BATES WHITE
ECONOMIC CONSULTING

Clean Heat Policy Efficacy in the U.S. Northeast

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I. Executive Summary

Bates White was engaged[1] to evaluate the value and efficacy of clean heat policies in the Northeast U.S. in the context of decarbonization goals established by states in the region.

The following is a summary of findings:

We conclude that policies allowing for and promoting the decarbonization of fuels currently used to heat homes and businesses can offer a cost-effective means to meet interim GHG reduction goals while electrification advances. Promoting emissions reductions from existing fossil-fuel based heating systems can accelerate the meeting of GHG goals while utilizing existing infrastructure, which limits the cost of achieving policy objectives.

- Residential and commercial space heating is a significant source of GHG emissions from the combustion of fossil fuels.
- Because carbon dioxide (CO_2) and other greenhouse gases (GHGs) are so persistent in the atmosphere once they have been emitted, there is critical value in reducing such emission earlier rather than later.
- Policies to decarbonize the economy can include various methods to support clean heat, aimed at reducing GHG emissions from residential and commercial heating. This is particularly relevant in the Northeast U.S., where fossil fuel heating dominates, constituting 80% of households in the region.
- Electrification of heating, through a shift from fuel combustion to electric heat pumps, is one strategy to meet emissions reduction goals, but the effectiveness depends significantly on the scale and timing of decarbonizing the generation of electricity. Decarbonization of energy use will require large additions of renewable generation and storage resources to reduce carbon emissions from electricity generation.
- Exclusive reliance on electrification, combined with electric grid decarbonization, presents significant challenges for a rapid transition. Large scale electrification of heating – for example of 60% of households – would entail more than a 14-fold increase in the number of installed heat pumps, totaling more than 11 million units in the Northeast U.S.
- Electrification on this scale will require significant changes in infrastructure, spanning the manufacturing, distribution, and installation services required to rapidly increase the number of heat pump installations.

[1] Our work has been funded by Global Partners LP and Sprague Energy.

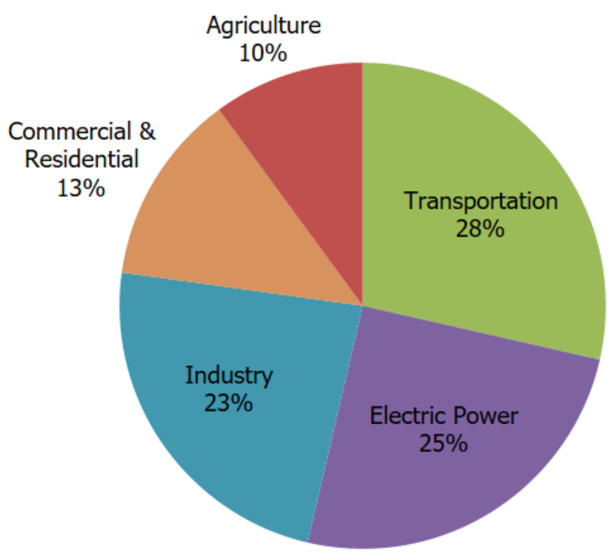
- Large scale electrification will also require significant additional infrastructure to generate and deliver low-carbon electric power, including 10,000 to 20,000 megawatts (MW), and potentially much more, generation capacity, and likely significant upgrades to feeders, substations, and the transmission system. The challenges of such large-scale modifications to the electric system may constrain the ability of electrification to achieve emissions reduction goals quickly.
- Decarbonizing the supply of electricity entails significant challenges and potentially very high costs. The pace of renewable generation additions will need to increase substantially, even compared to recent rates of expansion and historical levels of investment.
- Incremental costs of new generation capacity needed to meet demand from electrification of heating will require investment on the order of $40 billion in New England alone, and additional costs for required upgrades to the transmission and distribution systems in excess of $10 billion. Though there is substantial uncertainty in such cost estimates, the uncertainty is not that costs will in reality be very low, but that they will be substantially greater, particular considered over the entire Northeast region.
- The efficacy of policies to decarbonize heating depends critically on reducing the carbon intensity of the electric grid. Consequently, it is important to measure and track the carbon intensity of electricity supply, and to advance expansive policies that allow flexibility in methods to reduce GHG emissions from heating.
- As a complement to electrification-focused objectives, decarbonization of fuels currently used to heat homes and businesses can offer a cost-effective means to meet interim GHG reduction goals, easing the challenges of rapid electrification and the required buildout of renewable generation, transmission, and distribution infrastructure.
- As an estimate of potential emissions reduction value of low-carbon fuels (drawing on data from the California's successful Low Carbon Fuel Standard, or LCFS Program), we estimate that incorporation of renewable diesel and biodiesel for heating in the Northeast could provide net emissions reductions of approximately 7 million metric tons of CO_2 per year, which corresponds to the net emissions reduction from adding 1.6 million heat pumps – i.e. tripling the current share of residential heat pumps in the Northeast.
- Achieving a portion of decarbonization goals via mechanisms other than electrification alone will help mitigate the likelihood of local electricity price spikes and degraded reliability and resiliency of electric service.

II. Decarbonization of Residential and Commercial Heating

A. GHG Emissions from Heating

According to the most recent annual data from the U.S. Environmental Protection Agency (EPA), the emissions of GHGs in the U.S. in 2021 totaled 6,340 million metric tons (MMT).[2, 3] The shares of emissions by each major economic sector are summarized in Figure 1.

Figure 1: U.S. Greenhouse Gas Emissions by Economic Sector[4]



After peaking in 2007, GHG emissions from the electric power sector have fallen by 36%, driven by reduced generation from coal, and increased generation from natural gas and renewable sources such as wind and solar.

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2 U.S. EPA, "Greenhouse Gas Inventory Data Explorer," https://cfpub.epa.gov/ghgdata/inventoryexplorer/

3 The two most significant greenhouse gases in terms of contributions to atmospheric heating are carbon dioxide (CO_2) and methane, or natural gas (NH_4). These, and other greenhouse gases, have very different impacts per unit, and are typically evaluated on a comparable basis of CO_2 equivalent (CO_2e). On this basis, CO_2 comprised 79% of the U.S. GHG emissions in 2021, while methane represented 11% of the total. In this report, we generally refer to GHG quantities in CO_2e metric tons (MT). One metric ton equals approximately 2,205 pounds, about ten percent greater than a short ton.

4 U.S. EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks" Summary data accessed at: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Over the same period, emissions from the transportation sector have fallen, but only by 8%, and the sector has since become the largest source of GHG emissions in the U.S.[5] A variety of policies at the national and state level target reduced emissions from transportation, including fuel efficiency standards and mechanisms to promote fuel sources (including electricity) with lower carbon intensity than fossil fuels.

Direct emissions from the commercial and residential sectors represented 13% of total GHG emissions in 2021, overwhelmingly from the combustion of natural gas and petroleum products for heating and cooking. (Indirect emissions are associated with the consumption of electricity; accounting for both direct and indirect emissions, commercial and residential, industrial, and transportation sectors each account for approximately 30% of total emissions.[6]) Efforts to achieve substantial economy-wide decarbonization, and specifically to achieve "net zero" contributions to GHG in the atmosphere, necessarily must encompass the decarbonization of the heating sector. This is being pursued at the state level through clean heat (or renewable heat) programs that aim to reduce the use of fossil fuels for heating of residential and commercial buildings.

The goal of residential and commercial decarbonization efforts is ultimately to shift heating away from direct combustion of fossil fuels. The primary low-carbon alternative is expected to be high-efficiency heat pumps. Policies that promote the adoption of heat pumps in new construction and the conversion of existing systems can come in a variety of forms, as discussed further below. While the immediate policy focus is to guide or incentivize consumer behavior, there are a number of challenges associated with the scale of change that is needed. As we examine in Section B with respect to residential heat pump use, achieving penetration on the order of 75% of households in the Northeast would require managing supply constraints as well as significant impacts on the need for electric generation capacity and upgrades to the power distribution system.

B. Northeast State Policies Relating to Clean Heat

Multiple states across the Northeast are advancing policies to promote or mandate decarbonization of space heating. The following summarizes representative activity in three states: Massachusetts, New York, and Vermont.

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5 U.S. EPA, "Greenhouse Gas Inventory Data Explorer," https://cfpub.epa.gov/ghgdata/inventoryexplorer/.

6 EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-andsinks-1990-2021, derived from Table ES-6.

1. Massachusetts

The Massachusetts Commission on Clean Heat released a report in November 2022 conceptualizing next steps to decrease GHG emissions from heating. The transformation envisioned is massive, requiring "an additional 500,000 residential homes and roughly 300 million square feet of commercial buildings to utilize energy-efficient electric heating by 2030."[7] In the residential sector, specifically, the report anticipates "an average of 20,000-25,000 installations a year ahead of 2025, ramping up to 80,000 a year in the latter half of the decade."[8] In order to reach net zero GHG emissions by 2050 (as required by Massachusetts law), heating equipment sales will have to transition from 25% to 75% electric by 2030.[9]

The Commission recognizes the potential constraints given the speed and scale of electrification needed to meet certain emissions reduction targets. Investments will be needed in Massachusetts's grid in terms of transmission and distribution upgrades, resiliency improvements, and flexibility enhancements to manage increased load.[10] Additionally, Massachusetts will need to invest in additional renewable generation sources. To lever the decarbonization value of hundreds of thousands of heat pumps in the next decade, the carbon intensity of electricity consumed must be reduced further.[11]

2. New York

New York has been pursuing a variety of emissions reduction programs, including those focused on clean heating. New York's most comprehensive piece of climate legislation is the Climate Leadership and Community Protection Act (CLCPA), which aims for a 40% reduction in GHG emissions from 1990s levels by 2030 (and an 85% reduction by 2050),[12] as well as targeting 70% of electricity to come from renewable sources by 2030.[13] Given the aggressive emissions reduction goals of the CLCPA, addressing emissions from the heating sector is of high importance.

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[7] Massachusetts Commission on Clean Heat, *Final Report*, November 30, 2022, p. 1.

[8] Massachusetts Commission on Clean Heat, *Final Report*, November 30, 2022, p. 1.

[9] Massachusetts Commission on Clean Heat, *Final Report*, November 30, 2022, p. 1.

[10] See Section III for discussion on the increase in electricity demand.

[11] Massachusetts Commission on Clean Heat, *Final Report*, November 30, 2022, pp. 11-12.

[12] New York State Energy Research and Development Authority, *New York State Clean Heat: Advancing Building Electrification through Clean Heat and Cooling*, 2022, p. 2.

[13] NYSERDA, "Clean Energy Standard," https://www.nyserda.ny.gov/All-Programs/Clean-Energy-Standard.

The New York State Energy Research and Development Authority (NYSERDA) is responsible for climate programs including the New York State Clean Heat program (NYS Clean Heat). In a 2019 study comparing GHG emissions by sector in New York, researchers found buildings to contribute to the largest percentage of emissions (32%).[14] The NYS Clean Heat program is primarily focused on electrification measures, particularly through heat pump installation in buildings and homes.[15]

Additionally, New York is pursuing initiatives to encourage investment in renewable energy technology. In January 2023, Governor Hochul announced a Cap-and-Invest Program, which will cap GHG emissions and incentivize investment in electric vehicles, energy efficiency, and retrofitting homes and schools, among other initiatives. The emissions "cap" will decrease each year to keep GHG emissions in line with CLCPA targets.[16]

Most recently, (as of May 2023), state lawmakers in New York released a budget bill that includes a plan to prohibit fossil fuel equipment in buildings with seven floors or fewer by 2026. By 2029, this would include all new construction. While the bill will not affect existing buildings, it will greatly increase the building electrification in the state.[17] This builds on past initiatives, such as S.2936a/A.5029a, which was signed by Governor Hochul in November 2021, and prohibited the burning of grade 6 fuel oil in buildings in an attempt to reduce the level of toxic air pollutants being emitted.[18]

New York is not exclusively focused on electrification, but progress in incorporating other renewable fuel sources is not as swift as electrification measures. In December 2021, Governor Hochul signed New York bill S.3321-A/A.7290, which required that 5% of fuel oil sold in the state to be biofuel by July 2022. The mandate is still in place in New York's most populous counties, but much of upstate New York has planned to delay the

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14 New York State Department of Environmental Conservation, *2022 Statewide GHG Emissions Report*, 2022, p. iv.

15 NYSERDA, "Heat Pump Program (NYS Clean Heat)," https://www.nyserda.ny.gov/All-Programs/Heat-Pump-Program.

16 NYSERDA, "Governor Hochul Unveils Cap-and-Invest Program to Reduce Greenhouse Gas Emissions and Combat Climate Change," January 10, 2023, https://www.nyserda.ny.gov/About/Newsroom/2023-Announcements/2023-1-10-Governor-Hochul-Unveils-Cap-and-Invest-Program.

17 Tom DiChristopher, "New York reveals final deal to prohibit gas use in new construction," *S&P Global Market Intelligence*, May 2, 2023, https://www.capitaliq.spglobal.com/web/client?auth=inherit#news/article?id=75521879&KeyProductLinkType=6.

18 "Governor Hochul Signs Package of Bills Prohibiting Use of 'grade 6' Fuel Oil and Use of Pavement Products Containing Coal Tar." Governor Kathy Hochul. https://www.governor.ny.gov/news/governor-hochul-signs-package-bills-prohibiting-use-grade-6-fuel-oil-and-use-pavement-products.

5% mandate until later this year.[19] Additionally, S5344, which requires heating oil sold for use in any building in the state to be bioheating fuel that contains at least 50% biodiesel and/or renewable hydrocarbon diesel, currently sits in the Senate Committee on Environmental Conservation.[20]

New York's focus on electrification has been critiqued as limiting the state's ability to incorporate a wider array of options for stakeholders and customers. One stakeholder, National Grid, has proposed a hybrid approach that could be pursued in New York and Massachusetts mitigate costs and risks associated with relying heavily on a single electrification strategy.[21] Broader policies are envisioned that increase and incentivize utilities' use of green hydrogen and renewable natural gas (RNG), and that provide incentives for installing renewable heat equipment in homes and buildings, while allowing for consumer choice (i.e., giving consumers a choice as to what method of renewable heating would be best for them, rather than assuming electrification). Market-based carbon pricing mechanisms are promoted as a source of additional revenue for such incentive programs.[22]

3. Vermont

Vermont's Climate Action Plan aims to reach a 40% reduction in 1990 GHG emission levels by 2030. Last year, Vermont passed bill H.715 to implement a Clean Heat Standard in Vermont. At that time, the bill was vetoed by Governor Scott and the legislature failed to overturn the veto, falling short by a single vote.

Later in April 2023, Vermont's House passed bill S.5, known as the Affordable Heat Act.[23] This bill established tradeable clean heat credits, with obligated parties being required to retire credits representing the quantity of GHG emissions reductions caused by a clean heat measure.[24] Measures eligible for clean heat credits include

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19 Liz McCune, "Clean Fuels Industry Urges New York Department of Environmental Conservation to Continue Progress on Decarbonization with Bioheat® Fuel," *Clean Fuels Alliance America,* August 9, 2022, https://cleanfuels.org/news-events/news-releases/2022/08/09/clean-fuels-industry-urges-new-york-department-of-environmental-conservation-to-continue-progress-on-decarbonization-with-bioheat-fuel

20 "Senate Bill S5344." Ny State senate Bill 2023-S5344, n.d. https://www.nysenate.gov/legislation/bills/2023/S5344.

21 National Grid *Clean Energy Vision*, April 2022, p. 7.

22 National Grid *Clean Energy Vision*, April 2022, p. 22.

23 Pat Bradley, "Vermont House passes controversial Affordable Heat Act," *WAMC Northeast Public Radio,* April 25, 2023. https://www.wamc.org/news/2023-04-25/vermont-house-passes-controversial-affordable-heat-act

24 "'Obligated party means: a regulated natural gas utility serving customers in Vermont; or… for other heating fuels, the entity that makes the first sale of the heating fuel into or in the State for consumption within the State." Vermont Bill S.5 as introduced, https://legislature.vermont.gov/Documents/2024/Docs/BILLS/S-0005/S-0005%20As%20Introduced.pdf, pp. 5-6.

heat pumps, solar hot water systems, biofuels, and green hydrogen.[25] Governor Scott vetoed this bill, but his veto was overridden as of May 11, 2023.[26] The legislation also kept the "check back" provision, which requires an eventual vote of the legislature after the Clean Heat Standard is designed but before it is implemented. The Public Utility Commission, the state agency tasked with designing this program, is currently progressing through the hiring process for these clean heat positions.

Burlington voters also approved a measure in March 2023 that implements a carbon pollution impact fee starting at $150 per ton for new construction buildings that install fossil fuel thermal energy systems, and for existing commercial and industrial buildings 50,000 square feet or larger when the building is installing fossil fuel thermal energy space conditioning or domestic water heating systems instead of using renewable systems.[27]

4. Connecticut and Rhode Island

In July 2021, Connecticut passed a law similar to New York's S.3321-A/A.7290. The bill (HB6412) required that 5% of the state's heating oil mix be biodiesel by July 1, 2022. This percentage grows over time, with requirements for biodiesel to make up 50% of Connecticut's heating oil mix by 2035.[28]

One day later, Rhode Island's governor signed H5132A to expand the state's biodiesel requirements. Specifically, by July 1, 2023, all heating oil sold in Rhode Island is required to be at least 9.5-10.5% biodiesel (defined in the statute as inclusive of renewable diesel). By 2030, all heating oil sold in the state must be at least 49.5-50.5% biodiesel.[29] Rhode Island also currently provides incentives to homeowners looking to replace their oil heating with heat pumps.[30]

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[25] Vermont Bill S.5 as introduced, https://legislature.vermont.gov/Documents/2024/Docs/BILLS/S-0005/S-0005%20As%20Introduced.pdf

[26] The Associated Press, "Vermont clean heat bill becomes law as Legislature overrides governor's veto," May 11, 2023, https://apnews.com/article/vermont-affordable-heat-act-veto-override-e719f250f2582b29f2a9a2e1d2940acb.

[27] McCallum, K. (2023, March 10). Burlington considers kicking fossil fuels to the curb. Seven Days. https://www.sevendaysvt.com/vermont/burlington-considers-kicking-fossil-fuels-to-the-curb/Content?oid=37698510

[28] Oil & Energy Online, "Northeast Governors Signs B50 Bills into Law," July 2021. https://oilandenergyonline.com/articles/all/northeast-governors-sign-b50-bills-law/.

[29] State of Rhode Island, H 5132 Substitute A.

[30] "Heat Pump Incentives." Rhode Island Energy. Accessed June 27, 2023. https://www.rienergy.com/RI-Home/Energy-Saving-Programs/Heat-Pump-Incentives.

In Connecticut, the President of the Connecticut Energy Marketers Association ("CEMA") noted that incorporating biofuels in the heating oil fuel mix has no cost impacts on ratepayers.[31] Connecticut plans to first use biodiesel produced in the state at a plant that makes 40 million gallons of biodiesel per year.[32]

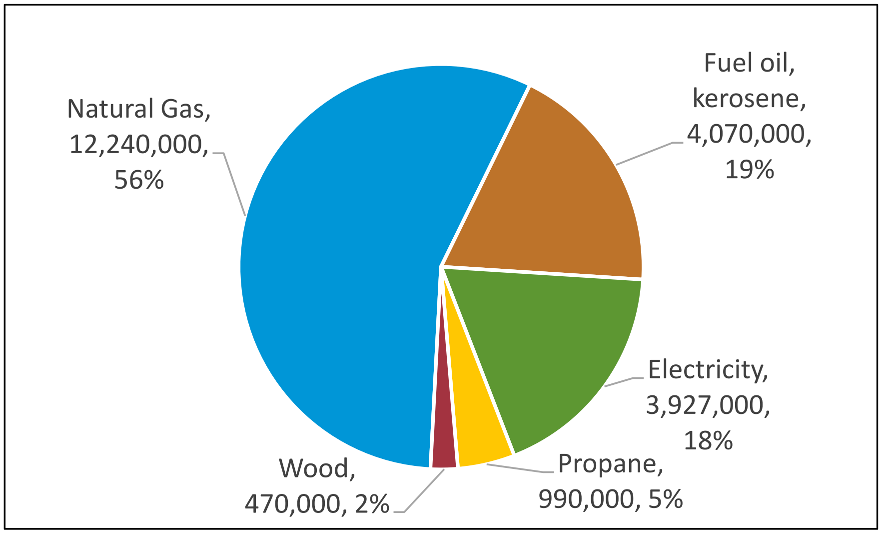
III. Decarbonization of Heating Through Electrification Alone Will Be Challenging in the Northeast

Residential heating in Northeast states is currently heavily dominated by systems burning natural gas and fuel oil/kerosene, which account for 75% of households. Figure 2 shows the relative shares of residential heating systems by fuel type, based on data for winter 2020/21.

[31] Oil & Energy Online, "Northeast Governors Signs B50 Bills into Law," July 2021. https://oilandenergyonline.com/articles/all/northeast-governors-sign-b50-bills-law/.

[32] Marc Robbins, "New heating oil laws kick in July 1st in Conn.," *WFSB*, June 28, 2022. https://www.wfsb.com/2022/06/29/new-heating-oil-laws-kick-july-1st-conn/.

Figure 2: Residential Heating Household Count by Fuel Type in Northeast States, Winter 2021/22[33]



Clean heat policies that rely on large-scale shifts from fossil heat to high efficiency electric heat pumps have the potential to substantially reduce GHG emissions. At the same time, there are significant hurdles to achieving high levels of heat pump penetration in a short period. Table 1 shows the mix of residential heating by fuel source in Northeast states and estimates of associated CO_2 emissions (combining data from 2020 and winter 2021/22).[34] Only 4% of households in the Northeast currently have winter heating from heat pumps, while 56% heat with natural gas, and 19% with fuel oil. About 15% of households have winter heat from other electric sources.

[33] U.S. Energy Information Administration (EIA), *2020 Residential Energy Consumption Survey*, https://www.eia.gov/consumption/residential/data/2020/, Table HC6.7.

[34] Northeast states here combine New England states: Connecticut, Maine, Massachusetts, New Hampshire, Vermont, and Rhode Island; and Middle Atlantic states – New Jersey, New York, and Pennsylvania.

Table 1: U.S. Northeast Residential Winter Heating by Fuel[35]

Heating Fuel Source	Households	Share	Estimated CO_2 Emissions, MT	Avg CO_2 Emissions, MT per Household
Natural Gas	12,240,000	56%	41,720,000	3.4
Fuel Oil	4,070,000	19%	29,570,000	7.3
Electricity	3,927,000	18%	8,620,000	2.2
Heat pump	*780,000*	4%	1,480,000	1.9

Table 1 includes estimates of CO_2 emissions based on EPA data for natural gas and fuel oil combustion. Estimated emissions for electric heat—including heat pumps—are indirect, based on emissions associated with electric power generation. The electricity emissions rates are calculated from EPA data for electric generation in the three relevant bulk power systems covering New York, New England and the Mid-Atlantic.

The importance of emissions reduction in residential heating is a function of the current reliance on fossil fuel combustion in the region, which also creates challenges in pursuing an emissions reduction strategy focused solely or predominantly on electrification. The scale of the challenge is illustrated in Table 2, which presents our estimate of the annual increase in peak electric load associated with various levels of heat pump penetration of the residential heating market in the Northeast states. The calculated impact is shown for assumed winter peak load contribution of heat pumps at two levels: 1.0 kW and 1.5 kW. Moving to an 80% share of residential heating with heat pumps, at 1.5 kW of peak load per unit, would cause an increase in winter peak of more than 23,000 MW, representing more than a quarter of the existing installed generating capacity of New York and New England combined.

[35] Residential heating counts from U.S. EIA Residential Energy Consumption Survey for 2020: https://www.eia.gov/consumption/residential/data/2020/; energy use estimates from U.S. EIA Winter Fuels Outlook Survey, March 2023: https://www.eia.gov/outlooks/steo/pdf/wf01.pdf

Table 2: Estimated Electric Peak Load Impacts by Heat Pump Penetration

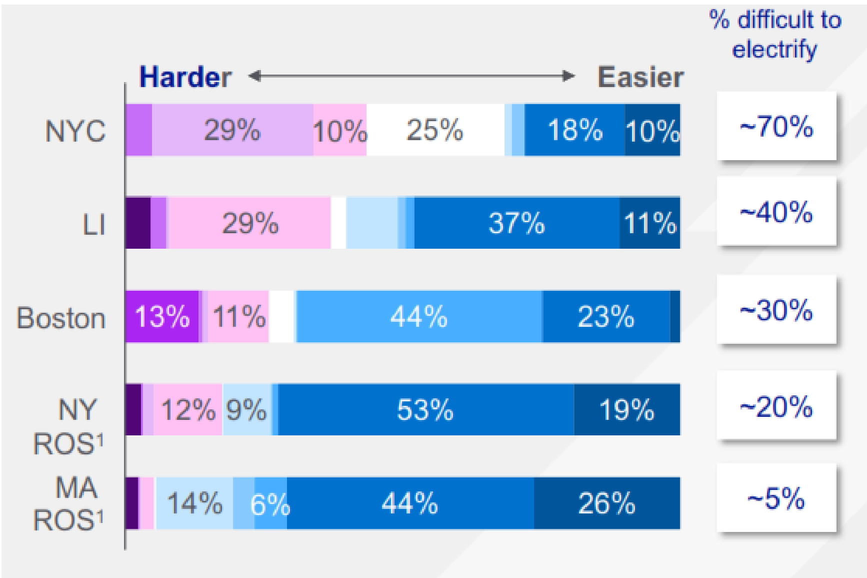
Heat Pump Share of Heating	Added Heat Pumps	Additional Peak Load, MW	
		1.0 kW per unit	1.5 kW per unit
40%	7,310,000	7,310	10,965
50%	9,340,000	9,340	14,010
60%	11,360,000	11,360	17,040
70%	13,390,000	13,390	20,085
80%	15,410,000	15,410	23,115

While the decarbonization benefits of transitioning to heat pumps are potentially large, there are also significant challenges to achieving the scale of anticipated change, even over a decade or more. To achieve a very high degree of decarbonization in home heating – e.g., use of high efficiency heat pumps in 70% of homes – would require more than 13 million heat pumps just for existing homes across the region. This will require significant changes in infrastructure, spanning the manufacturing, distribution, and installation services required for an approximately 14-fold increase in the number of residential heat pumps. This challenge has been recognized with respect to federal policy, as indicated by the announcement in April 2023 of $250 million in funding from the Department of Energy to accelerate electric heat pump manufacturing in the U.S.[36]

The challenges of achieving full electrification, particularly in urban areas, has been noted by National Grid, which has utility service territories spanning much of New York, Massachusetts, and Rhode Island. In a presentation to investors in July 2022, the company presented summary results from a study of electrification of the Northeast building stock, shown in Figure 3.

[36] U.S. Department of Energy, "Biden-Harris Administration Announces $250 Million to Accelerate Electric Heat Pump Manufacturing Across America," April 18, 2023, https://www.energy.gov/articles/biden-harris-administration-announces-250-million-accelerate-electric-heat-pump

Figure 3: "Ease of Electrification" for US Northeast building stock (% of square footage) (National Grid Presentation)[37]



Electrification of home heating will also require significant additional infrastructure required to generate and deliver electric power. The peak load impacts presented in Table 2 are high level approximations, as the actual net impact to peak load from heat pump installation will depend on a number of complex factors. For example, some heat pump installations could replace less efficient electric resistance heating (e.g., baseboard electric), which could reduce peak load. Conversely, certain heat pump installations in parts of the region – e.g., for larger homes, and/or those located in colder areas – could contribute significantly higher demand per unit. There are additional complexities regarding net impacts in the correspondence between the timing of heat pump peak load and the overall system net load peak, which will change over time, particularly with increased quantities of solar generation on the system. Also, it is important to note that the peak load impacts are for heat pumps only, and exclude any other sources of electrification load, most notably the wide scale adoption of electric vehicles for personal and business use. Transportation electrification will also add to the volume and complexity of electric load impacts going forward.

[37] Presentation, "National Grid US Investor Event," July 19, 2022, https://www.nationalgrid.com/document/147356/download.

Distribution system upgrade costs associated with electrification will be substantial. In the investor presentation noted above, National Grid projects compound annual growth in rate base (i.e., utility assets earning a reregulated rate of return) of 8% from 2022 to 2026, and identifies "strong [capital expenditure] drivers" associated with the energy transition, much of which occurs beyond 2026.[38]

A. Regional electric forecasts show substantial expected growth

Recent regional forecasts of electric demand incorporate estimates of future load resulting from electrification. New England's regional grid operator, ISO New England, reports on forecasted load in its annual Capacity, Energy, Loads, and Transmission forecast (CELT report), the most recent release from May 1, 2023. The New York Independent System Operator (NYISO) reports on forecasted load in its "Gold Book," the most recent release from April 2022.

Table 3 summarizes ISO-NE forecasts of net peak load and electrification load, showing both heating electrification and transportation electrification.

Table 3: ISO-NE Winter Peak Load and Electrification Forecast, MW, 2022/23-2032/33[39]

ISO-NE	2022/23	2032/33	Change	CAGR
Net peak load	20,047	26,267	6,220	3.0%
Heating electrification	175	2,965	2,790	36.9%
Transportation	116	3,420	3,304	45.6%

Table 4 shows comparable data for NYISO. Both the ISO-NE and NYISO forecasts reflect base, or reference, cases, and indicate similar growth rates for both heating and transportation electrification through the winter of 2032/33.

[38] *Id.*, slide 10.

[39] ISO New England, *2023 CELT Report*, May 1, 2023, Sections 1.2 and 1.7.

Table 4: NYISO Winter Peak Load and Electrification Forecast, MW, 2022/23-2032/33[40]

NYISO	2022/23	2032/33	Change	CAGR
Net peak load	23,893	28,756	4,863	2.1%
Heating electrification	329	8,174	7,845	42.9%
Transportation	78	2,112	2,034	44.3%

In total, the two forecasts anticipate 10,635 MW of added winter peak load from heating electrification, similar in magnitude to the lower peak load estimate in Table 2 at 60% heat pump penetration, though the two RTO forecasts exclude Pennsylvania and New Jersey, which are reflected in the estimates for the Northeast states.[41]

Note that though the net peak load growth appears comparatively low in the forecasts summarized above, the growth rates are far higher than recent trends, which have typically been flat or even negative over the past decade for many large electric systems in the U.S.[42]

An increase in peak load on the order of 10,000 MW will present significant challenges for the electric system. Using typical utility-scale wind or solar generation facilities for reference, the peak demand increase equates to the installed capacity of about 100 such facilities. Yet, the additional generation capacity need is likely far greater, because solar contributes relatively little capability in the winter. Furthermore, while wind typically generates at relatively high levels in the winter, large quantities of geographically dispersed generation are needed to bolster the assurance that wind will provide adequate aggregate generation at any particular time of need.

The scale of increased demand from electrification of heating and transportation will also present challenges for the electric distribution system, which was developed for very different volumes and distributions of load. Upgrades of distribution feeders and equipment will be needed to resolve potential overloads. In order to accommodate large increases in renewable generation, required upgrades will likely extend to substations and to the bulk transmission system. An analysis of distribution system impacts to Pacific Gas & Electric Company's (PG&E) northern California system from state policies driving aggressive growth in electric heating and electric

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40 NYISO, *2022 Load & Capacity Data: Gold Book,* April 2022, Tables I-1d, I-11d, and I-13c.

41 Detail on the forecast of heating load for the CELT forecast shows a reference case assumption that 69% of the housing stock has electric heating by 2050; See ISO New England, *Final 2023 Heating Electrification Forecast*, April 28, 2023, https://www.iso-ne.com/static-assets/documents/2023/04/heatFx2023_final.pdf, slide 21.

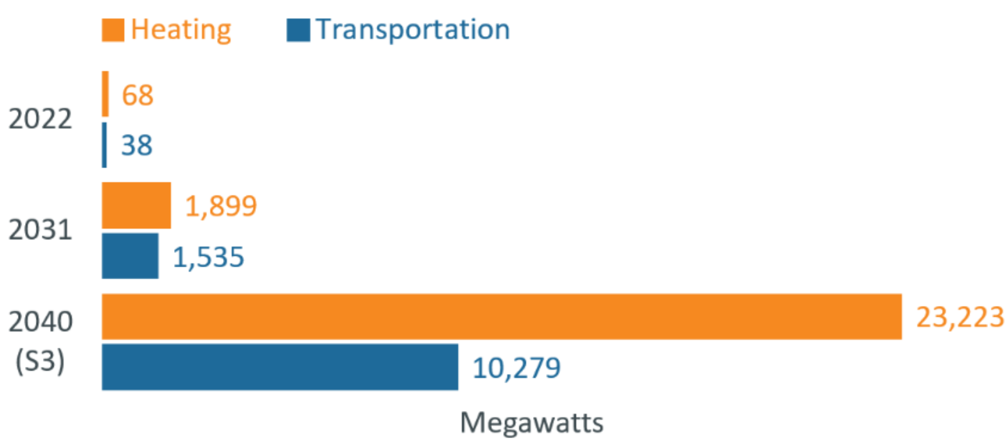
42 EIA data show that combined average annual electricity sales in the Northeast states (CT, MA, ME, NH, NJ, NY, PA, VT, RI) fell by approximately 1% for the period 2015-2019 (pre-COVID) compared to the previous five years 2010-2014. Data from: https://www.eia.gov/electricity/data/state/xls/861m/HS861M%202010-.xlsx.

vehicles concluded that a significant increase in needed feeder and substation upgrade projects could exceed the utility's planned capability over the next decade and present an impediment to electrification goals.[43]

B. Electrification beyond 2030

Scenarios of policy-driven electrification show accelerating impacts on the electric grid beyond 2030. A 2022 study by ISO New England looked at the growth of peak electric load under several scenarios based on implementation of state electrification policies.[44] A "deep decarbonization" scenario showed a more than tenfold increase in peak electric demand from heating between 2031 and 2040, shown in Figure 4.

Figure 4: Current and Projected Peak Electrification Loads (ISO New England)[45]



(The projected peak load values for 2031 in Figure 4 are different than those shown in Table 3, with Figure 4 reflecting data from an earlier CELT report).

43 Anna Brockway, Duncan Callaway, and Salma Elmallah, "Can Distribution Grid Infrastructure Accommodate Residential Electrification and Electric Vehicle Adoption in Northern California?," *Energy Institute at Haas WP 327R*, December 2022, https://haas.berkeley.edu/wp-content/uploads/WP327.pdf

44 ISO New England, "2021 Economic Study: Future Grid Reliability Study Phase," (July 2022); https://www.iso-ne.com/static-assets/documents/2022/07/2021_economic_study_future_grid_reliability_study_phase_1_report.pdf.

45 *Id.*, Figure 2-8, page 12.

C. Emissions reduction from electrification depends on decarbonization of the electric grid

Relying heavily on electrification to decarbonize residential and commercial heating necessarily requires that the carbon intensity of electricity be reduced significantly. Though electric generation has become less carbon intensive over time, particularly with the progressive retirement of coal-fired plants, a substantial amount of electric generation is still provided from plants fired with fossil natural gas. For example, in Massachusetts, about two-thirds of the electricity produced in the state in 2020 was fueled by natural gas.[46] Further decarbonization of electricity is necessary to maximize the emissions reduction potential of electrification.

The significance of this issue can be shown with data from the California Low Carbon Fuel Standard (LCFS) Program (discussed further in Section VI.B.2, below). Figure 5 shows the carbon intensity of electricity for transportation compared to that for biodiesel and renewable diesel (on a combined basis) as reported under LCFS. For most of the program, the carbon intensity of electricity has been substantially higher than that of biodiesel or renewable diesel. Moreover, the proposed 2023 carbon intensity value for grid electricity for transportation in California is 81 gCO_2e/MJ, more than twice the level of biodiesel/renewable diesel.[47] This reflects the fact that natural gas generation still represents a significant portion of grid electricity in California, particularly when the sun isn't shining – i.e., overnight, when most vehicle charging is assumed to occur.

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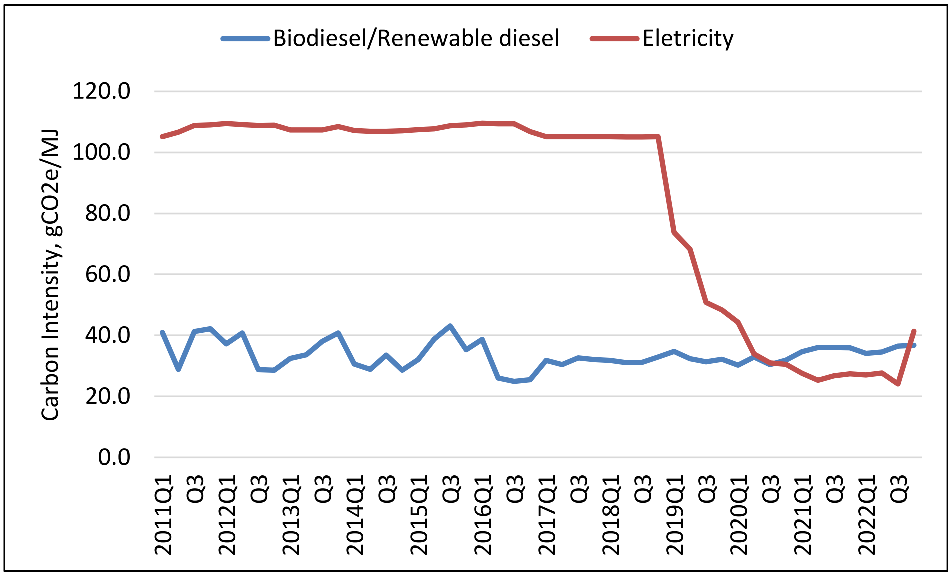
[46] Boston Solar. "Where does my electricity come from in Massachusetts?," September 15, 2022. https://www.bostonsolar.us/solar-blog-resource-center/blog/where-does-my-electricity-come-from-in-massachusetts/#:~:text=Massachusetts%20relies%20heavily%20on%20natural,%2C%20oil%2C%20and%20nuclear%20power.

[47] California Air Resources Board (CARB), *Low Carbon Fuel Standard Annual Updates to Lookup Table Pathways*, November 2, 2022. https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/2023_elec_update.pdf.

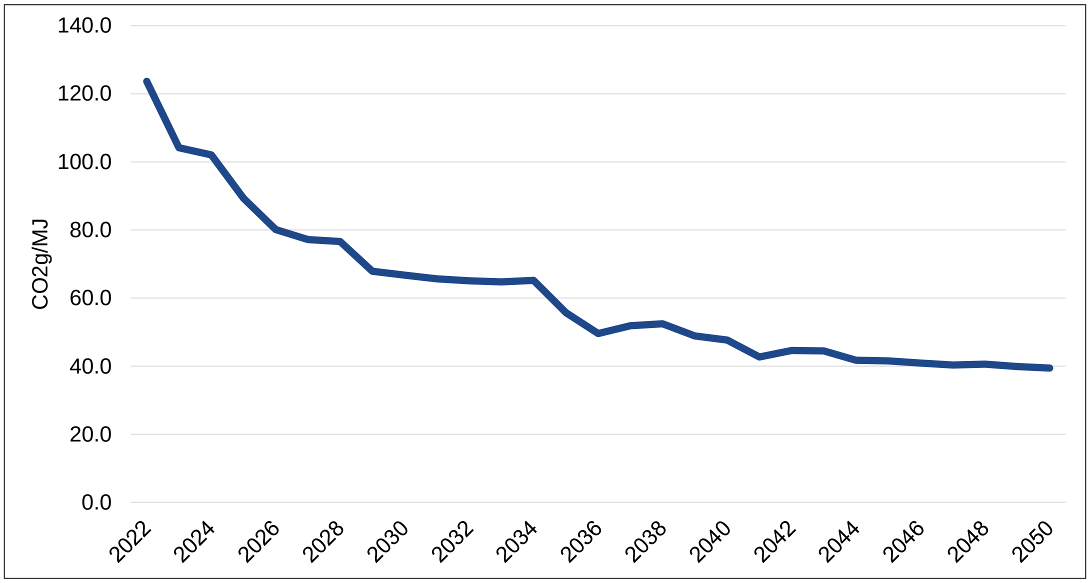
Figure 5: Carbon Intensity of Electricity and Biodiesel/Renewable Diesel, California[48]



There is no comparable source of information for comprehensive carbon intensity of the electric grid in the Northeast states. However, EIA modeling of the electric grid for the Annual Energy Outlook 2023 includes projection of electric generation and CO_2 emissions that provide a picture of potential trends, shown in Figure 6 for the combined New York and New England regions. The calculated carbon intensity values are for CO_2 only (i.e., they do not include other GHGs) for EIA's modeled case for "high uptake" under the Inflation Reduction Act (IRA). The data show that carbon intensity of the Northeast grid is expected to fall relatively slowly over the next two decades, and only toward the end of the period would approach the carbon intensity associated with biodiesel and renewable diesel as evaluated under the California LCFS program. This highlights the challenges of achieving CO_2 emissions reductions through reliance only on electrification.

[48] CARB, LCFS Data Dashboard, https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard.

Figure 6: Projected CO2 Intensity of Combined New York and New England Grids[49]



The efficacy of policies to decarbonize heating depends critically on reducing the carbon intensity of the electric grid. Consequently, it is important to measure and track the carbon intensity of electricity supply, and to advance expansive policies that allow flexibility in methods to reduce GHG emissions from heating.

IV. Exclusive Reliance on Electrification Will Be Very Costly

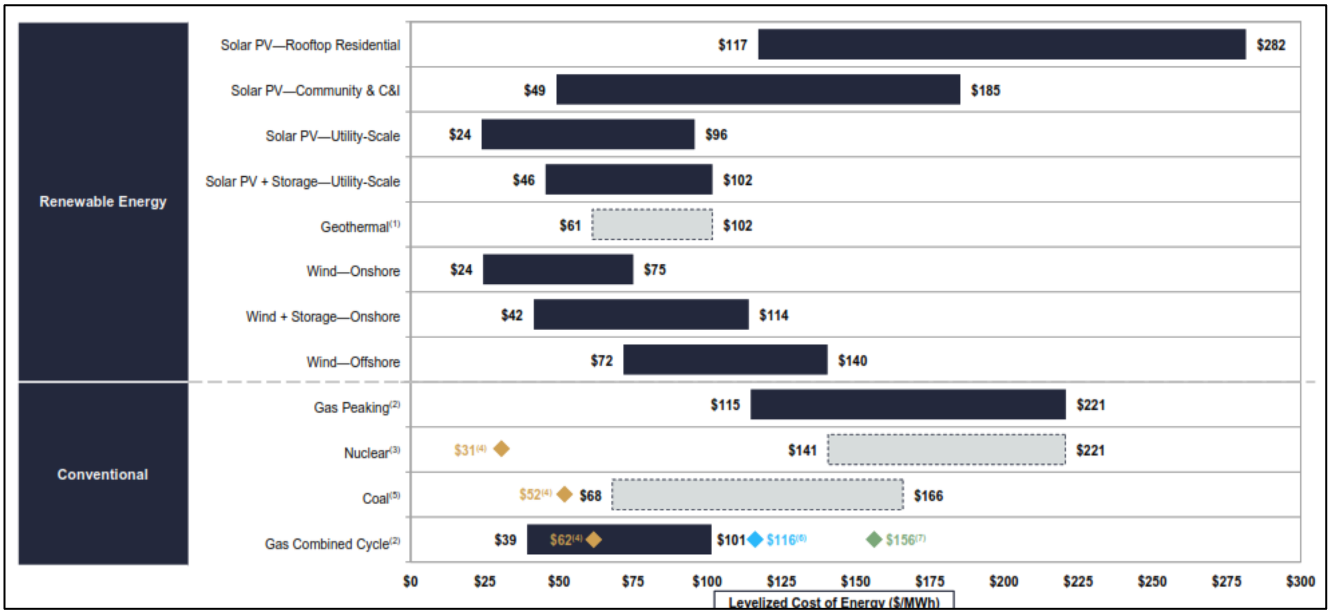
Pursuing decarbonization goals through exclusive reliance on electrification will be very costly. It requires not only a rapid transformation of heating and transportation from fossil to electric technology on the demand side, but also transformation of the electric grid to supply zero carbon power. To date, states in the Northeast have not developed detailed studies of impacts and costs of electrification policies. In part, this reflects the challenges of evaluating incremental costs in circumstances that are complex, dynamic and uncertain. It is nonetheless possible to put some bounds on likely costs.

49 Derived from EIA data on projected carbon emissions and electric generation from Annual Energy Outlook 2023, High Uptake of IRA case.

A. Renewable Generation Resources Have Low Operating Cost, But Total Cost May Increase Rapidly with Increased Penetration

The variable operating cost of renewable generation resources such as wind and solar is near zero, but the total cost of these resources must still be recovered from consumers. The current levelized cost of wind and solar resources – the investment cost plus fixed and variable costs over time, in dollars per unit of energy – are relatively low compared to other traditional generation sources. As shown in Figure 7, the estimated ranges of levelized cost for utility-scale solar and onshore wind, in $/MWh, are both below the levelized cost of a peaking gas-fired resource, which is the typical reference for incremental generation capacity need. However, as discussed below, this excludes a number of costs and factors that will become increasingly relevant for high renewables scenarios.

Figure 7: Levelized Cost of Energy, Unsubsidized (Lazard, 2023)[50]



(1) Given the limited data set available for new-build geothermal projects, the LCOE presented herein represents Lazard's LCOE v15.0 results adjusted for inflation.
(2) The fuel cost assumption for Lazard's unsubsidized analysis for gas-fired generation resources is $3.45/MMBTU for year-over-year comparison purposes. See page titled "Levelized Cost of Energy Comparison—Sensitivity to Fuel Prices" for fuel price sensitivities.
(3) Given the limited public and/or observable data set available for new-build nuclear projects and the emerging range of new nuclear generation strategies, the LCOE presented herein represents Lazard's LCOE v15.0 results adjusted for inflation (results are based on then-estimated costs of the Vogtle Plant and are U.S.-focused).
(4) Represents the midpoint of the unsubsidized marginal cost of operating fully depreciated gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas combined cycle or coal asset is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas combined cycle, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper- and lower-quartile estimates derived from Lazard's research. See page titled "Levelized Cost of Energy Comparison—Renewable Energy versus Marginal Cost of Selected Existing Conventional Generation Technologies" for additional details.
(5) Given the limited public and/or observable data set available for new-build coal projects, the LCOE presented herein represents Lazard's LCOE v15.0 results adjusted for inflation. High end incorporates 90% carbon capture and storage ("CCS"). Does not include cost of transportation and storage.
(6) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "Blue" hydrogen, (i.e., hydrogen produced from a steam-methane reformer, using natural gas as a feedstock, and sequestering the resulting CO_2 in a nearby saline aquifer). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is $5.20/MMBTU, assuming ~$1.40/kg for Blue hydrogen.
(7) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "Green" hydrogen, (i.e., hydrogen produced from an electrolyzer powered by a mix of wind and solar generation and stored in a nearby salt cavern). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is $10.05/MMBTU, assuming ~$4.15/kg for Green hydrogen.

The levelized costs for wind and solar shown in Figure 7 do not account for additional renewable integration costs that will be needed for upgrading the transmission system to accommodate large volumes of intermittent generation at a distance from load. More significantly, the reported costs do not account for the capacity need of the system. Wind and solar generation are intermittent resources, subject to periodic and uncertain wind and solar "droughts" that necessitate additional generation and storage capacity in order to "firm" the renewable capacity such that system reliability is maintained. The Lazard report from which Figure 7 is sourced includes estimates of firming costs via gas-fired peaking resources that can double or triple the levelized cost of wind and solar, depending on the regional system considered and the current penetration of resources.

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50 Lazard, Levelized Cost of Energy+ (April 2023). [https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/.](https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/)

To achieve very high levels of decarbonization of the electric grid, multiples of current renewable capacity and storage additions will likely be required. Annual additions of renewable capacity in New England averaged about 300 MW per year over the decade to 2019, and additions from 2020 through 2030 are estimated at a rate of 800 MW per year.[51] But achieving high levels of grid decarbonization will require much more renewable capacity and storage. A recent ISO-NE analysis examined a potential carbon-constrained buildout with 97 gigawatts (GW) of new solar, wind and battery storage capacity by 2050.[52] This compares to current *total* system generation capacity of approximately 26 GW. The analysis shows that resources added in later years will be essentially unused except during winter peak conditions, meaning there is less energy produced per unit of capacity, and therefore a substantially increased levelized cost of energy over time. Required upgrades to transmission and distribution systems to move generated power to increased electric load will further add to the cost of high electrification scenarios.

The ISO-NE study concluded that significant decarbonization with wind, solar, and energy storage is possible, but that it will be "extremely expensive."[53] While the most extreme results of the study apply to the period after 2040, the analysis highlights that decarbonization through electrification alone is subject to significant constraints in the ability to achieve high decarbonization of the electric grid.

B. Incremental Generation Cost Associated with Heating Electrification

As discussed in Section III, the peak demand impact of heating electrification policies in New England is on the order of 3,000 MW in the near term, and could be greater than 20,000 MW by 2040. This represents a peak generation need that would be additive to current expectations of supply changes from retired capacity and generation additions incentivized by federal Inflation Reduction Act, state supply policies (e.g., for offshore wind), and the ISO New England wholesale power markets. The incremental generation capacity needed to meet heating electrification demand will require substantial costs that will ultimately be borne by electricity ratepayers. Estimating the associated cost depends on the assumed mix of generation and is complicated by uncertainties regarding the net capacity value (i.e., the net contribution of a resource to meeting peak demand) that resources will contribute as more renewables are added to the system. The net capacity contribution of a

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[51] Brattle Group, "Achieving 80 Percent GHG Reduction in New England by 2050," 2019. https://www.brattle.com/wp-content/uploads/2021/05/17233_achieving_80_percent_ghg_reduction_in_new_england_by_20150_september_2019.pdf.

[52] ISO-NE, "Economic Planning for the Clean Energy Transition (EPCET) Pilot Study," June 2023. https://www.iso-ne.com/static-assets/documents/2023/06/a03_2023_06_15_pac_epcet_policy_scenario_results.pdf.

[53] *Id.*, slide 47.

renewable resources such as solar decreases as more solar is added to the system. Assuming that wind generation is more likely to be the needed marginal (zero emission) capacity in winter heating months (solar being less effective during New England winters), it is possible to calculate a rough estimate of potential incremental generation cost. If wind were accredited at 40% of its installed capacity (a very generous assumption[54]), adding wind to meet incremental peak demand of 10,000 MW would require 25,000 MW of installed wind capacity. At an installed cost of approximately $1,700 per kilowatt (kW), assumed by EIA for onshore wind,[55] this translates to $42.5 billion in incremental investment costs (=25,000 MW x $1,700/kW x 1,000).

Additionally, significant investment would also be needed for upgrades to the electric transmission and distribution systems. These costs have greater uncertainty, as they will depend on the timing and location of new generator installations as well as the location and pattern of electrification demand.

C. Significant Additional Electric System Costs Will Be Required

As noted, electric system costs beyond generation investment are uncertain, but they are likely to be significant. A 2018 study of U.S. regional impacts from electrification estimated required transmission investment in New England of approximately $11 billion through 2035 (in 2016 dollars).[56] The same study estimated incremental generation investment costs of approximately $30 billion to $49 billion (in 2016 dollars), consistent with the rough calculation presented above. The study further estimated consumer capital costs associated with electrification of heating of approximately $11 billion (in 2016 dollars).

While aggregate cost estimates of electrification are uncertain, the uncertainty is not that costs might actually be very low, but that they could be much higher. There are unavoidable incremental costs associated with retrofitting heating systems, increasing the number of generators needed to produce zero-emissions electric energy, and upgrading the transmission and distribution systems to accommodate new power flows.

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54 NYISO, for example, generally accredits installed wind capacity at less than 20%. See NYSERDA, "Request for Information LSRRFI22-1 (Capacity Accreditation," July 28, 2022. https://portal.nyserda.ny.gov/servlet/servlet.FileDownload?file=00P8z000001RFGaEAO.

55 EIA, "Cost and Performance Characteristics of New Generating Technologies, *Annual Energy Outlook 2022*"; https://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf

56 ICF, "Implications of Policy-Driven Residential Electrification," July 2018. https://www.aga.org/wp-content/uploads/2018/07/aga_study_on_residential_electrification.pdf.

V. Flexible, Technology Neutral Policies Can Complement Decarbonization Via Electrification

Electrification of residential and commercial heating – particularly in tandem with reductions in the carbon intensity of electricity generation – is a sensible strategy for decarbonization. However, the scale and pace of the required transition to electric heat with high-efficiency heat pumps are daunting, and the potential bottlenecks discussed above could either reduce the likelihood of achieving decarbonization goals on schedule, or substantially increase the costs of racing to get a huge volume of heat pumps, renewable production, and distribution assets in place in a short period of time. In addition, this required transition to electric heat would impose a particular burden on low- and moderate-income families, as replacing oil furnaces with heat pumps is costly and disruptive, while renewable heating oil blends exist as affordable options for home heating.

As a complement to electrification-focused objectives, policies allowing for and promoting the decarbonization of fuels currently used to heat homes and businesses can offer a cost-effective means to meet interim GHG reduction goals while electrification advances. Promoting emissions reductions from existing fossil-fuel based heating systems will rely on existing infrastructure, thereby avoiding the need for costly and time-consuming upgrades, while accelerating meeting GHG goals.

Decarbonization policies that rely exclusively on electrification involve risks that the cost of electricity will be driven up rapidly, undermining consumer incentives to electrify heating and transportation. Such policies may also foreclose other, more cost-effective, pathways to decarbonization, some of which may be unknown currently.[57]

To illustrate the potential value of complementary decarbonization policies, we draw on information from the successful California LCFS Program, discussed more fully in Section D.

[57] Potential drawbacks of 100% electrification policies are discussed in: Rapson, David S. and James B. Bushnell, "The Electric Ceiling: Limits and Costs of Full Electrification," National Bureau of Economic Analysis Working Paper 30593, October 2022. https://www.nber.org/papers/w30593.

A. Early reductions in GHG emissions are critical

CO_2, methane, and other GHGs are highly persistent in the atmosphere. CO_2 in particular may stay in the atmosphere for hundreds or thousands of years after it is emitted.[58] Consequently, every amount of CO_2 emissions that can be avoided will have long-term benefits toward limiting the overall atmospheric concentration of GHGs, and keep us within the bounds estimated to avoid a potential climate change catastrophe. There are two ways in which early emissions reductions provide significant benefits relative to delayed reductions. The first is that early reductions will ease the difficulty of achieving greater emissions reductions over a compressed period in the future. The second is that early reductions mitigate near-term global warming and associated disruptions and costs. These factors drive what has been termed the "Time Value of Carbon," which posits that there is a greater benefit from reducing carbon dioxide or other GHG emissions immediately than reducing the same amount of emissions in the future.[59] The high value of immediate action is magnified by uncertainties and the potential of catastrophic and irreversible effects when climate tipping points have been breached.

Later attempts to catch up to emissions reduction targets will be difficult and costly. An analysis by the International Monetary Fund (IMF) as part of its World Economic Outlook Report from October 2022 found that slower near-term GHG emissions reduction efforts, representing only "partially credible" policies, could nearly double the cost of a transitioning by 2030.[60]

In general, policies aimed at gradual and credible decarbonization policies provide households and firms the incentive and time to adapt to a low-emission economy. In contrast, policies that are implemented late, as a last resort to achieve emissions goals, are necessarily much more costly and burdensome to the economy. The implications of the analysis extend to policies narrowly focused on a single approach to decarbonization, such as electrification, to the exclusion of other methods. More flexible, multi-pronged, policies – including the accommodation of low-carbon fuels – allow for early emissions reductions and reduced costs.

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58 The amount of time CO_2 stays in the atmosphere cannot be identified by a single value. The U.S. EPA notes that some emitted CO2 is absorbed through geochemical or biological processes, while the balance can remain in the atmosphere for thousands of years. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

59 Preston, Felix, and Puja Jain. "The Time Value of Carbon." *Generation Investment Management*, May 27, 2021. https://www.generationim.com/our-thinking/insights/the-time-value-of-carbon/.

60 See summary discussion at: https://www.imf.org/en/Blogs/Articles/2022/10/05/further-delaying-climate-policies-will-hurt-economic-growth

B. Low carbon fuels can provide emissions reductions relying on existing infrastructure

Low carbon fuels such as RNG, biodiesel, and renewable diesel, applicable to decarbonizing residential and commercial heating concurrent with pursuit of electrification goals, have particular value because they are readily incorporated within the existing fuel distribution system.

RNG and renewable diesel are so-called "drop-in" fuels. They are functionally and chemically indistinguishable from the fossil fuels they displace, and consequently can be blended with fuels in the distribution system without limit and with no need for segregation of facilities or new infrastructure.[61] For home and business heating, RNG can be delivered through existing gas pipeline and distribution systems, and renewable diesel can be mixed in any concentration up to 100% in the diesel/fuel oil distribution chain. While biodiesel is not a drop-in fuel, it is currently blended and accommodated readily within existing diesel/fuel oil distribution networks in the Northeast.

Policies supporting the use of renewable fuels for heating in the Northeast could lead to a need for increased regional production capacity, but the distribution infrastructure for such fuels is essentially already in place.

C. Renewable fuel could provide significant GHG emissions reduction in the near term

As discussed in Section D, California's LCFS Programs has had remarkable success in promoting the rapid diversification of low-carbon fuels, including electricity, for transportation in the state. A notable example is the substantial growth of renewable diesel supply, which has tripled in the past four years (see Figure 10 below). Renewable diesel has grown to represent approximately 38% of the California transportation diesel market as of 2022, with biodiesel making up an additional 8% of the market.

On a weighted basis, renewable diesel and biodiesel currently provide a net reduction in GHG emissions relative to petroleum diesel of approximately 65%. If these renewable fuels had a 38% share of heating oil in the Northeast, it would provide net emissions reductions of more than 7 million MT of CO_2 per year, which

61 See, for example, U.S. EPA, "Renewable Natural Gas from Agricultural-Based AD/Biogas Systems," August 23, 2022, https://www.epa.gov/agstar/renewable-natural-gas-agricultural-based-adbiogas-systems.

corresponds to the net emissions reduction from adding 1.6 million heat pumps – i.e., tripling the current share of residential heat pumps in the Northeast.[62]

D. Decarbonization via low-carbon fuels can help mitigate price spikes and support reliability and resiliency

The challenges of rapid electrification include the potential that demand growth outstrips the capability of the transmission and distribution systems to move power economically, increasing the likelihood of local electricity price spikes and degraded reliability and resiliency of electric service. Achieving a portion of decarbonization goals via mechanisms other than electrification alone will help mitigate such risks. This a general feature of flexible compliance policies: encouraging alternative, and lower-cost, mechanisms tend to ease constraints that contribute to supply/demand imbalances that cause price spikes and supply shortfalls. The impact of a hard constraint on one compliance route can be eased by the availability of alternatives.

VI. Developing Efficient Decarbonization Policies

A. Economic Principles that Guide Efficient Decarbonization Policies

Since the substantial majority of GHG emissions are from the combustion of fossil fuels, decarbonization policies are ultimately about reducing the use of fossil fuels and meeting associated energy needs – such as for heating, transportation, and electric power generation – from other low- or zero-carbon fuel sources, including electricity. Successful emissions reduction policies generally create incentives that promote reduced demand for fossil fuels, and increased supply and diversification of low-emission alternatives.

The cost of compliance can be minimized through mechanisms that emphasize flexibility with respect to allowed compliance methods. In particular, cost-effectiveness is promoted by policies that are “technology neutral” in the sense of not specifying a single compliance pathway, but rather allowing for multiple methods – including approaches that may not yet exist – to achieve emissions reductions. Providing technology-neutral compliance flexibility creates incentives for market participants to identify and develop low-cost solutions. In the context of low carbon fuel programs, described below, neutrality with respect to fuel feedstocks encourages the exploration of new pathways and technologies that offer more cost-effective emissions reductions.

[62] This estimate assumes that additional heat pumps replace gas and fuel oil systems in equal share. It is thus conservative in that heat pumps currently offer greater savings relative to fuel oil systems, and would be expected to replace those at a higher rate.

Policies based on emissions allowances or credit mechanisms are particularly suited to providing compliance flexibility. Emissions reduction targets can be established, and compliance measured, through allowances and credits that provide a metric for the overall objective (e.g., GHG emissions limits) without mandating the specific means of compliance. Market participants will seek to minimize the cost of compliance through the use of high impact, low-cost methods, which can be validated by the program administrator to ensure that overall targets are being achieved.

Credit trading and banking can also help minimize compliance costs. Obligated parties that "over comply" in a particular period can sell credits to other market participants for the same period or future periods, which reduces the potential for supply or demand constraints to create spikes in compliance costs, while still achieving emissions reduction targets over time.

B. Allowance/Credit Program Examples

Emissions allowance or credit programs have been applied in various jurisdictions around the world to promote cost-effective reductions of air pollutant emissions. In the U.S., examples include the federal Cross-State Air Pollution Rule (CSAPR)[63] and the NOx Budget Trading Program,[64] and at the state level, the Regional Greenhouse Gas Initiative (RGGI), and California's Cap-and-Trade (C&T) and Low Carbon Fuel Standard (LCFS) programs. These types of programs set aggregate limits on total emissions or carbon intensity while allowing flexible methods for market participants to demonstrate compliance. Such programs establish how credits or allowances – e.g., representing a certain amount of emissions or carbon intensity – can be generated, and allow market participants to buy, sell, and even save these credits or allowances.

1. California Cap and Trade

California's Cap-and-Trade (C&T) Program, which specifies declining limits on statewide GHG emissions, was implemented beginning in 2013 and extended to encompass transportation fuel as of January 1, 2015. The C&T Program applies to emissions covering about 80% of California's GHG emissions and establishes a declining limit on major emissions sources. Allowances are created equal to the capped emissions each period, with one allowance equal to one metric ton of carbon dioxide equivalent emissions. The annual cap is reduced each year,

[63] U.S. E.P.A., "Overview of the Cross-State Air Pollution Rule (CSAPR)," February 16, 2023, https://www.epa.gov/csapr/overview-cross-state-air-pollution-rule-csapr.

[64] U.S. E.P.A., "NOx Budget Trading Program," February 24, 2023, https://www.epa.gov/power-sector/nox-budget-trading-program.

and correspondingly fewer allowances are created. Fuel suppliers must report GHG emissions from supplied fuel and are obligated to secure and surrender a corresponding number of allowances and offset credits for each compliance period.[65]

2. California Low Carbon Fuel Standard

A low carbon fuels program, or low carbon fuel standard, is a policy that requires fuels to meet a certain energy-related GHG target, such as a specific carbon intensity (CI), within a specified jurisdiction and timeframe.[66] Programs implemented to date apply specifically to transportation fuels, but the principles apply to the use of any alternatives to fossil fuel combustion, such as for space heating. Objectives of low carbon fuels programs include:

- Reduce GHG emissions from fuel combustion
- Reduce emissions of criteria and toxic air pollutants from fuel combustion
- Increase demand for and production of low carbon fuels
- Reduce demand for and production of fossil fuels
- Diversify fuel supply and enhance fuel security

California's Low Carbon Fuel Standard (LCFS) Program was the first comprehensive state initiative to promote the development, production, and use of low-carbon fuels for use in transportation. The program is designed to progressively reduce the carbon intensity of transportation fuel in California through a technology-neutral, flexible, and consequently efficient, mechanism.

The LCFS sets annual CI benchmarks for gasoline, diesel, and the fuels that replace them – including electricity – with the reference benchmarks decreasing over time.[67] Fuels with a CI lower than the benchmark generate credits, while those with a CI higher than the benchmark generate deficits. For each compliance period, transportation fuel providers must demonstrate compliance with the CI standard through the blending of fuels

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65 California Air Resources Board, "Cap-and-Trade Program," https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program.

66 Minnesota, New Mexico, and New York have active clean fuel standard bills under consideration in 2022. See Congressional Research Service, "A Low Carbon Fuel Standard: In Brief," July 7, 2021, https://sgp.fas.org/crs/misc/R46835.pdf.

67 California Air Resources Board, "LCFS Basics". Available at: https://ww2.arb.ca.gov/resources/documents/lcfs-basics

and/or purchase of LCFS credits. The LCFS allows market participants to determine how meet the program targets – i.e., with the mix of fuels they bring to market – and allows for trading of credits separate from fuels.[68] By accounting for the CI of each fuel, and the resulting credits and deficits, LCFS promotes lower-CI fuels without fuel-specific mandates.

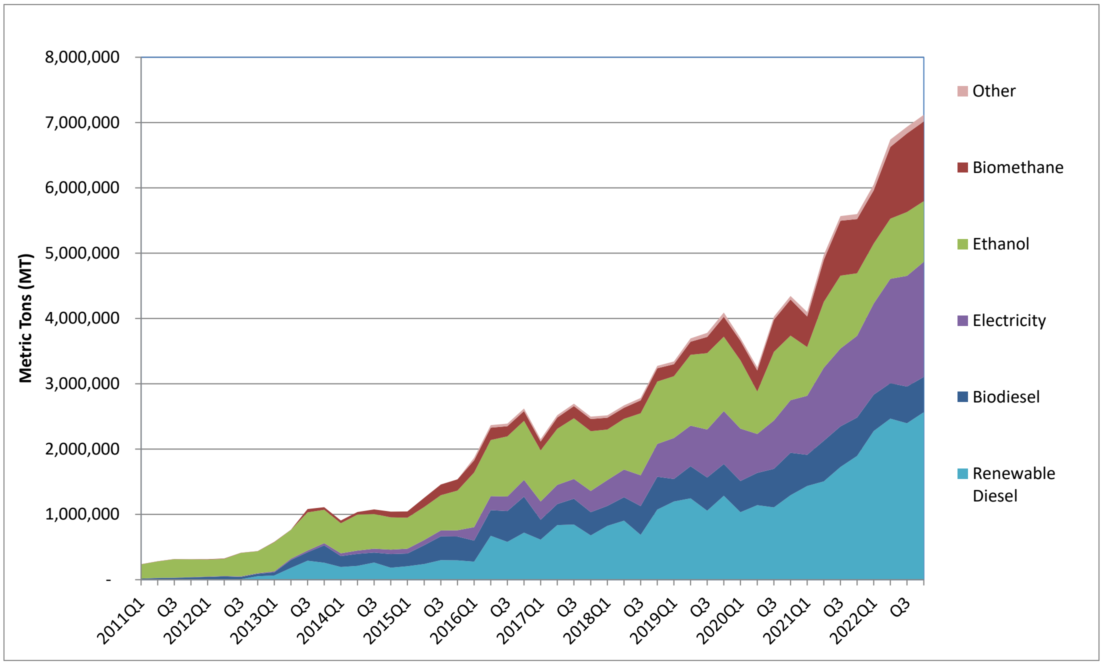
The LCFS was originally adopted in 2009, with implementation beginning in January 2011. The program was amended in 2011 and re-adopted in 2015, with further amendments in 2018 and 2020.

a) LCFS Impacts

The total volume of LCFS credits has grown to more than 26 million metric tons on an annual basis, with a substantial diversification of credits across fuel types. Figure 8 shows the credits produced from each fuel type by quarter from 2011 through 2022.

[68] California Air Resources Board, "LCFS Basics." Available at: https://ww2.arb.ca.gov/resources/documents/lcfs-basics

Figure 8: LCFS Credits by Fuel Type, by Quarter (Metric Tons)[69]



The LCFS program has prompted substantial diversification of alternative fuels with lower carbon intensity that consequently generate more LCFS credits per gallon. Renewable diesel, with an average carbon intensity less than a third of that of petroleum diesel, accounted for 37% of LCFS credits in 2022, while electricity represented 24% of the total.

The California transportation fuels market has changed substantially over the twelve years since LCFS implementation, consistent with the intent of the program:

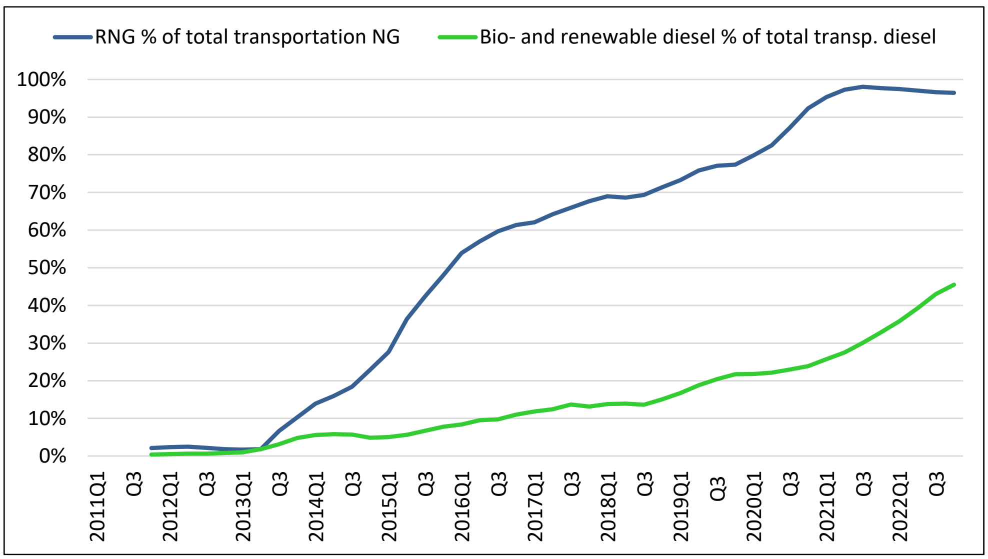
- Increasing volumes of low carbon intensity fuels have been drawn into the market;
- There has been substantial diversification of alternative fuels, with five distinct types each exceeding 10% of the LCFS credit pool;
- Alternative fuels with low carbon intensity, such as renewable diesel and electricity, have achieved growing shares of the transportation fuels market;
- Renewable diesel and biodiesel have grown to represent approximately 46% of the total transportation diesel pool;[70]

[69] CARB, LCFS Data Dashboard, https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard.

- Significant volumes of petroleum fuel have been displaced.

Figure 9 shows the percent shares of diesel and natural gas for transportation represented by renewable fuels. While renewable natural gas represents a relatively small volume of fuel – about 1.2% of the volume of biomass-based biodiesel on an energy-equivalent basis – it represents more than 36% of the credit volume from biomass-based biodiesel, because RNG has an extremely low (in fact, negative) CI.[71] RNG has essentially saturated the market for natural gas in transportation in California, while biodiesel, renewable diesel, and electricity continue to grow.

Figure 9: Renewable Fuels as Share of Diesel and Natural Gas for Transportation in California, 2011-2022[72]



Fuel diversification under LCFS reduces compliance costs

By supporting demand for low-carbon alternative fuels, and reliable revenue streams for alternative fuels producers, the LCFS program promotes increased investment in productive capacity, development of new

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[70] 2022 CARB data for biodiesel, renewable diesel, and petroleum diesel. https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard.

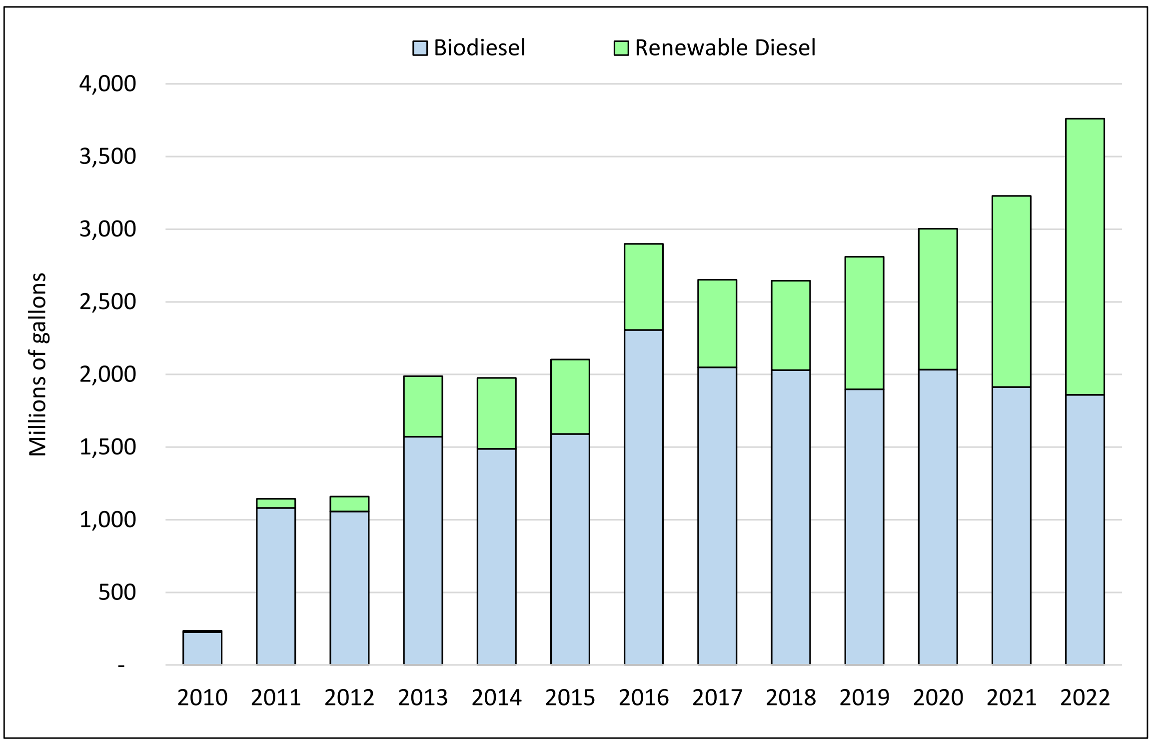
[71] RNG's negative CI is a consequence of methane having approximately 28 times the heating effect in the atmosphere as CO_2. Capturing RNG and burning it (producing CO_2) rather than have it escape to the atmosphere can result in a net reduction of heating effect, hence RNG can have a significantly negative CI under LCFS accounting.

[72] CARB, LCFS Data Dashboard , https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard.

technology and new low-carbon pathways, and improvements in productive efficiency. LCFS also creates price mitigating effects from the induced diversification and expansion of fuel supply. Over time, exploitation of new feedstocks, development of new and improved production methods, and the increased scale of production tend to reduce the cost of achieving carbon intensity reductions.

The low CI of biodiesel and renewable diesel, particularly for fuel produced from waste fats and oils, provides particular value for LCFS compliance (and for meeting obligations under the federal Renewable Fuel Standard, or RFS program). This value has incentivized investments in new production capacity and output. Figure 10 shows the substantial growth in biodiesel and renewable diesel supply since 2011.

Figure 10: U.S. Biodiesel and Renewable Diesel Net Supply[73]



Renewable diesel production capacity is expected to continue growing rapidly in the U.S., with the potential to more than double current levels by the end of 2025. Figure 11 shows historical and projected renewable diesel production capacity estimated by EIA in 2023.

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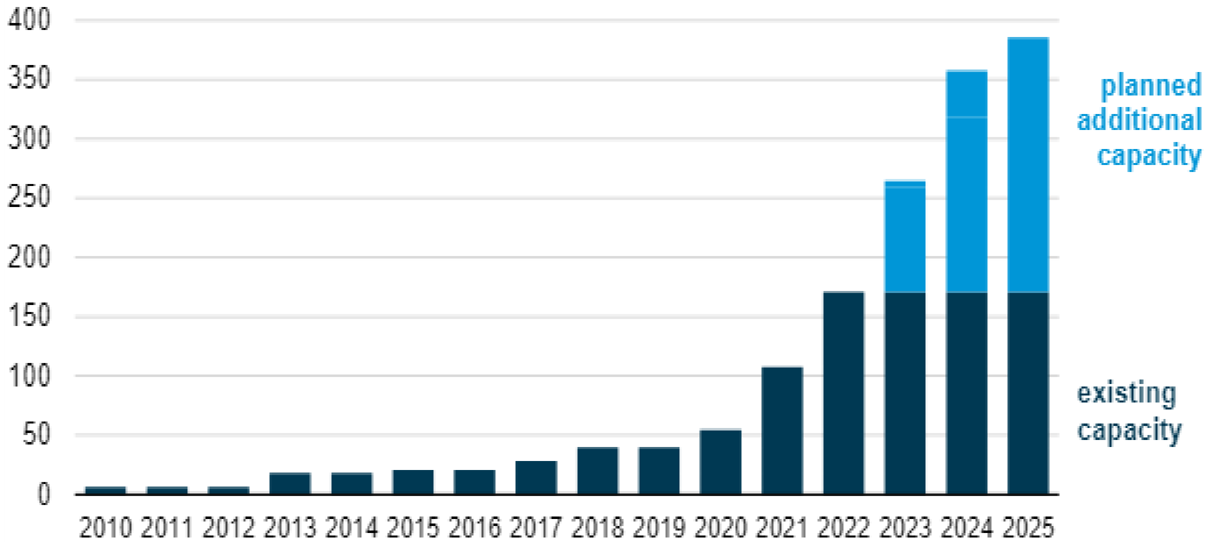
[73] U.S. EPA, RFS data, https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions

Figure 11: Annual existing and expected U.S. renewable diesel production capacity (2010-2025), thousands of barrels per day[74]



VII. Conclusions

We conclude that policies allowing for and promoting the decarbonization of fuels currently used to heat homes and businesses can offer a cost-effective means to meet interim GHG reduction goals while electrification advances. Promoting emissions reductions from existing fossil-fuel based heating systems can accelerate meeting GHG goals while relying on existing infrastructure, which limits the cost of decarbonization.

Electrification of heating, through a shift from fuel combustion to electric heat pumps, is one strategy to meet emissions reduction goals, but exclusive reliance on electrification, combined with electric grid decarbonization, presents significant challenges for a rapid transition. High levels of electrification will require

[74] EIA, Today in Energy, February 2, 2023; https://www.eia.gov/todayinenergy/detail.php?id=55399.

significant changes in infrastructure, spanning the manufacturing, distribution and installation services required to rapidly increase the number of heat pump installations. Large scale electrification will also require significant additional infrastructure to generate and deliver low-carbon electric power. The challenges of such large-scale modifications to the electric system may constrain the ability of electrification to achieve emissions reduction goals quickly.

As a complement to electrification-focused objectives, decarbonization of fuels currently used to heat homes and businesses can offer a cost-effective means to meet interim GHG reduction goals, easing the challenges of rapid electrification and the required buildout of renewable generation, transmission and distribution infrastructure. Additionally, achieving a portion of decarbonization goals via mechanisms other than electrification alone will help mitigate the likelihood of price spikes and degraded reliability and resiliency of electric service.