Northeastern Regional Assessment of Strategic Electrification: Summary Report

July 2017

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About NEEP

NEEP was founded more than 20 years ago as a non-profit to accelerate energy efficiency in the Northeast and Mid-Atlantic states. Today, it is one of six Regional Energy Efficiency Organizations (REEOs) funded, in part by the U.S. Department of Energy to support state efficiency policies and programs. Our long-term shared goal is to assist the region to reduce carbon emissions 80% by 2050. For more about our 2017 strategies and projects, see this 2-page overview or these project briefs. You can also watch this brief video regarding our history.

Disclaimer: NEEP verified the data used for this white paper to the best of our ability. This paper reflects the opinion and judgments of the NEEP staff and does not necessarily reflect those of NEEP Board members, NEEP Sponsors, or project participants and funders.

Getting to 80 Percent

New York and the New England states have adopted aggressive greenhouse gas (GHG) emission reduction goals. The deep decarbonization that will be required to achieve these goals is already well underway, as evidenced by the 19 percent drop in emissions from energy use in these seven states between 2001 and 2015. However, there's still a long way to go: the region's collective objectives will require emission reductions of about 80 percent below 2001 levels.

Table 1. Individual state decarbonization targets[1]

Connecticut	80% below 2001 levels by 2050
Maine	75-80% below 2003 levels in the long term
Massachusetts	80% below 1990 levels by 2050
New Hampshire	80% below 1990 levels by 2050
New York	80% below 1990 levels by 2050
Rhode Island	85% below 1990 levels by 2050
Vermont	75% below 1990 levels by 2050

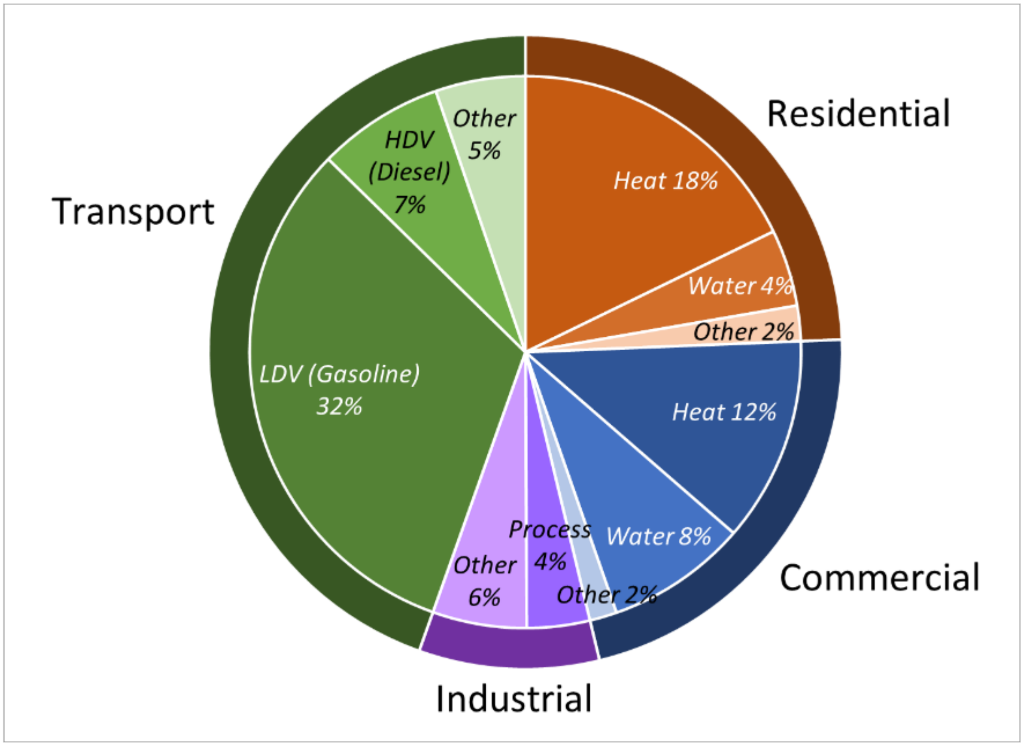
To date, state and market actions that reduce GHG emissions have focused on the electric supply sector and on increasing energy efficiency. But even enhanced energy efficiency and carbon-free electricity can reduce regional emissions by only about 40 percent by 2050—half the amount required. In other words, 2050 emissions would still be triple the target level. The remaining emissions result from direct fuel use in buildings, transportation, and industry.

Consumers in New York and New England use about 4.2 quadrillion British thermal units (BTU) of fossil fuels annually for direct end-uses. A small number of end-uses account for 85 percent of this direct fossil fuel use: space and water heating in residential and commercial buildings; industrial process heat and steam; and on-road vehicles.

Reducing emissions by 80 percent will require adding a third strategy: Move end-uses to electricity, and to other lower carbon fuels where electrification is not practical. Electric technologies with the potential to displace, and eventually replace, direct fossil fuel use are available now in the market, although at varying levels of maturity.

[1] Sourced from the Center for Climate and Energy Solutions, "Greenhouse Gas Emission Targets" at www.c2es.org/us-states-regions/policy-maps/emissions-targets. Note that state targets are not for energy only: they include emissions from waste, chemicals, agriculture, etc. This report addresses only energy-related emissions, and it assumes the same targets would apply to energy emissions alone.

Figure 1: Direct fossil fuel use totals 4.2 quadrillion BTUs in New York and New England. Just a few end-uses dominate that consumption.



Source: Synapse Energy Economics, based on data from the U.S. Energy Information Administration

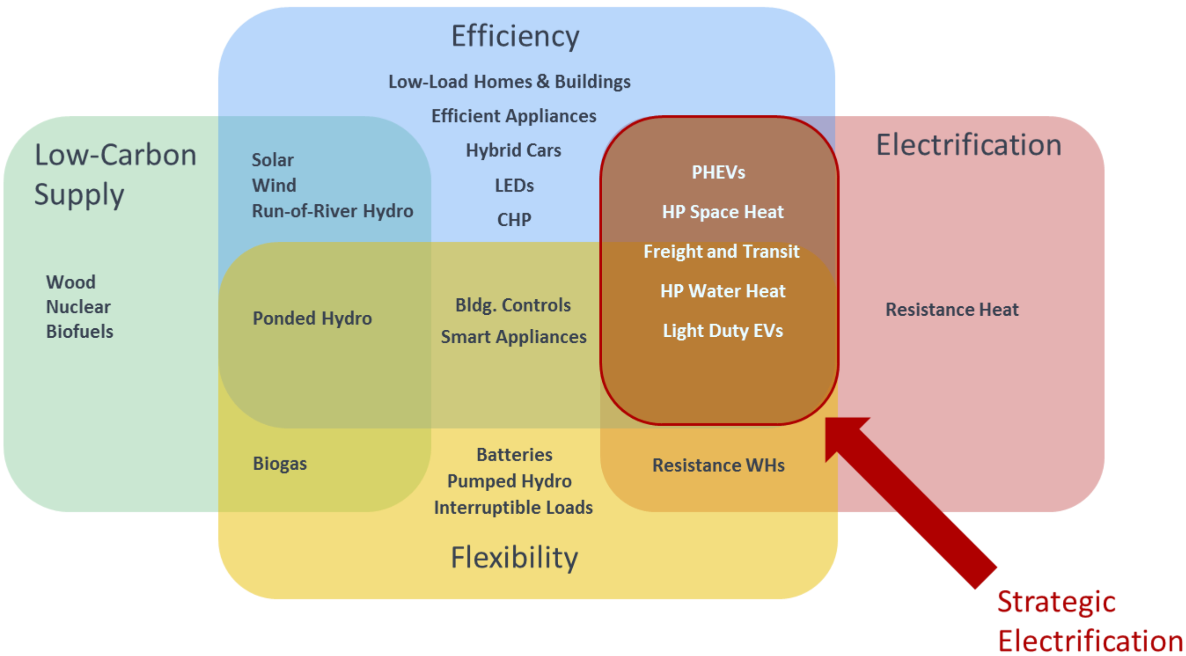
This report examines electrification in detail. We show how electrification can work with efficiency and clean electric supply to drive deep decarbonization. Executing these strategies will require careful planning and informed decision-making about how, when, and if end-uses are moved to electricity, as well as how the electric grid evolves and develops to meet new demands. What is required is not simply electrification, it is *strategic electrification*.

> ***Strategic electrification*** *means powering end-uses with electricity instead of fossil fuels in a way that increases energy efficiency and reduces pollution, while lowering costs to customers and society, as part of an integrated approach to deep decarbonization.*

Technologies and Markets

Decarbonization will require advancing markets for a wide range of technologies, each of which contribute one or more of the properties required: low-carbon energy supply; energy efficiency; flexibility; and electrification. Some technologies may be favored because they contribute more than one of these properties. Such an approach will involve deploying a combination of these technologies in a way that meets policy goals for emissions reduction, economic development, energy security, resiliency, consumer savings, and reduction of trade deficits from the import of fossil fuels produced elsewhere.

Figure 2. Strategic electrification in the context of decarbonization



As markets for these new electric technologies develop, they face a common set of market barriers:

- **Economic barriers**, including high first costs and inadequate return on investment;
- **Technical or infrastructure barriers**, including performance risks and lack of supporting infrastructure;
- **Social or institutional barriers**, including customer and installer awareness and confidence in the technologies; and
- **Policy or regulatory barriers**, including existing energy efficiency program paradigms and a reluctance to pick winners and losers.

Our assessment of these markets and the technologies available to serve them includes:

Space heat: Air source heat pumps (ASHPs) are the dominant technology here. To a much lesser extent, ground source systems have a role to play, especially in new construction or in meeting large loads. In regular homes and buildings, current ASHPs are not well suited to heat the entire building on their own. This is due to the predominance of ductless mini-split units and reduced heating outputs at the coldest temperatures. Installations are not necessarily coupled with heating system replacements, but are instead serving as additional heat (and cooling) sources. Multi-head and whole-building systems are becoming more available. At the large commercial scale, variable refrigerant flow systems are a growing option. Heat pump customer economics are stronger for buildings heated with delivered fuels such as oil than for those heated with natural gas. However, economics of heat pumps for new construction can be favorable even against natural gas. Resident behavior regarding the interaction between heat pump and combustion heating systems is not well characterized and likely highly variable across installations. Current heat pump market share among households purchasing heating systems is about 5 percent across the region.

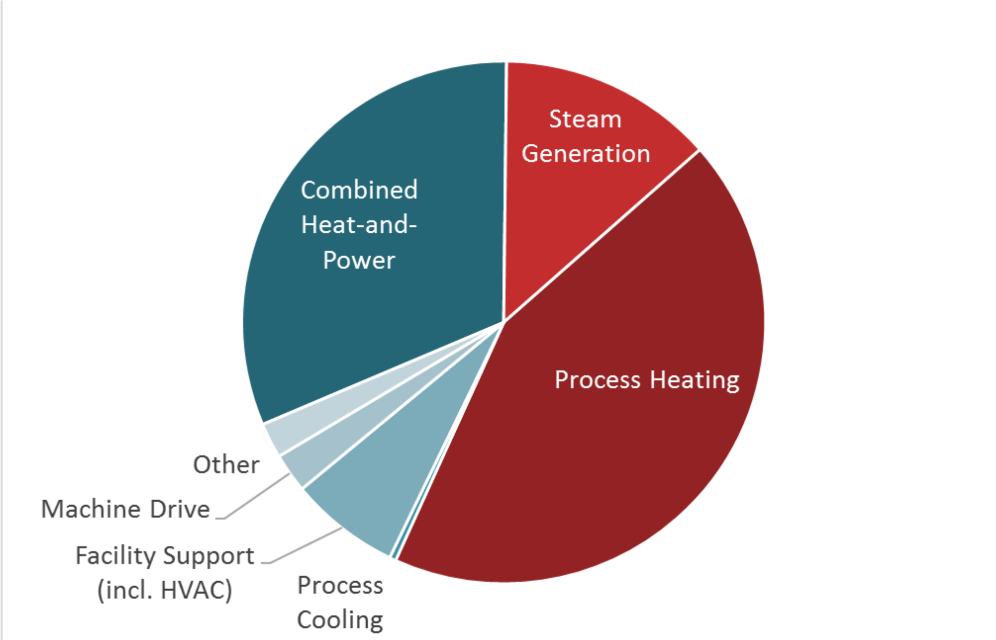
Water heat: The heat pump water heater (HPWH) market is nascent but growing in the Northeast, and it is supported by utility rebates in most states due to load reduction benefits over electric resistance. It accounts for an estimated 1 percent of all water heaters sold. Primary market interest, and customer economics, are focused on replacements for electric resistance or delivered fuel water heaters. Similar to other heat pumps, HPWHs are not cost-competitive against gas in the Northeast due to high electricity prices and low gas prices. Replacement at emergency failure of existing water heaters is common, and customers have a strong tendency to replace in kind. In addition, HPWHs require space with sufficient air-flow to maintain performance and efficiency; this limits the scaling of the market.

Industrial process heat and steam: Process heating and steam generation are the dominant needs met by industrial direct fuel use. Nationally, these end-uses account for 86 percent of industrial consumption of fossil fuels. Electrification opportunities are centered in four industries: manufacturing of food, chemicals, non-metallic minerals (glass and cement), and primary metals (iron and steel, aluminum, and other metals). Electrification is unlikely where combined heat and power or combustion of byproducts (such as black liquor in paper-making) are common.

For process heating, the dominant industries in the region are glassmaking and the production of iron and steel products. Electric steelmaking relies on arc furnaces, which run electric current through the metal stock that is to be melted. These are more thermally efficient than traditional fossil-fired blast furnaces.

In the production of chemicals and food, most process heat is delivered along with moisture, in the form of steam. Full electrification of steam generation depends on completely replacing fossil-fired boilers with electric technologies, such as those based on electric resistance boilers, electrode or induction boilers, or microwave heating.

Figure 3. Dominant forms of industrial fuel usage



From a purely technical standpoint, all or nearly all of fossil fuel use for process heat and steam generation in the Northeast could be electrified by 2050. However, implementation would face high barriers, such as the amount of investment that industries have sunk into existing process infrastructure. Industrial process equipment is different from consumer-facing products in that it is not generally governed by a stock turnover dynamic. In addition, high first costs and uncertain savings may create a form of "sticker shock" that discourages electrification. Biofuels may offer a more attractive option for many process managers looking to reduce greenhouse gas emissions.

Cars and light trucks: The main path for strategic electrification of cars and light trucks is replacement of conventional internal combustion engine-based vehicles with electric vehicles (EVs), although mode switching (e.g. to electrified rail or buses) is also a potential contributor. The primary technical barrier is that EVs can only store a certain amount of energy onboard the vehicle, and this amount has been limited by battery technology. Therefore, wide adoption of EVs would require buildout of the charging infrastructure necessary to replenish the battery, supplementing home charging. It remains to be seen what level of public charging infrastructure is necessary to facilitate wide adoption of EVs. As for economics, EVs currently require an upfront cost premium when compared with internal combustion engine-based vehicles. Notably, EVs are generally cost-competitive in the present day based on a comparison of total lifetime costs of ownership, after accounting for incentives. Battery costs are expected to continue to decline, while cycle life is expected to improve; these advances would reduce the cost of EVs. Range is also expected to increase as batteries improve. EVs represent only about 1 percent of vehicle sales today across New York and New England, although that share has doubled since 2014. One potential path for wide adoption of EVs would be to combine electric vehicle technology with autonomous driving technology to create autonomous EVs. These vehicles would peddle "transportation as service" as a model, in which individuals would hail a self-driving car to provide a service rather than owning and operating a vehicle themselves. High capital costs for these vehicles could be offset by reduced operating cost, given high utilization.

Medium- and heavy-duty vehicles: The technologies available for electrification of freight and other uses of medium- and heavy-duty vehicles are essentially the same as those available for electrification of light vehicles: mode switching to electrified rail and replacement of vehicles with electric-drive alternatives. Any substantial buildout of electrified rail is incredibly costly and has less potential reach than replacement of diesel vehicles with electric versions. Electric trucks, buses, and other medium- and heavy-duty vehicles are at a much less mature state of development than electric light-duty passenger vehicles. Electric trucks and buses have only recently begun to gain a foothold, often in pilot-scale programs.

The dynamics of electrification of the medium- and heavy-duty vehicle fleets are very different from that of the car and light truck fleet. Medium- and heavy-duty vehicles have expected lives of over 20 years, meaning that stock turnover is much slower than turnover of smaller vehicles. Only 15 percent of the freight miles traveled are for trips under 100 miles, where range anxiety is expected to be less of a barrier to adoption of electric medium- and heavy-duty vehicles. Many medium- and heavy-duty vehicles are part of a single-owner fleet, making purchasing decisions more similar to those in the industrial sector than to consumer-facing sectors such as cars or residential heating. Fleet conversion to electric technologies should only be expected when the electric alternative offers a clear value proposition *and* when the technology proves itself relatively risk-free.

Transportation of freight or people for distances of several hundred miles or more will likely remain difficult to electrify using battery-based technology for the foreseeable future. Biofuels (especially biodiesel) offer some opportunity to switch away from fossil fuels for this class of trips. The biggest opportunities for reductions in fossil fuel use in these applications may simply be improvements in vehicle efficiency.

Policy Landscape

In order to deploy strategic electrification at the scale necessary to contribute significantly to the region's ambitious climate change goals, policymakers will first need to set a regional vision. They must then remove barriers that inhibit efficient market development and aggressively implement a wide range of market development policies and programs to implement the vision. States and cities are acting today to develop markets and increase adoption of electrification technologies through a variety of policies and programs. Policies and programs to accelerate adoption of new technologies share common features across the building and transportation sectors. Policies fall into five categories:

Table 2. Percent of medium/heavy-duty freight miles in trips <100 mi. by state of origin	
Connecticut	9%
Maine	13%
Massachusetts	20%
New Hampshire	28%
New York	15%
Rhode Island	41%
Vermont	21%
Region	**15%**

1. *Mandates and targets:* Targets describe goals to achieve certain levels of technology deployment, performance, or emissions reduction. They provide signals to investors regarding the types of policies and programs that will be implemented, as well as outline the types of support policies (e.g. mandates, incentives, etc.) that will be necessary to meet the target. Mandates are regulatory policies that place obligations on various parties (e.g. building owners and developers, public agencies, utilities) to install or procure specific technologies and/or achieve certain levels of performance, efficiency, or emissions reduction. Targets and mandates can overcome decision-making barriers and inertia, increase investor confidence, and (in the case of binding mandates) provide certainty regarding the outcome.

2. *Pricing-based options:* Programs that change the upfront or operating cost of electric technologies can overcome economic barriers to increased adoption. Policymakers can influence cost effectiveness via a variety of mechanisms, including the provision of upfront and operating incentives, development of new electric rate structures, or pricing of externalities (e.g. carbon pricing). Revenue for incentives can come from regulated rates or surcharges, taxes, or emissions allowance auctions (e.g. from RGGI). Pricing mechanisms most effectively stimulate private investment when they can provide investors with transparency, longevity, and certainty. Furthermore, transparent policies can afford more certain rates of return, thereby reducing the cost of capital.

State-by-state electrification policies and programs

VERMONT

- Integrated strategic electrification as a key strategy in the 2016 state comprehensive energy plan
- Utilities offer PHEV and BEV rebates as part of their Renewable Energy Standard (RES) compliance
- Utilities provide incentives and leasing for ASHPs and HPWHs as part of meeting their energy efficiency and Renewable Energy Standard obligations.
- State Infrastructure Bank provides loans for EV charging stations

NEW HAMPSHIRE

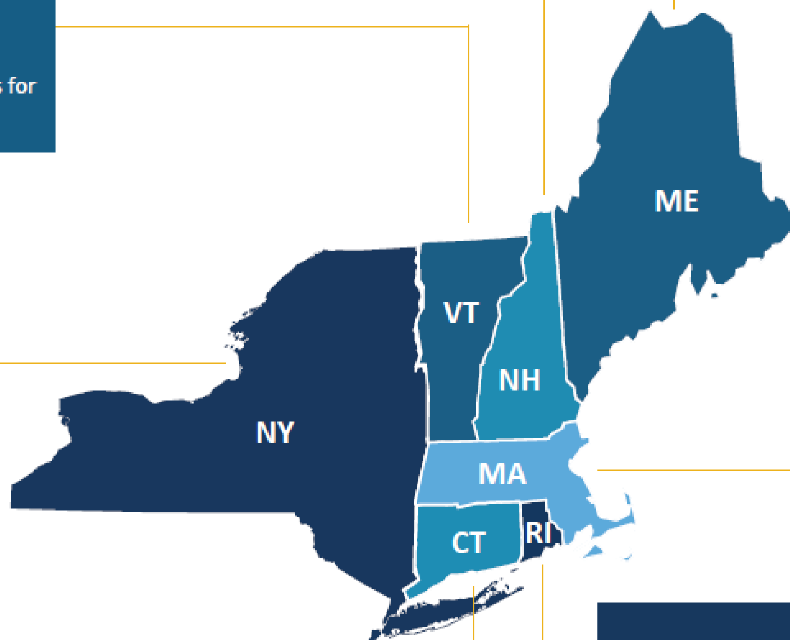
- Developed first-in-nation RPS carveout for renewable thermal (does not include ASHP)
- Some residential ASHP and HPWH rebates from individual utilities
- Time-of-use rate through Liberty Utilities with low nighttime pricing for EVs

MAINE

- Significant uptake in residential ASHP/HPWH through Efficiency Maine rebate and financing programs (over 20,000 rebates FY14-FY16)
- Only state in Northeast with over 30% of energy demand in industrial sector; ~70% of homes heat with oil

MASSACHUSETTS

- Released Commonwealth Accelerated Renewable Thermal Strategy in 2014
- Finalizing rulemaking to integrate heat pumps and other renewable thermal energy into Alternative Portfolio Standard
- Robust rebates for small- and large-scale ASHP and GSHP through MassCEC Clean Heating & Cooling Program; ASHP and HPWH rebates through Mass Save
- Expanding Solarize Mass program to include heat pumps, EVs, and storage (Solarize Mass Plus)
- Variable rebates for PHEVs and BEVs, depending on the size of the battery (MOR-EV)
- Grants to businesses and government agencies for installation of EVSE (Level 1 or Level 2) through EVIP



NEW YORK

- Released Renewable Heating & Cooling Policy Framework in 2017
- NYSERDA developing rebate and higher-ed technical assistance program for GSHP; targeting driving cost reductions in heat pump sector
- Under Reforming the Energy Vision (REV), state will need to set a social cost of carbon
- Variable rebates for PHEVs and BEVs, depending on the size of the battery (Drive Clean Rebate)
- Incentives such as the free use of certain HOV lanes and discounted EZ-Pass toll fees
- Residential time-of-use rate for EV charging (whole house), and non-residential time-of-use rate for EV charging with a separate meter (both through ConEd)
- Rebates for EVSE installation for qualified properties (EV Charger Rebate Program)

CONNECTICUT

- Released renewable thermal feasibility study in 2017
- Heat pump rebates available through Energize CT
- Variable rebates for PHEVs and BEVs, depending on the size of the battery (CHEAPR).

RHODE ISLAND

- Released Renewable Thermal Market Development Strategy in 2017
- Exploring workforce engagement and development programs to drive heat pump uptake (e.g. through engaging delivered fuel dealers)
- Variable rebates for PHEVs and BEVs, depending on the size of the battery (DRIVE)
- 43,000 ZEV target by 2025
- Goal to achieve zero-emission passenger and freight rail fleet by 2050.

3. *Facilitating emerging financing and business models:* Innovative financing and pay-per-use business models are emerging in the heat pump and EV sectors that may transform the way end-users access transportation and thermal energy services. These include third-party ownership models, wherein a developer or utility owns and manages the thermal or transportation asset and provides end-users access to the thermal or mobility services with little to no upfront investment. In the best cases, these models can also increase access to private sector capital, overcome upfront cost concerns, simplify decision-making, and spur professional marketing. Policy and regulatory support is often necessary to enable the development of these business models.

4. *Quality assurance and evaluation, measurement, and verification:* Quality assurance (QA) programs are efforts to ensure that technologies meet minimum performance standards for installation and performance. The most prominent QA efforts are the development and adoption of technology and installer certification schemes. Evaluation, measurement, and verification (EM&V) assesses the energy performance of technologies and energy efficiency activities. EM&V is commonly required by state regulators to evaluate the success of utility energy efficiency programs. These tools can increase customer confidence in new technology, unlock new business models and incentive structures, improve installation quality, and drive technology performance by making performance information transparent.

5. *Marketing, outreach, and education:* Marketing, outreach, and education initiatives can drive adoption and successful usage of electric replacement technologies through increased awareness, increased confidence, and strengthened resolve and commitment from consumers/property owners. Low levels of consumer and practitioner awareness of electrification technologies (and of their maturity) is a significant deployment barrier, and policymakers can amplify the results of other types of policies (e.g. pricing, QA, and mandates) by investing sufficient effort in marketing and outreach activities, sometimes in collaboration with nonprofit and private sector entities.

The above policy types have been successfully deployed in the *transportation and heating sectors* in Northeast states at varying levels of impact. Examples from the transportation and heating sectors are available in the full *Northeastern Regional Assessment of Strategic Electrification* report. In contrast, electrification of *manufacturing processes* faces a very different business and policy context from transportation and heating, and it remains a nascent field.

Regulatory barriers inhibit the use of utility energy efficiency programs to achieve strategic electrification in many states. These include fuel-switching rules that preclude utilities from using energy efficiency funds to promote electric technologies, cost-effectiveness requirements that vary by state, lack of sufficient alignment between electrification and utility financial interests (particularly in decoupled electric markets), and incentives that encourage consumers to purchase efficient fossil-fuel appliances rather than electric replacements. Addressing these barriers would greatly improve the ability of policymakers to leverage energy efficiency programs in their efforts to accelerate technology deployment via the policy and programmatic tools described here. Looking ahead, it will be important for policymakers to examine these issues in greater detail.

Modeling the Electrification Required to Achieve GHG Targets

Achieving the goal of 80 percent GHG emissions reduction by 2050 using electrification would require a "maximum electrification" market path, along with enhanced energy efficiency and a nearly decarbonized electric supply. We modeled the result of rapid market transformation for new electric technologies, combined with the expected pace of equipment replacement, to show that a 77 percent GHG reduction can be achieved through electrification of the dominant direct fuel uses (space and water heating, on-road vehicles, and process heat and steam). The remaining 3 percent reduction would need to be acquired from the other, smaller end-uses.

Recognizing that markets may not be able to transform as quickly as the "Max Electric" case would require, we also modeled a "Plausibly Optimistic" case. Here the pace of market transformation is more plausibly within reach of aggressive policy intervention, and a 69 percent GHG emissions reduction can be achieved with energy efficiency, clean electricity, and electrification. From 69 percent to 80 percent could be achieved with sufficient supplies of low-carbon biofuels, such as biodiesel, bioheat, and renewable natural gas. (As modeled, an 80 percent reduction in GHG emissions from replacing diesel and heating oil with drop-in biofuel options would be sufficient to reach an overall 80 percent emission reduction target.) We use this case for subsequent analyses.

In both cases, heat pumps must displace a large fraction of natural gas use in buildings—a challenging proposition given the current favorable customer economics of natural gas compared with heat pumps in retrofit markets. Figure 4 illustrates the rising market shares of heat pumps and EVs in the "Max Electric" and "Plausibly Optimistic" scenarios.

Table 3 provides a comparison of these two modeled cases with the reference case based on the 2017 Annual Energy Outlook from the U.S. Energy Information Administration.

Figure 4: Sales shares for residential heat pumps and electric cars and trucks under the "Max Electric" and "Plausibly Optimistic" scenarios. Heat pumps displace oil and propane faster than they displace natural gas in both scenarios.

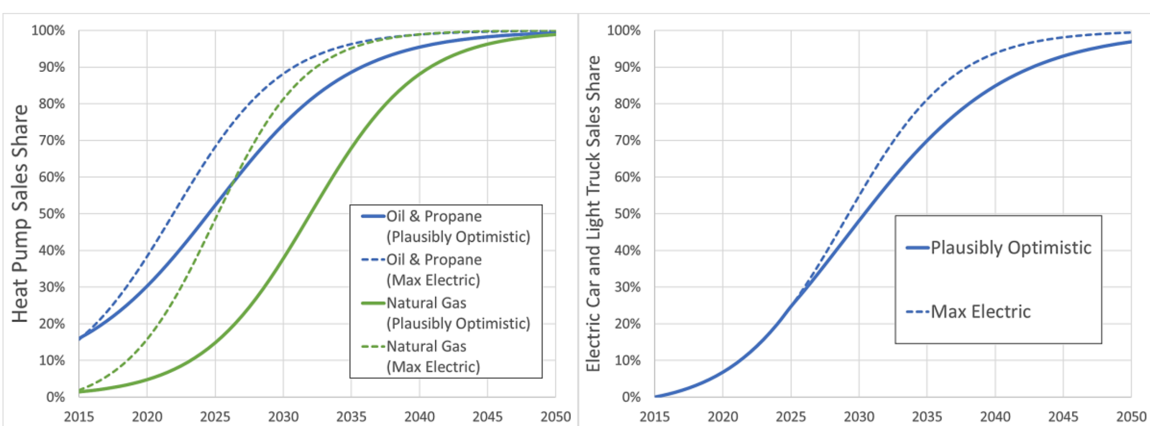


Table 3: Comparing the "Max Electric" and "Plausibly Optimistic" scenarios with the reference case based on the 2017 Annual Energy Outlook.

	Max Electric	Plausibly Optimistic	Reference (AEO 2017)
2050 GHG reduction from 2001 levels	77%	69%	24%
2050 electric consumption	402 TWh	339 TWh	259 TWh
Electric energy efficiency	~2% annual savings via long-lived measures	~2% annual savings via long-lived measures	~1.1% annual savings via long-lived measures
Clean electricity	95% in 2050	95% in 2050	61% in 2050
Residential heat pumps	Delivered fuels: 96% sales share in 2035 Natural gas: 95% sales share in 2035	Delivered fuels: 89% sales share in 2035 Natural gas: 68% sales share in 2035	6% total installed share in 2050
Commercial heat pumps	Delivered fuels: 89% sales share in 2035 Natural gas: 78% sales share in 2035	Delivered fuels: 80% sales share in 2035 Natural gas: 66% sales share in 2035	4% total installed share in 2050
Cars and light trucks	81% sales share in 2035	70% sales share in 2035	3% sales share in 2035
Medium and heavy-duty road vehicles	50% of miles electric in 2035	25% of miles electric in 2035	0.3% of miles electric in 2035
Process heat and steam	16% fossil energy displaced in 2035	13% fossil energy displaced in 2035	None

Electric consumption increases by about one-third in the Plausibly Optimistic case, relative to the reference case. Non-electric fuel use falls by about half by 2050.

Figure 5: Regional electric sales in the Plausibly Optimistic case, compared with the reference case

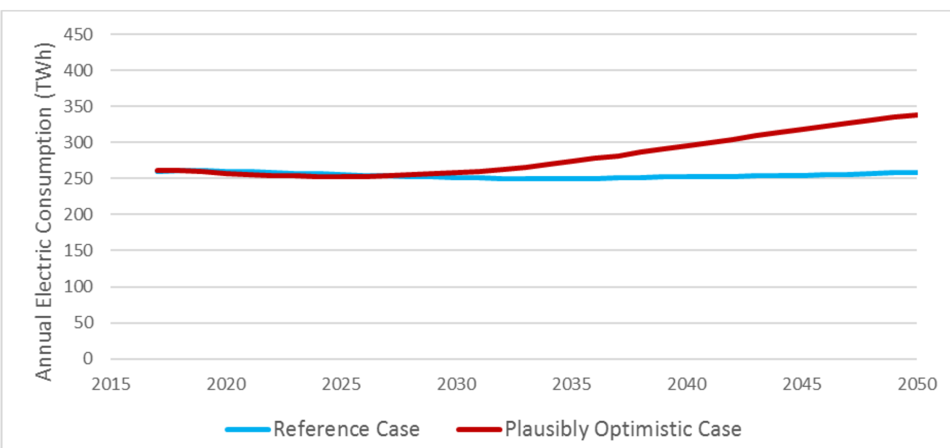


Figure 6: Direct (non-electric) fuel use by sector in the Plausibly Optimistic case

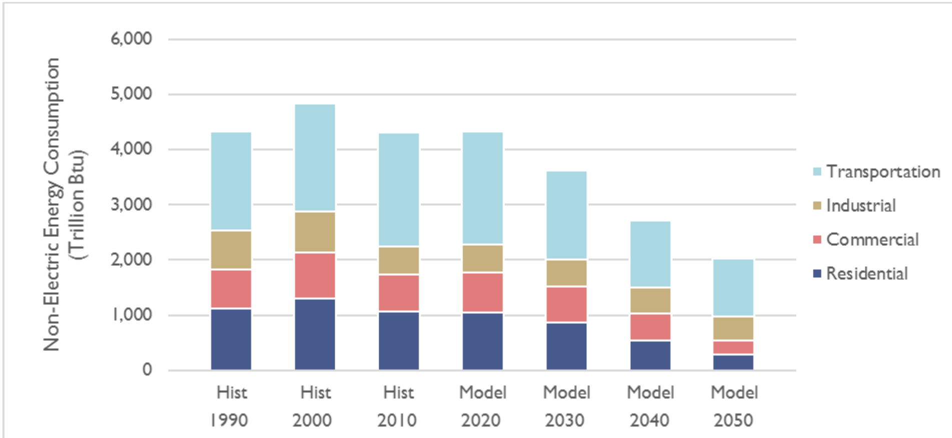
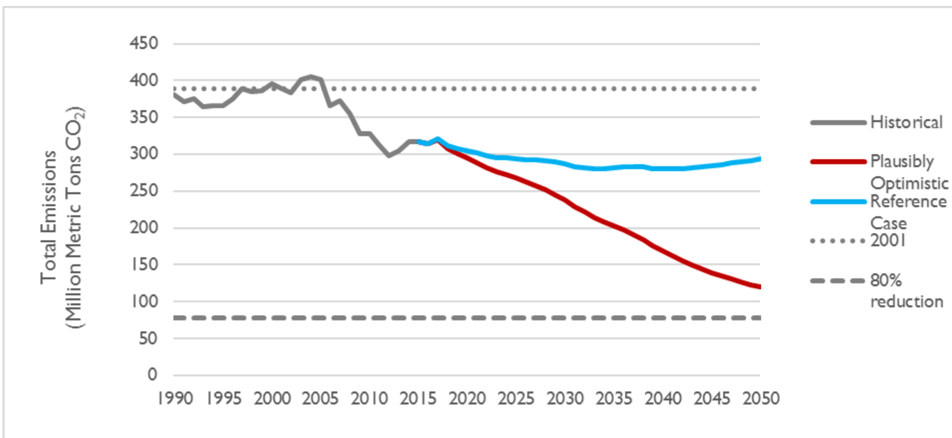


Figure 7: Greenhouse gas emissions in the Plausibly Optimistic case, compared with the reference case



Stepping back from either aggressive energy efficiency or pursuit of nearly zero-carbon electricity supply would impede the region's ability to meet the 80 percent emission reductions target. With energy efficiency at the level assumed by the EIA, instead of the enhanced efficiency assumed in the Plausibly Optimistic case, electricity consumption would increase by more than 60 percent. This would increase strain on electric supply and the grid. If electricity supply were supplied by 80 percent zero-carbon resources, instead of 95 percent, GHG emissions would fall to only 63 percent below 2001 levels.

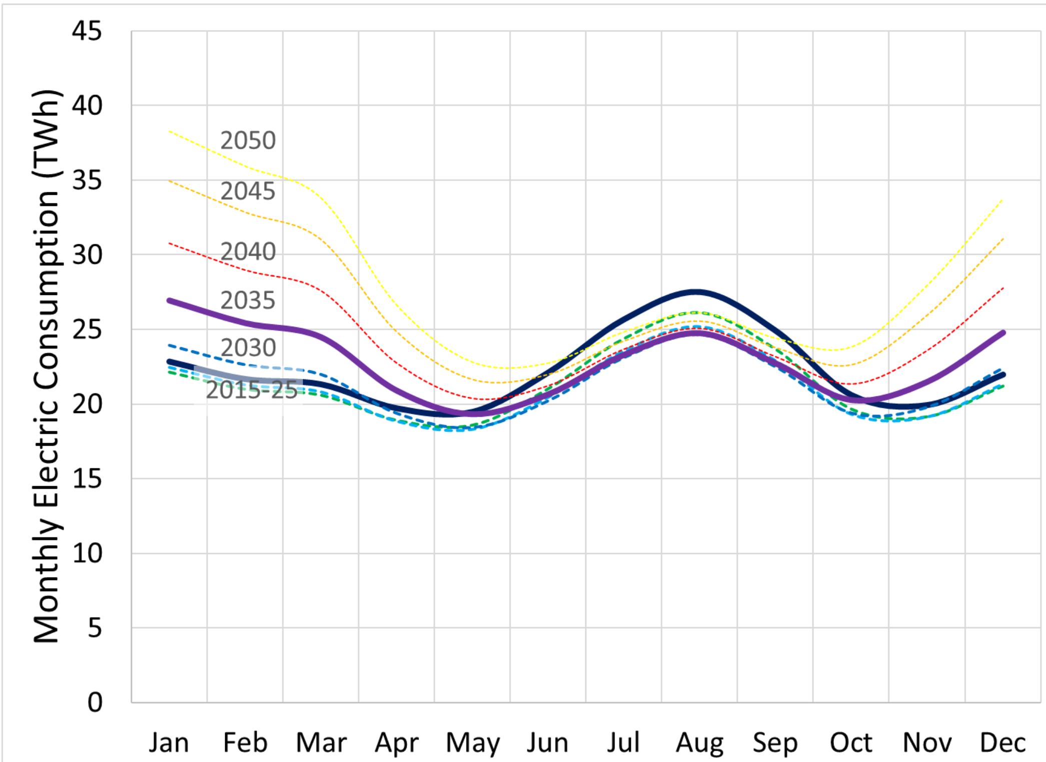
Impacts of Electrification on the Grid

Electrification will impact the electric grid in three primary ways:

1. Increased need for electric supply
2. Increased peak load on transmission and distribution systems
3. The introduction of significant new controllable loads as a grid resource

Increased need for electric supply: Meeting an increased demand for electricity will require additional supply resources; these sources must be nearly zero-carbon in order to meet decarbonization objectives. The new electric end-uses reflected in a strategic electrification portfolio have their own seasonal characteristics. Heating loads in particular are highly seasonal, but driving patterns also vary over the year. The "butterfly curve" in Figure 8 shows this changing annual dynamic between 2015 and 2050 as the region electrifies. In the Plausibly Optimistic scenario, January consumption exceeds August consumption starting in 2032.

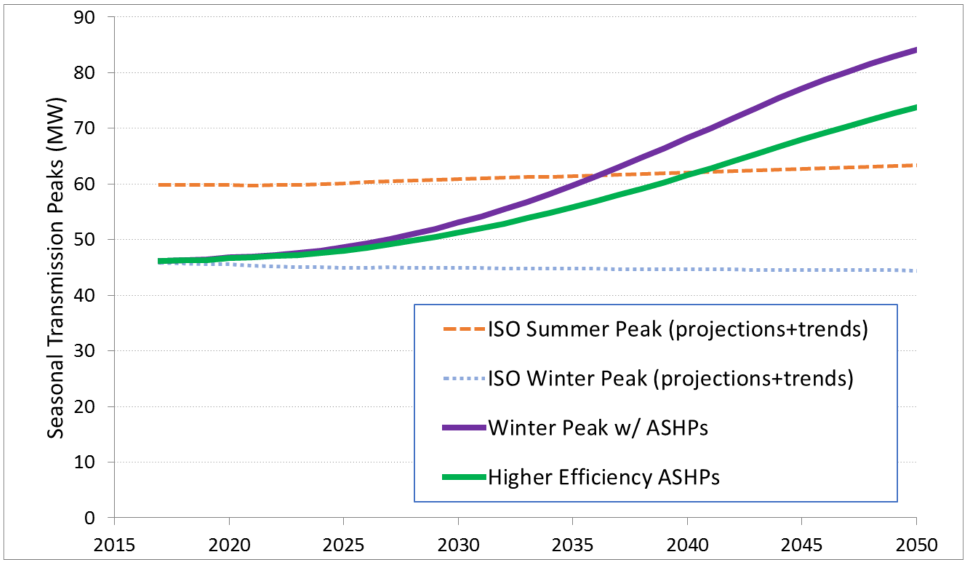
Figure 8: Approximate monthly electricity consumption, 2015–2050, as modeled under the Plausibly Optimistic scenario, showing the shift to winter use



As monthly loads in the winter exceed mid-summer monthly loads by increasing amounts, winter demand will increasingly drive supply market dynamics. Summer consumption falls in this scenario due to enhanced energy efficiency, and then rises back toward current levels as transportation electrifies.

Transmission and distribution: It is likely that substantial new transmission investment will be required to both reach the sources of renewable electricity and integrate variable resources while maintaining reliability. New winter peaks will at some point create the need for transmission upgrades. Meanwhile, distribution loads could also increase considerably under electrification. If heat pumps and EVs are adopted in clusters, as has happened with solar PV, the local distribution circuits serving these residential neighborhoods could see problematic new stresses. Household-, neighborhood-, or circuit-level approaches to managing loads may be promising. Electric energy efficiency targeting winter peaks could defer grid upgrades.

Figure 9: More efficient heat pumps can delay the crossover from summer to winter peaking. The figure shows approximate summer and winter peaks based on ISO projections, along with winter peaks after electrification with baseline vs. higher efficient heat pumps.[2] These projections use the ISO projections of energy efficiency, not the "Plausibly Optimistic" case level.



Load flexibility: End-uses likely to be central to strategic electrification—electric vehicles and heat pumps for water heating—have the ability to act as distributed energy resources to increase operational flexibility on the distribution and transmission grids. This flexibility would enable the shaping of the daily load shape, but it would not mitigate the seasonal shift in energy use. These new end-uses are prime candidates for shaping dynamic loads because they each have some kind of storage built in: electric vehicle batteries and the thermal storage in water tanks. Heat pumps for space heating may also provide some flexibility through pre-heating, especially in higher-performance building shells. The options for harnessing these resources depend on how well this storage can be utilized. As an example, increasing digitalization may provide new control opportunities. Rate structures may be a primary tool to shape these loads, although direct utility control may also be effective—especially where geographic variation matters.

Consumer Impacts

The actions and choices of network utility customers —both electric and gas—will impact other users of that shared infrastructure. As electrification proceeds, it will likely not be evenly distributed—either geographically or socioeconomically. Where the cost of the shared portions of the distribution system is allocated among customers based on the customers' energy use (as it is nearly universally for residential and small commercial customers), increasing system utilization should reduce rates. If a fixed cost is spread over more units, the cost per unit can fall. There are three leading dynamics that will impact all customers: possible increases in electric system utilization; decreases in the utilization of the natural gas distribution system (ultimately culminating in stranded cost risks); and cost impacts associated with ratepayer-funded activities to prime the pump on emerging technologies.

[2] The baseline assumption is that heat pump coefficients of performance (COPs) rise to 4.0 for new systems by 2050. In the high-efficiency case the residential COPs rise to 5.0 by 2043, and then remain fixed. COPs for new commercial systems in the high-efficiency case rise to 4.5 by 2038 and then remain fixed.

Electric system utilization: Strategic electrification has the potential to increase electric volumetric sales (kWh) more quickly than peaks (kW), if new loads are managed well. Much of the region's grid was built to handle summer peaks, so rising winter peaks do not create large immediate costs. This creates an opportunity in the near term to develop load management tools (whether in technology or in rates) that can contain peak growth, keep the utilization high (or prevent it from falling), and put downward pressure on rates.[3]

Natural gas system utilization: If electrification reduces natural gas sales for heating in residential and commercial sectors, the effective utilization of the gas distribution system will fall. The need to spread fixed costs over lower sales volume would increase rate pressure. To the extent that rates rise, it improves the customer economics for others to adopt electric space and water heating options, further exacerbating the challenge. The customers remaining connected to the natural gas system as this cycle progresses are those who were not early adopters. This raises important equity issues that will require careful planning. At the extreme end of a shift of building and water heat from natural gas to electricity, natural gas distribution systems may become stranded costs.

Ratepayer funding of market development: To the extent that utilities invest in enabling infrastructure to drive new markets (such as EV charging infrastructure) ahead of the ability for those markets to deliver the revenue required to pay for that infrastructure, all utility customers would cover those costs. Regulators, utilities, and advocates will need to work carefully to strike appropriate balances between the utility's interest in investing in rate-based infrastructure, public policy objectives, shared costs, and the need to foster competitive markets.

Next Steps

We have divided next steps into three classes: First, we identify policy and program actions to grow and mature the markets for electrification technologies over the next five to ten years. Second, we have distilled a set of difficult policy questions that will need answers as the electrification technology markets mature. Finally, there are research questions and data gaps that will require responses for the purposes of planning.

Electrification technology markets robust and active enough to launch the region toward an 80 percent reduction in emissions, even when accounting for low-carbon fuels, will require substantial market development from the current level of niche and nascent markets. For example, the residential cold climate heat pump market should grow by 15 percent or more per year between now and 2025 to be on pace. Developing markets at the required pace over the next five years would require concerted and active policy and program intervention. The region would need to build on and expand the programs in place today and take advantage of opportunities as they arise (such as the funding from the Volkswagen emissions settlement[4]). Promising steps in this direction include:

- expand the use of explicit targets, goals, and mandates for electrification to create market certainty;
- launch or support marketing campaigns to increase customer awareness of electric options;

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[3] All else being equal, if infrastructure costs make up half of electric rates and system utilization increases by 10 percent electric rates could fall by 5 percent.

[4] The U.S. EPA website about the Mitigation Trust Fund can be found at https://www.epa.gov/enforcement/volkswagen-clean-air-act-civil-settlement#mitigation

- support and expand state, city, and/or utility incentives for EVs, heat pumps, and heat pump water heaters;
- expand electric vehicle charging infrastructure, particularly in multi-family housing, workplaces, and fast-charging for longer-distance travel;
- develop and scale new financing models for cost-effective electric technologies; and
- continue data collection, analysis, and testing to characterize the performance of heat pumps, heat pump water heaters, and EVs.

In addition to these market development activities, some difficult policy questions need to be resolved in the next five years to guide future action. These will be critical to implementing appropriate policies and actions and to respecting planning timelines for the electric and natural gas networks. Such questions include:

- What are the appropriate roles for electric distribution utilities in fostering electrification? Do these roles require changes in the utility business model or regulatory paradigm?
- What rate structures would help to advance strategic electrification, and will advanced meters be deployed if they are necessary to implement these rates?
- What is the right balance between biogas and electrification for current gas uses? What is the future of the natural gas utility pipeline networks and business models?
- If incentives are going to play a meaningful role in advancing electrification, where will the money come from?

In addition to (and potentially informing) these challenging questions, there are also real data and knowledge needs to address over the next few years:

- Data on the market uptake and performance of heat pumps and electric vehicles,
- Pilots on the control and capabilities of electrification technologies as grid resources,
- Analysis of the capacity of distribution circuits to meet electrification needs before substantial upgrades are required, and
- Analysis of power supply and transmission options for a markedly different seasonal load shape across the northeastern United States and eastern Canada.

Planning for a fundamental change in how fuels are used for heat and mobility will necessarily be an evolving and iterative process. To succeed, the region will need coordination across sectors and states.