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Greenhouse Gas Mitigation Analysis for New England

NESCAUM White Paper: Policy Summary
September 2018

Introduction

On August 31, 2015 the New England Governors and Eastern Canadian Premiers (NEG/ECP) adopted *Resolution 39-1*,[1] which established a regional 2030 greenhouse gas (GHG) emissions reduction marker range of at least 35-45 percent below 1990 levels. This marker was selected to keep the region on track to reach its regional 2050 goal of reducing GHG emissions by 75-85 percent below 2001 levels.[2] To assess options for achieving these targets in New England, NESCAUM has conducted a scenario analysis of market penetration pathways for various low- and no-carbon technologies. This analysis is designed to provide high-level insights about the magnitude of actions needed to achieve New England's ambitious climate goals. There are several key lessons that can be drawn from this analysis.[3]

Key Lessons

- *Immediate action is required.* The scale of change that needs to occur is massive. Given the long time-horizon for stock-turnover, New England policy-makers need to start implementing policies now to avoid costly early retirements of fossil fuel technologies. This is particularly pertinent to the electric grid, which operates on a decadal time-scale and is critical to decarbonize early to provide a low-carbon source of energy for the electric technologies needed to reduce carbon emissions in the other major sectors.
- *Climate mitigation action will have a negligible impact on the region's economy.* From a macroeconomic perspective, the impacts of the GHG mitigation scenarios on jobs and overall gross state product are minimal across the region, resulting in a fraction of a percent change from the reference, or business-as-usual, case. In most scenarios analyzed, there was a small positive impact on employment levels, while impacts on gross state product growth were essentially zero.
- *Electrify end-use energy consumption.* To reduce GHG emissions, end-use energy consumption should be shifted to electric technologies, such as electric vehicles in transportation and air source heat pumps for residential and commercial buildings, which emit no direct emissions. These electric technologies are also typically more energy

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[1] NEG/ECP (2015). *Resolution 39-1*: Resolution Concerning Climate Change, 39th Annual Conference of the New England Governors and Eastern Canadian Premiers, St. Johns, NL, August 30-31, 2015, http://www.coneg.org/Data/Sites/1/media/39-1-climate-change.pdf.

[2] NEG/ECP (2001). *Climate Change Action Plan 2001*, New England Governors/Eastern Canadian Premiers, https://www.novascotia.ca/nse/climate.change/docs/NEG-ECP.pdf.

[3] This analysis was developed by NESCAUM as an organization. Any views or opinions contained in this White Paper may not necessarily reflect those of individual NESCAUM member agencies. Support for this analysis was provided by the Barr Foundation and the John Merck Fund.

efficient than fossil fuel technologies, which reduces overall energy demand in the economy.

- *Decarbonize the electric grid.* The increase in electrification will shift emissions from the end-use sources to the power plants that produce electricity. New England will need to deeply decarbonize the electric grid in order to ensure that GHG emissions significantly decline from the electric generation sector as the grid experiences a significant increase in load. A continuing shift to natural gas, even though less carbon-intensive than coal and oil, is not capable of meeting the region's 2030 and 2050 goals, and diverts investments from longer-term zero-carbon technologies.
- *Focus on building thermal.* The New England region is unique in the amount of energy needed to heat homes and businesses and the amount of heating oil consumed to do so. Further, the primary technology modeled to reduce emissions in this sector, air source heat pumps, is not cost-competitive under current policies. These challenges highlight the importance of a more concerted policy effort to decarbonize the building thermal sector in New England.
- *Energy efficiency is effective at reducing GHGs in the short-term, but is not, in and of itself, a long-term solution to deep decarbonization.* Energy efficiency is a cost-effective method for reducing emissions and flattening load growth under current conditions. However, if future GHG reduction targets are to be met through electrification of other end-use sectors, like transportation and buildings, electric demand will increase significantly, potentially 2 to 3 times above current generation by 2050. To meet this growth, new zero-carbon generation will need to be added to the grid, while continuing to displace all forms of current fossil generation. As the grid decarbonizes, energy efficiency as a GHG reduction strategy will have diminishing impacts. Other benefits, however, will continue to exist, such as reducing the extent of needed electric capacity additions. Therefore, it should be recognized that at some future point decreasing demand from a low-carbon electricity grid will not be a significant GHG reduction strategy. Instead, it will be driven by other goals, such as cost reductions.
- *A price on carbon could simplify carbon reductions.* In addition to implementing individual discrete policies to push multiple markets toward low-carbon technologies in each sector, an economy-wide price on carbon could provide a relatively simple and effective method to achieve the required GHG reductions.

Conclusion

While this analysis is not a detailed assessment of policy options nor is it intended as a blueprint of specific low-carbon technology shares needed to achieve desired reductions, the above overarching lessons provide high-level guidance on steps that need to be taken, the urgency with which policies should be developed, and the magnitude of changes needed to achieve New England's ambitious climate action goals.

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Introduction

New England faces a challenge in meeting science-based greenhouse gas (GHG) reductions both in the mid- and long-term planning horizons (2030 to 2050). Most New England states have legislation or executive orders requiring an 80 percent GHG reduction by 2050 from 1990 levels, with intermediate targets typically of 35-45 percent by 2030 or 2035. Individual state actions, however, cannot fully exploit GHG mitigation opportunities from common source sectors across the region, hence the need for regional coordination.

In support of regional efforts, the Northeast States for Coordinated Air Use Management (NESCAUM) conducted a scenario analysis of GHG reduction pathways for major emissions sectors common to the New England states.[4] A scenarios analysis in this context provides GHG reductions relative to a baseline reference case given various low- and no-carbon technology penetration pathways. Central to all scenarios in this analysis is the development of a near-zero carbon electricity grid as a necessary condition for meeting GHG reduction goals that also heavily rely on electrifying the transportation sector and more fully electrifying the residential/commercial buildings sector.

This report will present the methodology used to develop the business-as-usual scenario, briefly describe the mitigation scenarios, examine the associated modeled GHG and macroeconomic impacts, and conclude with a discussion of the key takeaways. This analysis is not a prescriptive analysis designed to produce specific targets for low-carbon technology penetration, but is instead an indicative analysis designed to show the estimated magnitude and timing of needed changes and the relative importance of major economic sectors.

Business-as-Usual Scenario (BAU)

The Long-Range Energy Alternative Planning System (LEAP)[5] was used to create the business-as-usual (BAU) forecast and analyze potential new actions to meet the 2030 and 2050 reduction

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[4] This analysis was developed by NESCAUM as an organization. Any views or opinions contained in this White Paper may not necessarily reflect those of individual NESCAUM member agencies. Support for this analysis was provided by the Barr Foundation and the John Merck Fund.
[5] *See* LEAP: Introduction, at https://www.energycommunity.org/default.asp?action=introduction (accessed August 1, 2018).

goals. LEAP is a flexible, widely-used integrated modeling tool that can track energy consumption, production and resource extraction in all sectors of an economy and account for the dependencies between energy demand and supply. It is not, however, a least-cost optimization method. Instead, it can be used to compare costs in a relative sense across different scenarios by assessing different combinations of low- and no-carbon technologies and measures that collectively can meet GHG reduction goals.

A BAU forecast is designed to show the projected annual GHG emissions under current policies and programs and provides a point of reference for assessing various mitigation scenarios. As with any modeling exercise, it is important to note that uncertainty exists when examining future years, which means that projections are estimates based on the best available data. The BAU for the New England LEAP model projects emissions through 2050 and was developed using a variety of data sources. The primary data sources used in the development of the BAU forecast are shown in Table 1.

Table 1 – Primary Data Sources

Source	Description
Annual Energy Outlook 2017	The Annual Energy Outlook (AEO) is compiled each year by the U.S. Energy Information Administration (EIA) and provides projected energy consumption across all sectors of the economy at a detailed level. The results used for this analysis are specific to New England.
ISO-NE Forecasts	ISO-NE Forecasts are generated by New England's regional electric grid operator and show projected electric capacity in the region.
MOtor Vehicle Emission Simulator	The MOtor Vehicle Emission Simulator (MOVES) is developed and maintained by the U.S. Environmental Protection Agency (EPA) and provides simulated data by vehicle type for the transportation sector. These data include vehicle miles traveled (VMT), vehicle efficiency, and energy consumption.
State Inventory and Projection Tool	The State Inventory and Projection Tool (SIT) is developed and maintained by the EPA and provides an estimated inventory of GHGs. This analysis uses the SIT tool to estimate non-carbon dioxide GHGs, such as methane from waste, methane from agriculture, and hydrofluorocarbons from industrial processes.

Except for non-CO_2 GHG emissions sectors, data from the above sources are used to estimate activity within each sector. Total GHG emissions are calculated based on the technology mix of the activity, the efficiency of each technology, and the associated GHG emission rates. This provides a reasonable BAU forecast of New England's GHG emissions through 2050 that is in line with the AEO 2017 published by the EIA. While granular data is available in the LEAP model, this analysis is best used as a high-level directional analysis to identify key sectors and the magnitude of action that needs to be taken to achieve deep decarbonization.

Figures 1 and 2 provide a high-level view of the BAU scenario for New England through 2050 as modeled in LEAP. The transportation sector is currently, and is projected to continue to be, the largest emitter of GHGs in New England. This is followed by the buildings sector, as represented by the residential and commercial sectors in Figure 2, and the electricity sector. Further examination of Figure 3 reveals that within those sectors respectively, light duty vehicles and space heating play crucial roles.

Figure 1 - Business-as-Usual GHG Emissions through 2050 for New England

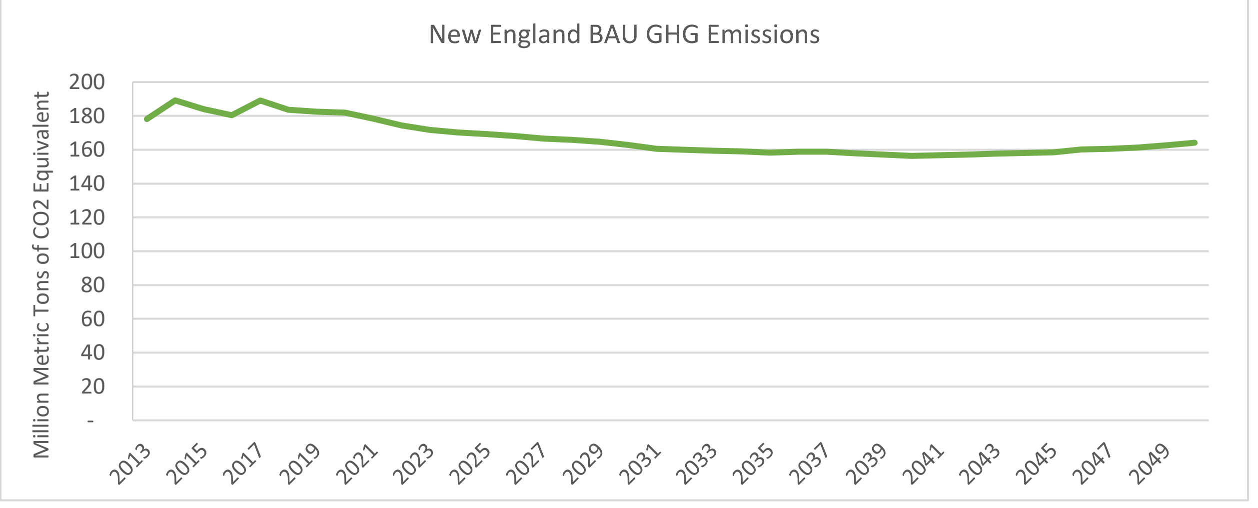


Figure 2 - Business-as-Usual GHG Emissions by Sector through 2050 for New England

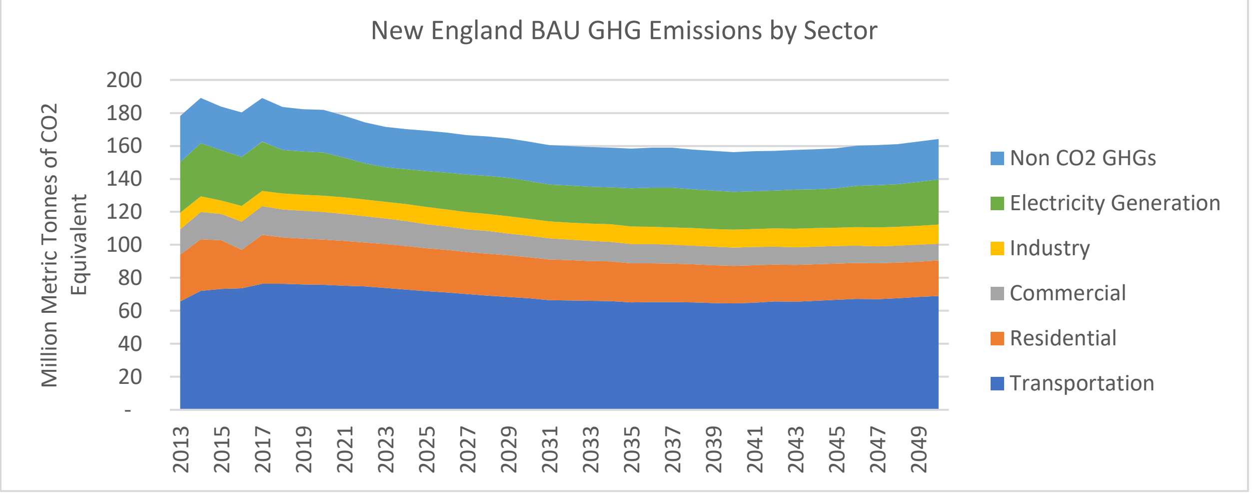
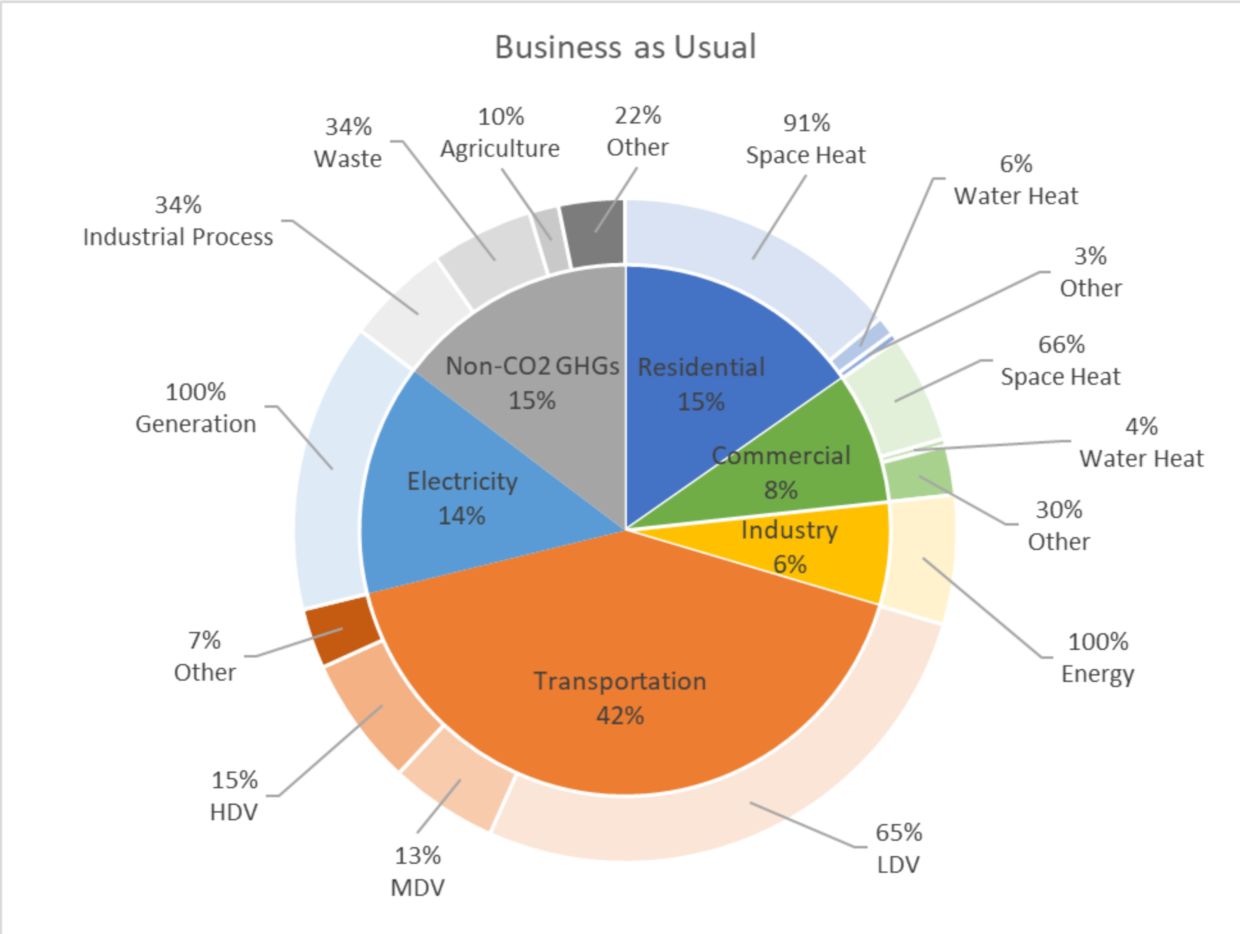


Figure 3 – Business-as-Usual GHG Emissions by Subsector in 2030 for New England



Overview of GHG Mitigation Scenarios

The New England region has a unified climate action goal to reduce GHGs within a range of 35-45 percent by 2030 and 75-85 percent by 2050 from a baseline of 1990 emission levels. This equates to annual emissions of 105 to 124 metric tons of CO_2 equivalent by 2030 and 29 to 47 metric tons of CO_2 equivalent by 2050. To achieve these targets, action needs to be taken in all key sectors within New England, including: buildings, transportation, industry, electricity generation, and non-CO_2 GHG sources. The following table provides a brief description of each sector along with the low- and no-carbon technologies examined in the analysis.

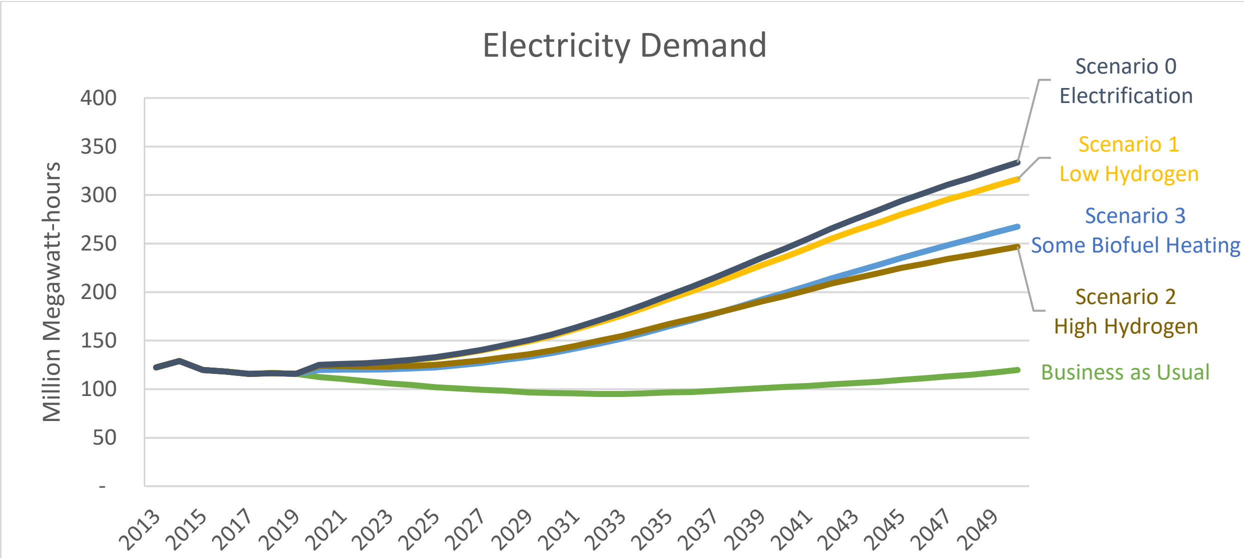
Table 2 – Major Sectors and Low-Carbon Technologies

Sector	Description	Low Carbon Technologies
Buildings	The buildings sector includes both residential and commercial space. The main driver of emissions for this sector is space heating.	Air source heat pumps, electric furnaces, and advanced biofuel[6] furnaces
Transportation	The transportation sector includes light-, medium-, and heavy-duty on-road vehicles, non-road vehicles, aviation, marine, and rail.	Electric drivetrains, hydrogen fuel cells, and advanced biofuel engines
Industry	The industry sector is assumed to rely primarily on fuel-switching instead of technological changes.	Advanced biofuels and electricity
Electricity Generation	The electricity generation sector encompasses generation within New England along with electric imports into the region.	Offshore wind, onshore wind, utility solar, residential solar, and imported hydroelectric power
Non-CO_2 GHG Sources	The non-CO_2 GHG sources sector is a catch-all for any additional emissions, and includes emissions from waste, agriculture, industrial processes, land use change, and leaks from natural gas distribution.	While concrete actions are not assessed in this analysis, the mitigation scenarios assume some level of emission reductions within these areas to highlight the importance of addressing these sectors in order to meet reduction goals.

Given that most of the low-carbon technologies in this analysis rely on electricity as their power source, the mitigation scenarios result in increased electricity use across the region, as seen in Figure 4. Increases from current levels of 2 to 3 times are projected by 2050 based on the scenarios. However, significant electrification of the economy only results in sufficient emission reductions if it draws power from a decarbonized electric grid. This highlights the importance of achieving deep decarbonization of electricity generation in New England to achieve economy-wide GHG reduction goals.

[6] "Biofuel" as used throughout this report refers to liquid biofuels, such as cellulosic ethanol and biodiesel.

Figure 4 – Increased Electrification in New England Under Mitigation Scenarios



Four core scenarios and two sub-scenarios were developed to evaluate a range of technologies that can be implemented to achieve New England's GHG reduction goals. The rate of adoption, or penetration pathways, of low-carbon technology for each sector is similar across each of these scenarios. However, the technologies that comprise those low-carbon shares vary among scenarios. Multiple scenarios were developed to show that a range of technologies can be used to achieve the climate action goals.

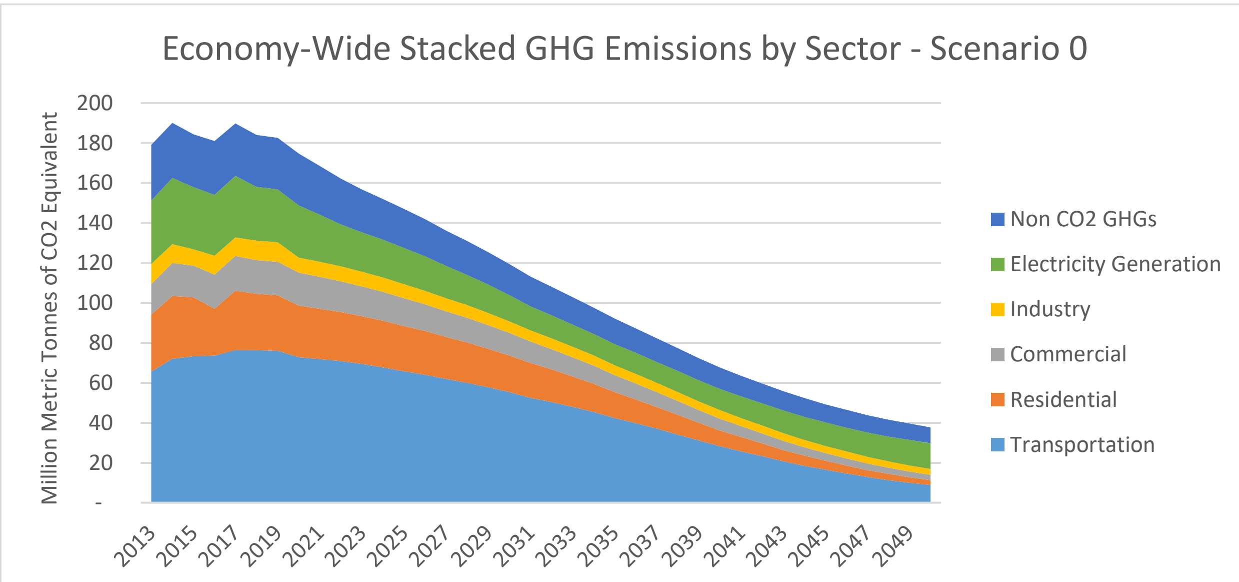
The penetration pathways of low-carbon technologies in this analysis follow a non-linear curve, which represents increasing adoption rates as the markets for low-carbon technologies mature and the supporting infrastructure expands (i.e., electric vehicle charging). The non-linear adoption rate is also necessary to ensure that the mitigation scenarios achieve both the 2030 and 2050 reduction targets. These penetration rates result in roughly a 90 percent penetration of zero-carbon technologies by 2050 across most sectors in the analysis. This exemplifies the magnitude of change that needs to occur within New England to meet its climate action goals.

The exception to this increasing adoption rate is seen in the electric generation sector. Given the importance of low-carbon electricity and the relatively mature market for solar, wind, and hydro energy, the electricity generation sector exhibits a different penetration path than other sectors. This path shows rapid deployment in early years with diminishing deployment rates over time. This rate still exhibits a 90 percent penetration of zero carbon technologies by 2050. Nuclear capacity as forecasted by AEO is assumed to be constant through all scenarios. The lower percentage of nuclear in the scenarios relative to BAU reflects the projected growth in overall generating capacity. Table 3 displays the mitigation scenarios examined in this analysis, which is followed by high-level summaries of each one.

Table 3 – Mitigation Scenarios

Scenario Number	Scenario Title
Scenario 0	Heavy Electrification
Scenario 1	Electrification with Low Penetration of Hydrogen
Scenario 1.1	Aggressive Energy Efficiency
Scenario 1.2	VMT Reductions
Scenario 2	High Penetration of Hydrogen in Transportation
Scenario 3	Electrification with Some Advanced Biofuel Heating

Figure 5 – Reductions in All Sectors are Necessary to Meet Climate Action Goals



<u>Scenario 0 – Heavy Electrification</u>

Scenario 0 does not contain hydrogen technologies and instead relies on electric vehicles to drive emissions reduction in the transportation sector. In subsectors where electrification does not currently appear technically feasible, such as long-haul trucking and aviation, advanced biofuel engines are assumed to be the dominant technology. Air source heat pumps are the primary technology used for space heating, while the less-efficient electric furnaces comprise the rest of the low-carbon share. Figure 7 highlights the importance of air source heat pumps, as the discrepancy in technology efficiencies causes their energy demand to be almost equal to electric furnaces despite air source heat pumps providing three times the amount of space heating in Scenario 0. Industrial process energy relies heavily on electricity as its fuel, but also sees some use of advanced biofuels. Lastly, scenario 0 exhibits a large added capacity of wind and solar within the electric generation sector and a modest addition of hydroelectric capacity. The resulting emissions reductions in 2030 and 2050, based on 1990 levels, are 37 percent and 80 percent respectively. Figure 5 shows the reduction pathways by sector for Scenario 0.

Figure 6 – Energy Demand by Heating Technology in 2050 for BAU

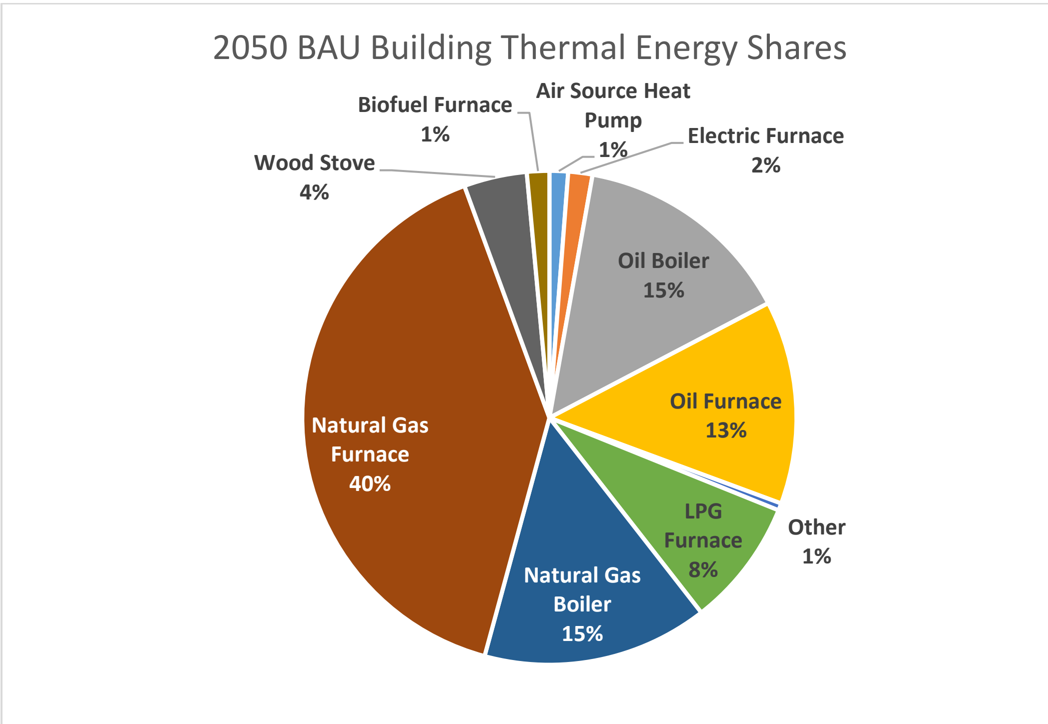
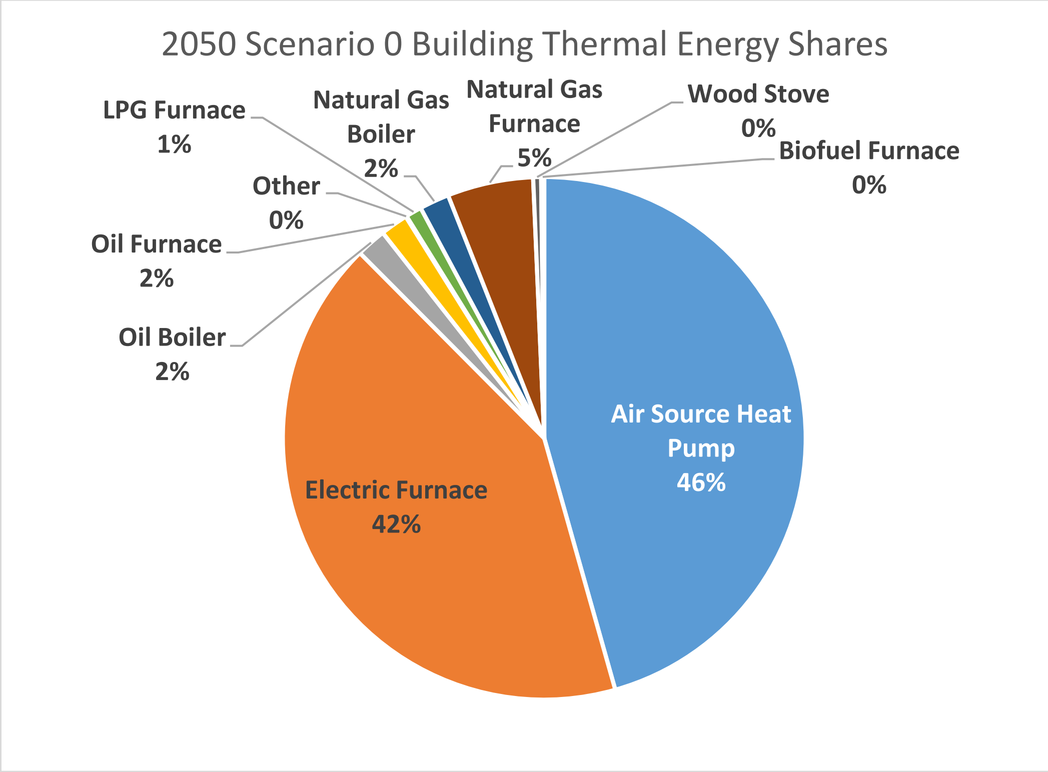


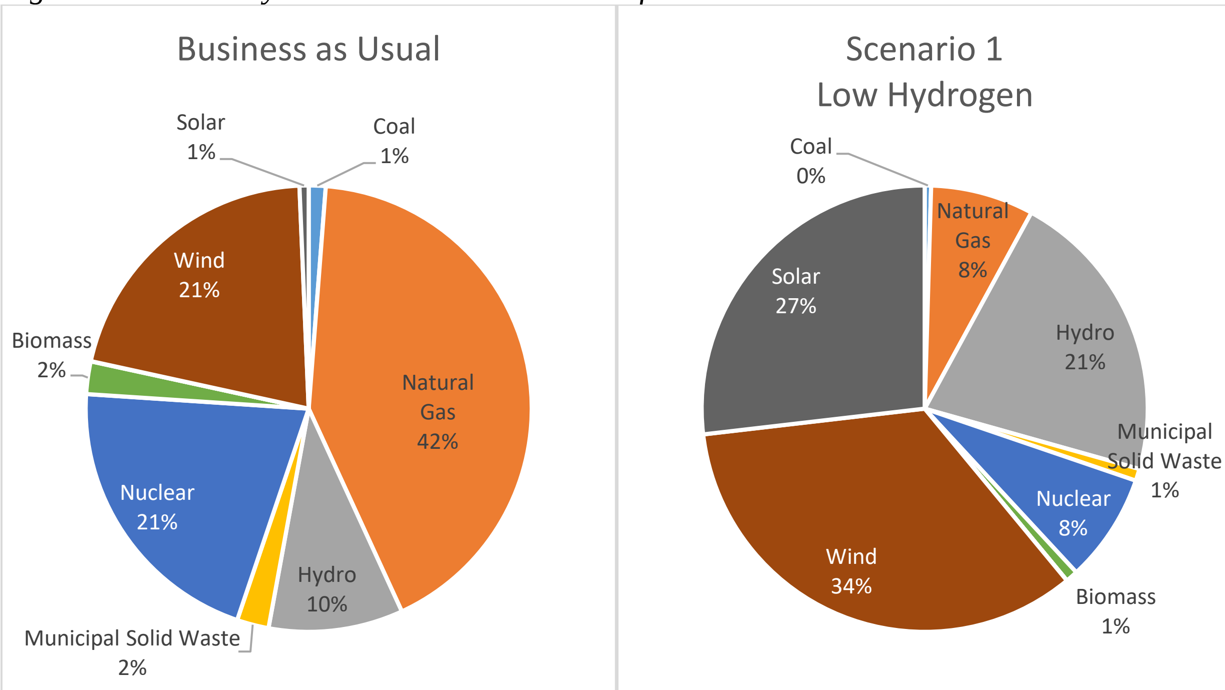
Figure 7 – Energy Demand by Heating Technology in 2050 for Scenario 0



<u>Scenario 1 – Electrification with Low Penetration of Hydrogen</u>

Scenario 1 is similar to scenario 0, but it assumes a low level of penetration of hydrogen fuel cells across all transportation subsectors, edging out some of the electric and advanced biofuel vehicles. It also assumes a higher proportion of solar to wind in added generation capacity than Scenario 0. Figure 8 contrasts the electricity generation mix between BAU and Scenario 1 in 2050. The resulting emissions reductions in 2030 and 2050, based on 1990 levels, are 38 percent and 81 percent respectively.

Figure 8 – Electricity Generation Shares in 2050 for BAU and Scenario 1



<u>Scenario 1.1 – Aggressive Energy Efficiency</u>

Scenario 1.1 contains the same assumptions as scenario 1, except it assumes additional energy efficiency in the buildings sector resulting in a 25 percent reduction in demand for electricity and natural gas by 2050. This scenario demonstrates the diminishing effectiveness of energy efficiency in reducing GHG emissions as low-carbon technologies gain higher penetration rates. From a GHG emission perspective, the efficiency of a zero-carbon technology has no impact. One technology could require double the amount of input energy as another technology for the same output, but both technologies would still produce zero emissions. However, there are other important benefits to higher efficiency, such as lower fuel expenditures and reduced costs by avoiding the need to build additional generating capacity. The resulting emissions reductions in 2030 and 2050, based on 1990 levels, are 39 percent and 82 percent respectively.

<u>Scenario 1.2 – VMT Reductions</u>

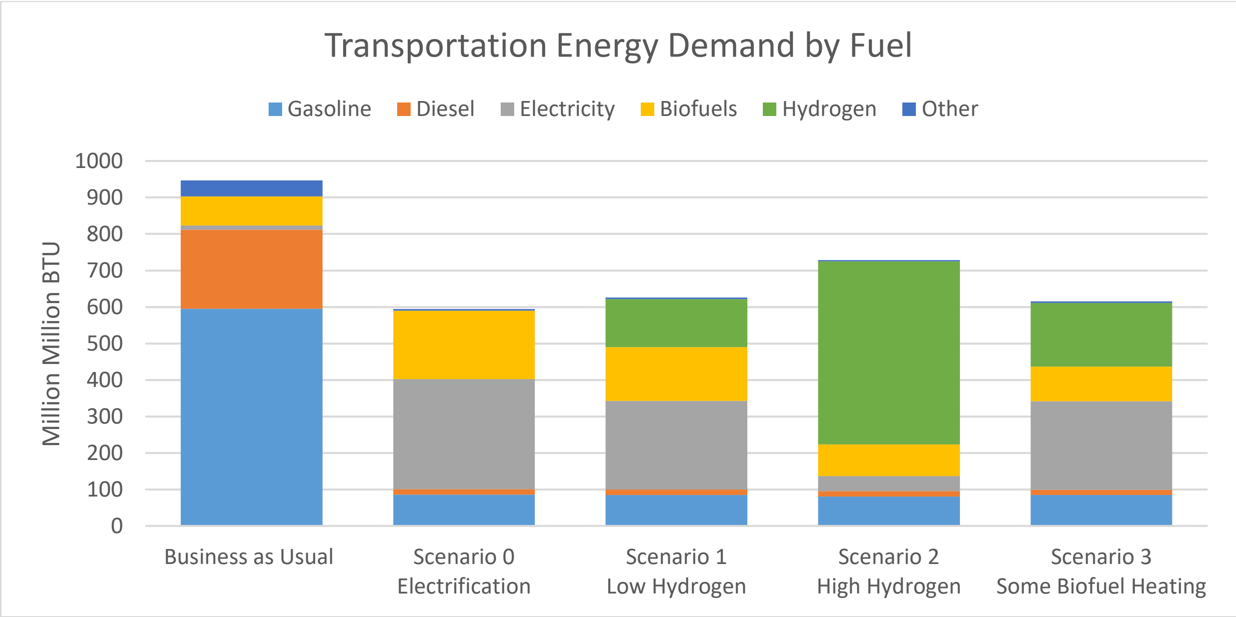
Scenario 1.2 contains the same assumptions as scenario 1, except it assumes additional vehicle miles traveled (VMT) reductions in the light-duty vehicle sector, resulting in a 25 percent reduction in VMT by 2050. The purpose of this scenario is to explore the same dynamic for VMT reductions as was seen with energy efficiency efforts in scenario 1.1. From a GHG perspective, it does not matter how many cars are on the road, as long as they are zero carbon. Other benefits associated with VMT reduction include increased quality of life, improved public health, reduced costs to drivers, and by avoiding the need to build additional electric generating

capacity. The resulting emissions reductions in 2030 and 2050, based on 1990 levels, are 40 percent and 82 percent respectively.

Scenario 2 – High Penetration of Hydrogen in Transportation

Scenario 2 assumes a high penetration of hydrogen fuel cells across all areas of the transportation sector, with advanced biofuel engines being the complimentary technology everywhere except for the light-duty sector, where electric vehicles play the complimentary role. The high use of hydrogen in the transportation sector for scenario 2 can be seen in Figure 9. The scenario also assumes advanced biofuels as the dominant fuel in industrial process energy and an even split between air source heat pumps and electric furnaces in the buildings sector. Lastly, scenario 2 relies more on hydropower than the other scenarios. However, it still sees a majority of the added capacity coming from wind and solar sources. The resulting emissions reductions in 2030 and 2050, based on 1990 levels, are 40 percent and 82 percent respectively.

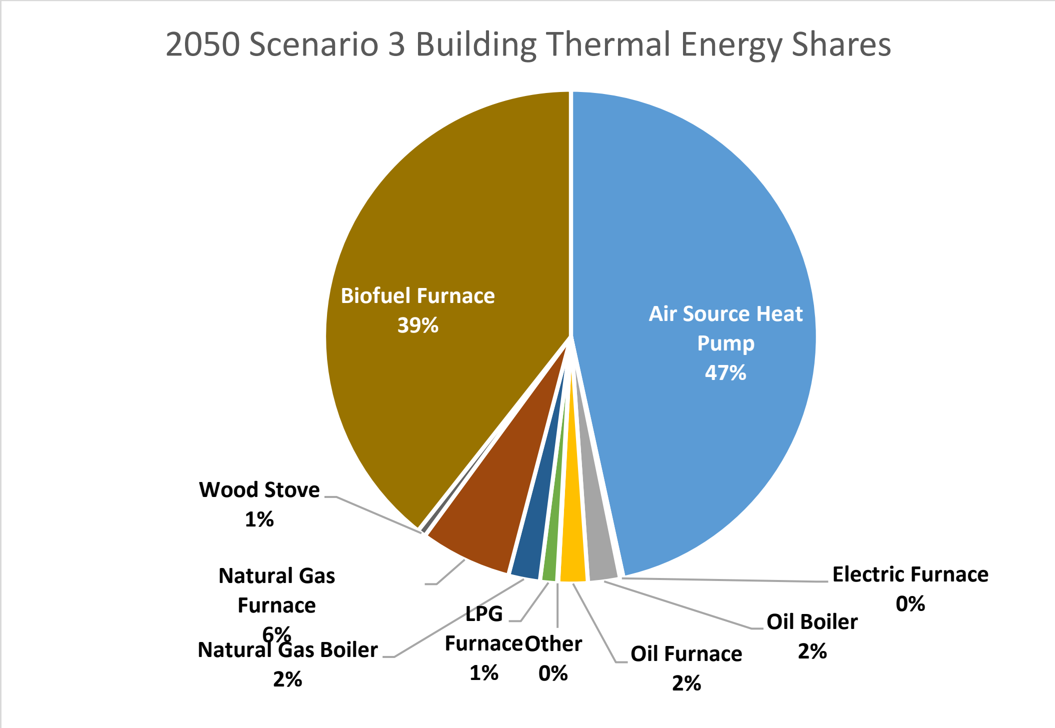
Figure 9 – 2050 Energy Demand by Fuel in the Transportation Sector



Scenario 3 – Electrification with Some Advanced Biofuel Heating

Scenario 3 is similar to scenario 1, except that it assumes no electric furnaces in buildings and instead substitutes the use of liquid biofuel furnaces. Air source heat pumps still comprise the majority of the low-carbon technology share for heating in the buildings sector, but biofuel furnaces comprise a non-trivial portion. This drastic change in heating technologies from the BAU scenario is shown in Figures 6 and 10. Scenario 3 also assumes a higher penetration of hydrogen fuels cells for heavy-duty vehicles. The resulting emissions reductions in 2030 and 2050, based on 1990 levels, are 40 percent and 82 percent respectively.

Figure 10 – Energy Demand by Heating Technology in 2050 for Scenario 3



The scenarios outlined above, and summarized in Table 4, show possible technology mixes to achieve the 2030 and 2050 reduction goals. Figure 11 shows the reduction pathway for each mitigation scenario, while Figure 12 shows the economy-wide energy demand by fuel type in 2050 for each scenario.

Table 4 - Summary of Zero-Carbon Technology in Key Sectors of the Mitigation Scenarios

Sector	Subsector	Zero Carbon Technology Share		Zero Carbon Technology Splits			
		2030	2050	Scenario 0	Scenario 1[1,2]	Scenario 2	Scenario 3
Electricity Generation[3]		81%	90%	75% Wind and Solar 25% Imported Hydro	75% Wind and Solar 25% Imported Hydro	65% Wind and Solar 35% Imported Hydro	75% Wind and Solar 25% Imported Hydro
Buildings	Residential & Commercial Heating	31%	90%	75% Air Source Heat Pump 25% Electric Resistence	75% Air Source Heat Pump 25% Electric Resistence	50% Air Source Heat Pump 50% Electric Resistence	68% Air Source Heat Pump 32% Advanced Biofuels
Industry	Process Energy	49%	79%	75% Electric 25% Advanced Biofuels	75% Electric 25% Advanced Biofuels	75% Advanced Biofuels 25% Electric	75% Electric 25% Advanced Biofuels
Transportation	Light-duty	15%	85%	100% Electric	80% Electric 20% Hydrogen	80% Hydrogen 20% Electric	80% Electric 20% Hydrogen
Transportation	Medium-duty	26%	90%	100% Electric	80% Electric 20% Hydrogen	80% Hydrogen 20% Advanced Biofuels	80% Electric 20% Hydrogen
Transportation	Heavy-duty	26%	90%	60% Advanced Biofuels 40% Electricity	40% Electric 40% Advanced Biofuels 20% Hydrogen	80% Hydrogen 20% Advanced Biofuels	50% Hydrogen 40% Electric 10% Advanced Biofuels
Transportation	Off-Road, Air, and Rail	26%	90%	100% Advanced Biofuels	80% Advanced Biofuels 20% Hydrogen	80% Hydrogen 20% Advanced Biofuels	80% Advanced Biofuels 20% Hydrogen
Non-CO2 GHGs	Waste	52% reduction of methane emissions by 2030 and 89% reduction by 2050.					
Non-CO2 GHGs	Industrial Process	37% reduction of hydroflurocarbon emissions by 2030 and 76% reduction by 2050.					
Non-CO2 GHGs	Natural Gas and Oil System	31% reduction of methane leaks by 2030 and 75% reduction by 2050.					

[1]Scenario 1.1 additionally assumes a 25% reduction in residential and commercial building energy demand.

[2]Scenario 1.2 additionally assumes a 25% reduction in the number of miles traveled by light-duty vehicles.

[3]The zero carbon technology share for the electricity generation section applies to added capacity.

Figure 11 - Business-as-Usual and Mitigation Scenarios through 2050 for New England

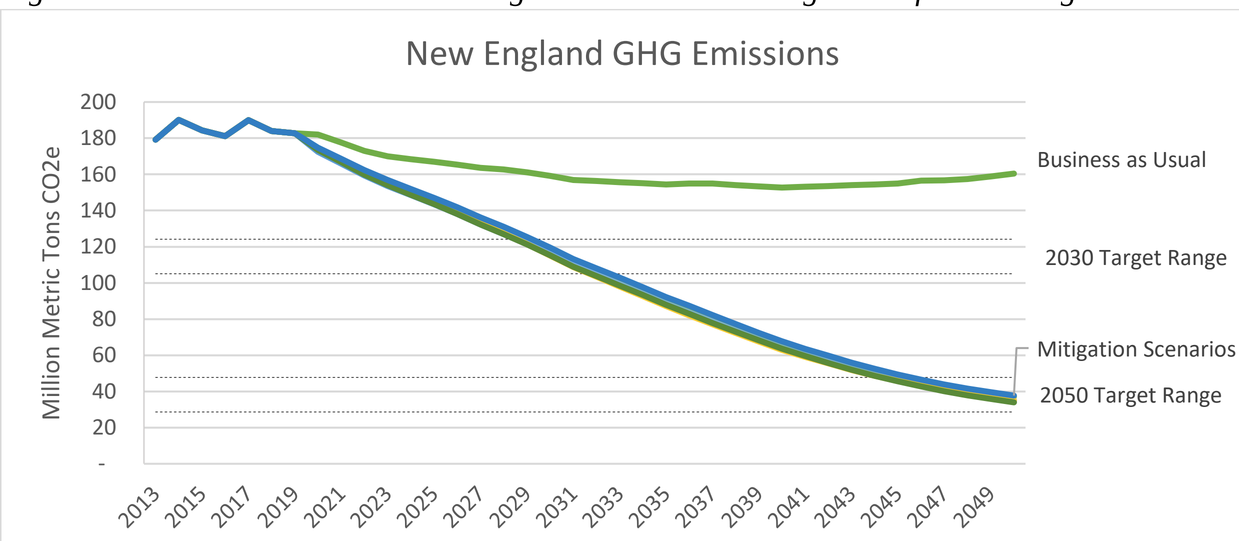
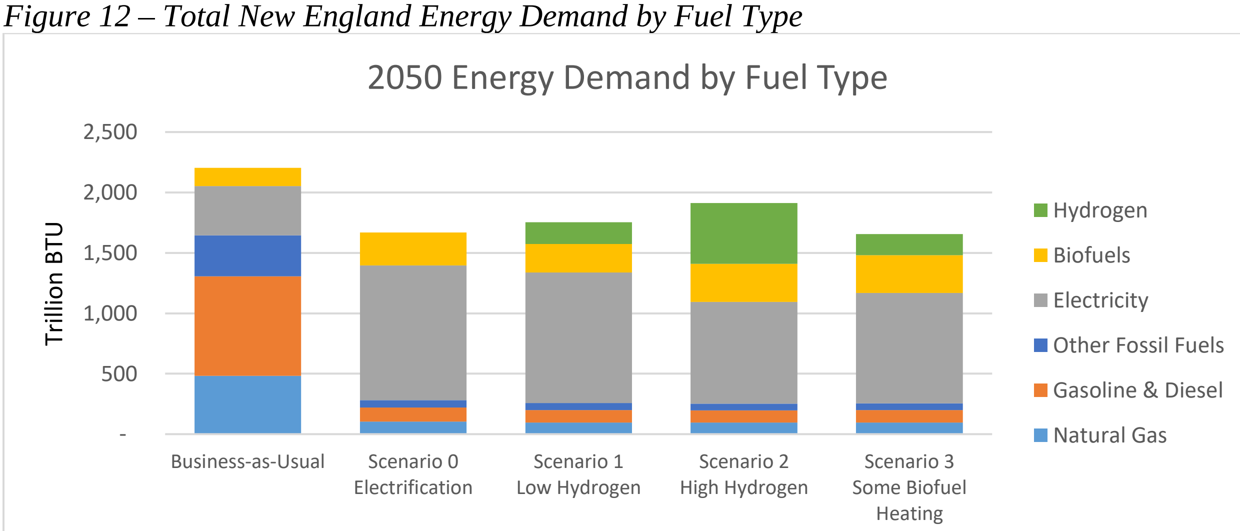


Figure 12 – Total New England Energy Demand by Fuel Type



The scenarios in this analysis are designed to represent a broad spectrum of low carbon technologies being considered throughout a wide body of climate mitigation policy work. Numerous other scenarios could be constructed that would probe different policy objectives and low carbon technologies. The key takeaway from these scenarios is that massive changes need to occur across multiple sectors of the New England economy to reach the region's emission reduction targets. While it is impossible to know exactly which technologies will dominate in the future, this analysis shows that reduction goals can be met with known technologies, but that policies and incentives will be needed to accelerate the process of decarbonizing New England.

Macroeconomic Analysis

This section summarizes the approach and results of the macroeconomic analysis conducted for the scenarios presented in Table 4. It is important to note that projection of costs to 2050 will be inherently uncertain over such an extended period of time. Therefore, we have chosen to focus on benefits and costs projected to the year 2030 due to the increasing uncertainty of technology, fuel, and other cost projections beyond that point. Even projecting out to 2030 is subject to large uncertainties; therefore, we also compare the estimated economic impacts of the mitigation measure to the Reference Case (the BAU case) cost projection in a relative sense. This helps provide context for the magnitude of the scenario costs, i.e., whether they are "large" or "small" relative to the overall BAU Reference Case projection without the GHG mitigation measures.

The macroeconomic impacts in New England of the scenarios NESCAUM modeled were estimated using the Regional Input-Output Modeling System (RIMS II) economic model developed by the Bureau of Economic Analysis (BEA).[7] The RIMS II system is based on an input-output (I-O) accounting framework that tabulates the industrial distribution of inputs purchased and outputs sold of nearly 500 U.S. industries. The model consists of a set of industry multipliers that translate the direct costs – estimated in LEAP – associated with a particular measure into macroeconomic estimates of:

- Employment
- Value-added (Gross State Product)
- Personal Earnings
- Output (value-added plus the value of intermediate goods used in production)

Input-Output economic modeling relies on a detailed accounting of inter-industry relationships in the study region. The underlying data in I-O models describe the value of all industrial inputs required by a particular industry to produce a unit of output for sale to final consumers. The key concept captured in I-O modeling is how economic impacts are generated through different rounds of spending. The first round of spending is known as direct costs. In this analysis, the

[7] Bureau of Economic Analysis, U.S. Department of Commerce, *Regional Input-Output Modeling System (RIMS II)*, https://www.bea.gov/regional/rims/index.cfm (accessed May 5, 2017).

direct costs are estimated in the LEAP model and include changes in fuel expenditures, equipment investment, and installation costs. The second round, known as indirect effects, represents the inter-industry requirements of the directly affected industries. The third round represents the additional income spent or not spent locally as households earn more or less income, which is referred to as induced effects.

The BEA develops two types of multipliers. Type I multipliers capture direct and indirect effects. Type II multipliers capture direct, indirect, and induced effects. In this analysis, BEA staff prepared Type II RIMS multipliers specific to New England and provided them to NESCAUM.

In the following tables, the total impacts for each mitigation measure are compared to a Reference Case economic forecast to contextualize the magnitude of the economic impact of each mitigation measure analyzed. The Reference Case economic forecast was developed at NESCAUM using the REMI PI+ model.[8] The REMI model used to develop the Reference Case provides a useful baseline to give a sense of the overall magnitude of the economic impacts of the selected mitigation measures.

Table 5 presents the total employment impacts of the selected mitigation measures over the entire 2020 – 2030 timeframe. In the Reference Case, total employment over the analysis timeframe is roughly 124 million jobs. Our analysis finds that all employment impacts are less than 0.25 percent of Reference Case employment trends, and in most cases represent a small positive impact on employment levels. A notable exception is scenario 2, which is the scenario that assumes a high deployment of hydrogen fuel cell transportation technologies. In this case, the high cost of hydrogen fueling infrastructure leads to a marginally negative impact on employment. However, because the processes used in the installation and manufacturing of hydrogen fueling infrastructure involve capital intensive industries, the gross state product (GSP) impacts associated with this scenario are slightly positive (see Table 6).

For the employment impacts shown in Table 5, Scenario 0 relies heavily on electrifying all modes of transportation where electrification is feasible. There are two primary reasons employment impacts are the greatest in this scenario: (1) the incremental fueling infrastructure costs are low since much of the delivery network (i.e., the electric grid) is already in place; and (2) the efficiency premium realized by the electric drivetrain relative to the conventional internal combustion engine leads to large overall fuel savings.

[8] REMI PI+ Version 1.4, Build Date 10-03-2012.

Table 5 - Total 2020-2030 Employment Impacts

	Total Job Impacts (jobs)	Percentage of Reference Case
Reference Case Total NE Employment	124,509,073	NA
Scenario 0	257,794	+0.21%
Scenario 1	110,817	+0.09%
Scenario 2	-121,351	-0.10%
Scenario 3	195,204	+0.16%

Table 6 presents the total contribution to GSP impacts of the selected mitigation measures over the entire 2020 – 2030 timeframe. In the Reference Case, total GSP over the analysis timeframe is roughly 12 trillion dollars. In this context, all of the GSP impacts are less than 1 percent of the Reference Case GSP projection. Given the uncertainties in economic projections to 2030 and beyond, the measures can be considered to have little to no impact on projected GSP.

Table 6 - Total 2020-2030 Gross State Product (GSP) Impacts

	Total GSP Impacts ($ millions)	Percentage of Reference Case
Reference Case Total NE GSP	12,146,529	NA
Scenario 0	59,348	+0.49%
Scenario 1	46,684	+0.38%
Scenario 2	62,603	+0.52%
Scenario 3	48,116	+0.40%

Within the uncertainties of economic projections several decades into the future, the RIMS II results indicate that the analyzed GHG mitigation scenarios have a negligible level of economic impacts relative to the Reference Case. Some factors that the macroeconomic impact analysis did not account for which could lead to greater positive in-state economic impacts include:

- Consideration of health benefits from reduced air pollution, such as avoided emergency room visits, asthma attacks, and premature mortality.
- Policies that foster a greater share of industries involved in the production of clean technologies locating in New England, such as electric vehicle battery and air/ground source heat pump manufacturers.
- Policies or economic trends that change the gap between electricity and fossil fuel prices, such as transportation pricing mechanisms.
- Creation of revenue generating mechanisms that can be used to offset the upfront cost of clean technologies, such as using economy-wide carbon pricing or cap-and-trade allowance revenue to provide incentives for the early introduction of clean energy technologies.

Discussion

Overall, the GHG reduction scenarios analyzed differ in the implementation rates of some measures and combinations of measures. In general, however, all scenarios share many common features that reflect relatively limited degrees of freedom in achieving the deep GHG reductions needed for an 80 percent reduction by 2050 in the New England region. All scenarios require a deep decarbonization of the electricity sector coupled with extensive electrification of the buildings and transportation sectors. While advanced biofuels are assumed variable to some extent, the existence of sufficient biofuel stocks to achieve deep GHG reductions is less certain at this stage, as well as the overall lifecycle emissions in the production of advanced biofuels. Hydrogen generated through zero-carbon electrolysis for use in hydrogen fuel cells is a significantly different technology option for transportation, but currently its costs relative to electric batteries are high. While not highlighted in this analysis, however, hydrogen fuel cells may be a more viable technology for long-haul heavy-duty transportation.

The scale of change needed to meet GHG reduction targets necessitates immediate policy action. The longer that significant action is delayed, the higher the likelihood that forced early retirements of fossil fuel technologies will be necessary to achieve reduction targets. To prevent the cost burden of these early retirements, policies should begin to be implemented in the near-term.

This report is not designed to recommend specific policies actions. However, it is worth noting that policy action needs to be taken across all sectors of the economy to ensure the region is underway towards achieving sufficient GHG reductions capable of meeting long-term targets. While a multitude of policies to incentivize the use of low-carbon technologies in each of the subsectors is the current approach, a more efficient future approach would be to implement an economy-wide price on carbon, either through a carbon fee or a cap-and-invest system. This would internalize the cost of carbon, correcting a market failure and sending the appropriate price signals to producers and consumers in the economy. With the true cost of fossil fuels captured through the carbon price, there would be an even playing field on which low-carbon technologies would be more likely to compete on a cost-basis with fossil fuel technologies. The New England states have experience with a cap-and-invest program through the Regional Greenhouse Gas Initiative (RGGI) and could further leverage California and Quebec’s existing experience with an economy-wide carbon market. Policymakers should consider the relative effectiveness of a singular economy-wide price on carbon as an integral part of regional planning for achieving New England’s GHG mitigation targets.

Conclusion

New England's greenhouse gas reduction targets can be met using known technologies. Electric grid decarbonization coupled with the electrification of end-use energy consumption, particularly in the buildings and transportation sectors, offers a clear path towards meeting climate action goals. However, the magnitude of change needed to reach these goals is massive. New England will need to quickly achieve large-scale technology transformations across all of the region's generation and end-use energy sectors. Current policies address only parts of the needed transformation, and only at an incremental level. Rapid scale-up in low- and no-carbon technology penetration and in policy to foster the needed levels of technology penetration is a pressing immediate need.

Appendix A – Key Data Inputs

Table A.1 – Key Data Sources for Reference Case

Sector	Primary Data Sources	Unit of Activity
Residential	AEO 2017 outputs	Number of households by housing type (single family and multi-family), square footage per household for heating and cooling end-uses, and proportional usage of each technology
Commercial	AEO 2017 outputs	Commercial square footage and proportional usage of each technology
Industrial	AEO 2017 outputs	Total energy consumption by fuel type
On Road Transportation & Off Road Equipment	New England-specific MOVES run	Vehicle-miles traveled
Aviation and Rail	AEO 2017 outputs	Total energy consumption by fuel type
Electricity Generation	AEO 2017 outputs and ISO-NE Forecasts	Exogenous capacity and share of electricity production by generation type
Non-CO_2 GHGs	EPA State Inventory and Projection Tool	Carbon dioxide equivalent emissions

Table A.2 – Key Data Sources for Cost Data

Sector	Primary Data Sources	Unit of Cost
Residential	Provided by Abt Associates to NESCAUM on September 22, 2016 for the RI GHG Emission Reduction Study	Cost of device
Commercial	Provided by Abt Associates to NESCAUM on September 22, 2016 for the RI GHG Emission Reduction Study	Cost of device
Industrial	AEO 2017 outputs	Fuel cost
On Road Transportation	California Pathways inputs	Cost of vehicle
Aviation, Rail, and Off Road Equipment	AEO 2017 outputs	Fuel Costs
Electricity Generation	Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants (November 2016) https://www.eia.gov/analysis/studies/powerplants/capitalcost/	Capital Cost, Fixed O&M Costs, Variable O&M Costs