Ducted Split Unitary HP
CT	$1,279	$2,295	$2,576	$4,689	$2,100	$2,375
DC	$1,303	$2,490	$2,415	$2,335	$1,244	$1,406
DE	$875	$2,754	$2,573	$2,476	$1,229	$1,390
ME	$1,810	$3,914	$3,998	$6,766	$2,843	$3,220
MD	$1,388	$2,382	$2,310	$2,406	$1,229	$1,389
MA	$2,132	$3,267	$3,398	$6,355	$2,825	$3,197
NH	$1,178	$2,816	$3,064	$5,401	$2,351	$2,662
NJ	$967	$2,251	$2,121	$2,725	$1,310	$1,482
NY	$1,305	$2,527	$2,414	$4,182	$1,885	$2,134
PA	$1,400	$2,518	$2,255	$2,926	$1,531	$1,729
RI	$1,297	$3,036	$3,388	$5,326	$2,612	$2,953
VT	$1,443	$3,902	$4,039	$5,955	$2,579	$2,920
VA	$1,253	$2,578	$2,571	$2,550	$1,216	$1,376

*Total operating costs without AC operation. Red represents higher total operating costs, green represents lower total operating costs.

Table C3. 15-Year Net Present Value (NPV) of Purchasing Heat Pump Space Heating Systems Compared to Baseline Space Heaters (Without AC)*

Heat Pump System	Ducted Split Unitary Heat Pump		3-Zone Ductless Multi-Split			
Baseline System	Gas Furnace	Propane Furnace	Gas Boiler	Oil Boiler	Propane Boiler	Electric Resistance
CT	-$19,747	-$3,081	-$23,260	-$10,271	-$6,594	$23,175
DC	-$7,043	$7,245	-$11,233	$3,971	$3,055	$4,475
DE	-$12,366	$9,452	-$17,196	$6,886	$4,622	$5,974
ME	-$23,716	$4,398	-$24,990	$1,998	$3,124	$41,083
MD	-$5,721	$6,126	-$9,720	$3,009	$2,127	$5,757
MA	-$19,218	-$2,951	-$21,605	-$7,091	-$5,337	$35,280
NH	-$24,715	-$482	-$27,003	-$6,004	-$2,769	$29,699
NJ	-$12,078	$2,750	-$17,396	-$978	-$2,568	$7,886
NY	-$16,140	-$1,890	-$21,275	-$5,670	-$7,025	$18,578
PA	-$9,773	$1,213	-$14,212	$88	-$3,226	$7,979
RI	-$27,001	-$134	-$29,622	-$7,341	-$2,754	$24,766
VT	-$24,559	$8,797	-$26,320	$5,230	$7,037	$34,051
VA	-$7,350	$9,585	-$11,095	$5,894	$5,841	$7,920

*NPV assumes 15-year lifespan, 2% discount rate, no electrical upgrades or ductwork, no incentives, and no AC installation or operation. Red represents negative NPV (lifetime economic loss from installing and operating a heat pump system instead of baseline equipment), green represents positive NPV (lifetime economic savings from installing and operating a heat pump system instead of baseline equipment).

Table C4. Incremental Cost-Effectiveness ($1000/ton) for NOx Emissions Reductions Associated with Heat Pump Space Heaters (without AC)*

Cost per Ton of NOx Reductions Associated with Installing Heat Pump Space Heating Instead of Baseline Equipment					
NOx	Split Unitary HP		3-Zone Multi-Split		
	Methane Gas Furnace	Propane Furnace	Gas Hydronic Boiler	Oil Hydronic Boiler	Propane Hydronic Boiler
CT	$670	$55	$750	$189	$115
DC	$295	-$142	$429	-$79	-$57
DE	$274	-$128	$380	-$97	-$63
ME	$338	-$38	$353	-$18	-$27
MD	$242	-$124	$378	-$62	-$41
MA	$331	$31	$371	$78	$56
NH	$494	$6	$538	$77	$34
NJ	$345	-$47	$490	$17	$43
NY	$451	$30	$578	$93	$110
PA	$288	-$19	$400	-$1	$50
RI	$521	$2	$566	$88	$32
VT	$341	-$75	$365	-$47	-$60
VA	$164	-$129	$246	-$83	-$78

*Reflects the incremental cost of reducing one ton of NOx emissions by installing and operating heat pump space heaters instead of baseline equipment (assuming existing compatible distribution systems during installation), excluding AC installation and operation. Red (positive numbers) represents the cost per ton of NOx reduction from installing heat pump space heaters; green (negative numbers) represents savings per ton of NOx reduction from installing heat pump space heaters. Savings occur when lifetime installation and operating costs (NPV) are cheaper for heat pumps than for baseline equipment.

Table C5. Incremental Cost-Effectiveness ($1000/ton) for CO2 Emissions Reductions Associated with Heat Pump Space Heaters (without AC)*

Cost per Ton of CO2 Reductions Associated with Installing Heat Pump Space Heating Instead of Baseline Equipment					
CO2	Split Unitary HP	3-Zone Multi-Split			
	Methane Gas Furnace	Propane Furnace	Gas Hydronic Boiler	Oil Hydronic Boiler	Propane Hydronic Boiler
CT	$392	$44	$457	$131	$94
DC	$129	-$98	$205	-$48	-$41
DE	$212	-$120	$295	-$78	-$58
ME	$255	-$35	$268	-$14	-$25
MD	$110	-$86	$186	-$38	-$30
MA	$261	$29	$292	$63	$53
NH	$393	$6	$428	$63	$32
NJ	$255	-$42	$365	$13	$39
NY	$292	$25	$383	$68	$93
PA	$176	-$16	$253	-$1	$42
RI	$380	$1	$416	$68	$29
VT	$265	-$70	$284	-$38	-$56
VA	$124	-$119	$186	-$65	-$72

*Reflects the incremental cost of reducing one ton of CO2 emissions by installing and operating heat pump space heaters instead of baseline equipment (assuming existing compatible distribution systems), excluding AC installation and operation. Red (positive numbers) represents the cost per ton of CO2 reduction from installing heat pump space heaters; green (negative numbers) represents savings per ton of CO2 reduction from installing heat pump space heaters. Savings occur when lifetime installation and operating costs (NPV) are cheaper for heat pumps than for baseline equipment.