Deep Decarbonization in Nova Scotia: Phase 1 Report

Nova Scotia Power Inc.

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Energy+Environmental Economics

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Table of Contents

Acronyms

AEO	Annual Energy Outlook
DR	Demand Response
EE	Energy Efficiency
GHG	Greenhouse Gas
MMT	Million Metric Tons
NEMS	National Energy Modeling System
NREL	National Renewable Energy Laboratory
NRCAN	Natural Resources Canada (Department of Natural Resources)
NSPI	Nova Scotia Power Inc.
SDGA	Sustainable Development Goals Act
UARB	Nova Scotia Utility and Review Board

Executive Summary

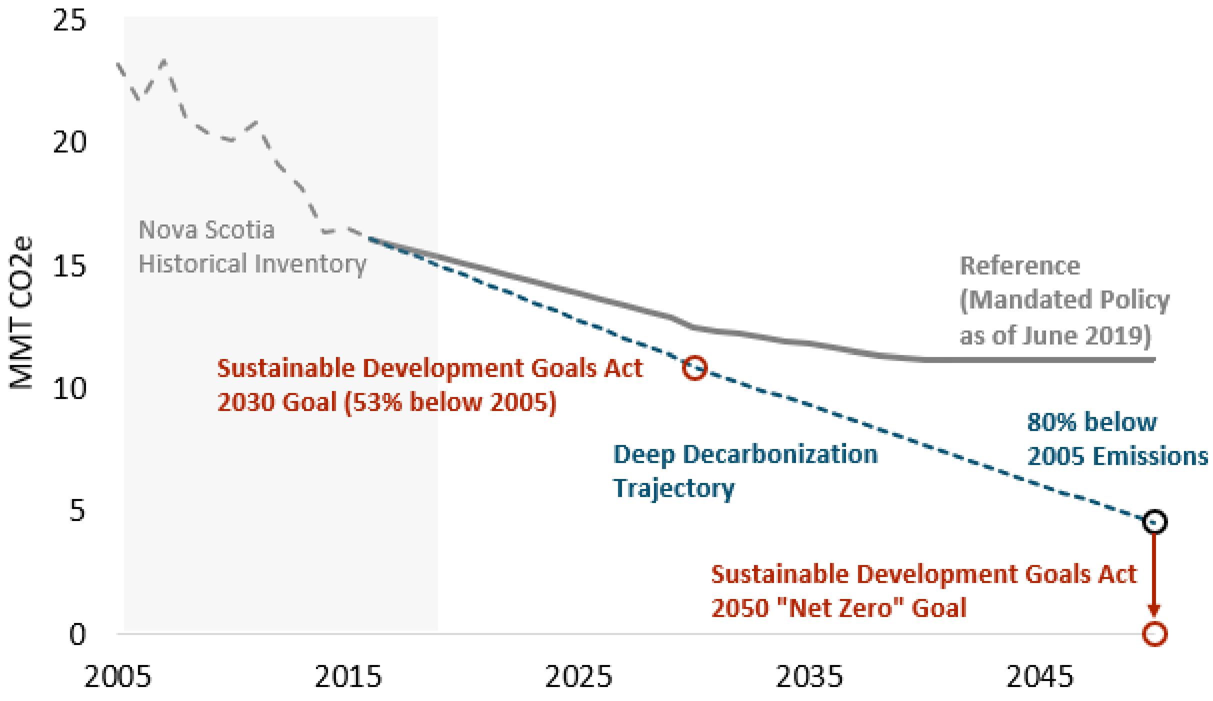
Study Background

The Province of Nova Scotia has been a leader in recognizing the threat of climate change and enacting policy to tackle the problem. On October 30, 2019, Nova Scotia's legislature passed the Sustainable Development Goals Act (SDGA), establishing provincial greenhouse gas (GHG) emission reduction goals of at least 10% below 1990 levels by 2020; at least 53% below 2005 levels by 2030; and "net zero" by 2050, which requires balancing all GHG emissions with removals or offsetting measures.

As the province's primary electricity provider, Nova Scotia Power Inc. (NSPI) recognizes that it must play a critical role in enabling the transition to a low-carbon economy, including decarbonizing its generation fleet, supporting energy efficiency and conservation, and enabling electrification. To better understand the scope and scale of emission reduction measures required to meet these climate goals, NSPI commissioned Energy and Environmental Economics, Inc. (E3) to perform an independent analysis of strategies to achieve long-term, province-wide GHG reductions, with a focus on electricity, buildings, and transportation sectors.

This study, commissioned prior to passage of the SDGA, identifies potentially viable pathways for reducing GHG emissions 80% below 2005 levels by 2050, a level of reduction often called "deep decarbonization". The detailed pathways provide NSP with an indication of the level of electricity sector emissions reductions that may be required as part of economy-wide decarbonization, and also demonstrate the potential impacts of electrification on load. Attainment of the 80% reduction goal would reduce economy-wide emissions to 4.6 million metric tons (MMT) in Nova Scotia in 2050 (Figure 1). Meeting the SDGA's "net zero" target would require additional abatement beyond what is considered in this study.

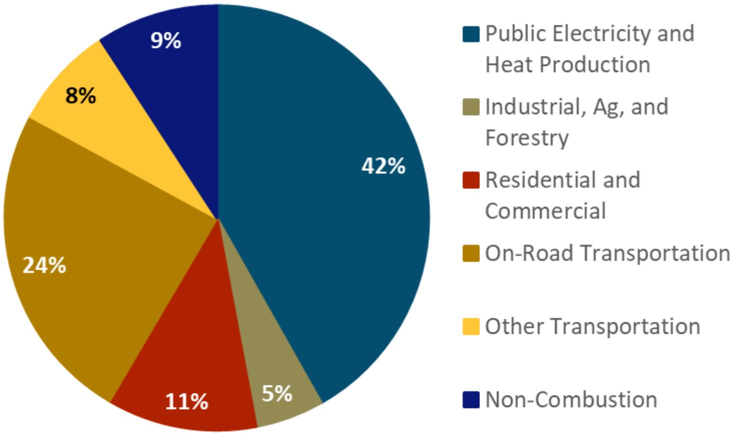
Figure 1. Nova Scotia Historical Greenhouse Gas Emissions and Greenhouse Gas Emission Targets



Nova Scotia's GHG emissions declined rapidly between 2005 and 2016. Many factors contributed to the decrease in GHG, including the electricity sector's transition to renewable and cleaner sources of energy, as well as investments in energy efficiency. Despite this trend, E3's modeling demonstrates that additional abatement measures will be required to meet the 80% by 2050 goal. As discussed in Section 2.4, the Reference scenario shows projected emissions levels under existing policy (prior to SDGA), such as Nova Scotia's hard caps on electricity sector GHGs. The "Mitigation" scenarios demonstrate the incremental effort required to achieve the 80% target.

Figure 2 presents Nova Scotia emissions by sector in 2016. Electricity generation, heat for buildings, and transportation represent most of the emissions in the economy. The emissions profile in Figure 2 represents the starting point for E3's pathways analysis. From here, E3 investigated pathways to achieving deep decarbonization of the Nova Scotia economy focusing on the sectors that are the largest emitters and the most relevant to an electric utility: electricity generation, transportation, and buildings. Emissions from other sectors (industrial, agriculture, forestry, and non-combustion) are included in the study but are not the primary focus of the policy analysis discussed in this report.

Figure 2. Nova Scotia Emissions by Sector in 2016



Source: E3 calculations based on greenhouse gas emissions inventory data and categories for Nova Scotia from Environmental and Climate Change Canada[1]

Approach

E3's modeling approach for this project relied on E3's deep decarbonization scenario tool, PATHWAYS. PATHWAYS is an economic, energy, and GHG emissions accounting tool; E3 has used PATHWAYS in

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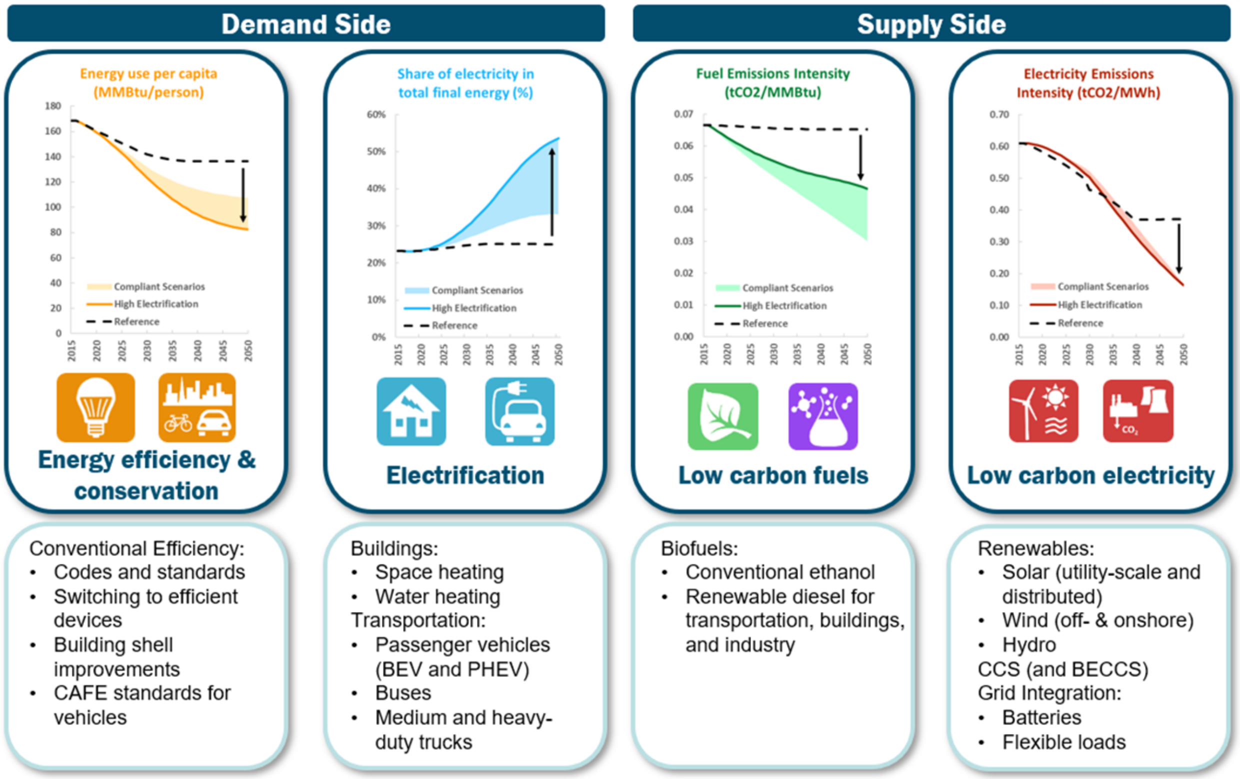
[1] Greenhouse Gas Inventory from Environmental and Climate Change Canada: https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

jurisdictions across North America, including Minnesota, California, Maryland, and Oregon to help utilities and government agencies develop economy-wide low carbon scenarios. E3 developed a PATHWAYS model customized to Nova Scotia, as described in detail in Section 2. Figure 3 shows the four "pillars" of decarbonization for Nova Scotia and other jurisdictions in North America: (1) energy efficiency and conservation; (2) electrification; (3) low-carbon fuels; and (4) low-carbon electricity. For each pillar, a range of values is depicted based on the main scenarios evaluated in the study.

Figure 3. Four "Pillars" for Decarbonizing the Nova Scotia Energy System



Conventional Efficiency:
- Codes and standards
- Switching to efficient devices
- Building shell improvements
- CAFE standards for vehicles

Buildings:
- Space heating
- Water heating

Transportation:
- Passenger vehicles (BEV and PHEV)
- Buses
- Medium and heavy-duty trucks

Biofuels:
- Conventional ethanol
- Renewable diesel for transportation, buildings, and industry

Renewables:
- Solar (utility-scale and distributed)
- Wind (off- & onshore)
- Hydro

CCS (and BECCS)

Grid Integration:
- Batteries
- Flexible loads

Because there is substantial uncertainty about the availability and relative cost of many of the technologies needed to achieve deep decarbonization, E3 utilizes a scenario-based approach to quantitative modeling. This report presents the results of several custom scenarios: a "Reference" (business-as-usual) scenario and three core “mitigation” scenarios (Building Electrification Only, Moderate Electrification, and High Electrification) which vary across a number of dimensions including reliance on electrification and utilization of advanced, carbon-neutral fuels for heating and transportation. Two additional “book end” sensitivity scenarios (High Biofuels, Very High Electrification) are discussed in the appendix. Details on scenario definition are presented in Section 2.4 and Appendix Section 5.2.

Key Findings and Implications for Nova Scotia Power

E3’s PATHWAYS modeling generated several key findings related to deep decarbonization in Nova Scotia.

1. **Synergistic action is required across sectors.** Figure 5 below lays out a set of strategies and milestones that will enable the province to reach 80% reductions in greenhouse gases by 2050. This timeline demonstrates the need for broad and integrated effort across the power, transportation, and building sectors. Complementary efforts would also be required in industrial and non-combustion energy sectors, though these efforts were not modeled in detail in this study. The initial stages of transformation have begun but would need to be accelerated to achieve the 2050 target.

2. **Low-carbon electricity is essential to achieving decarbonization by enabling emissions reductions in the electricity sector, as well as by enabling complementary reductions in buildings and transportation from electrification.** Over the last decade, the electricity sector in Nova Scotia has reduced emissions by more than 30% relative to 2005 levels, thanks to a transition to cleaner and renewable energy sources. Maintaining this momentum would require continuing to integrate low-carbon resources like wind and hydro into its portfolio, while ensuring reliability and affordability. This transition would enable NSPI to meet energy demand from existing electric load

as well as new load growth from space and water heating and transportation, without emitting more carbon.

Figure 4. Nova Scotia Historical Emissions and Projected 2030 and 2050 Emissions by Mitigation Scenario

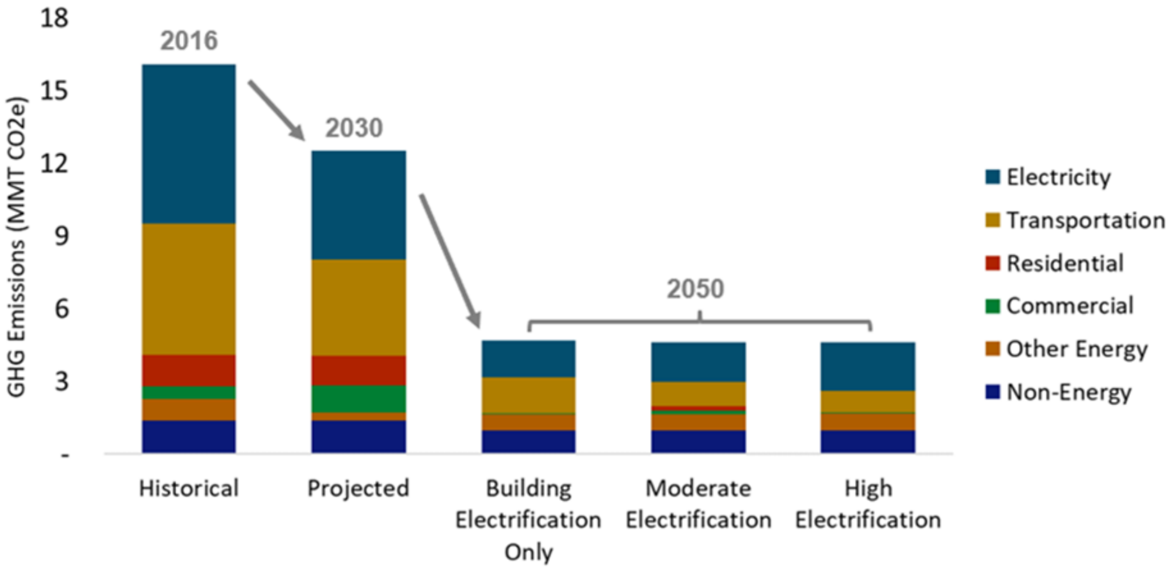
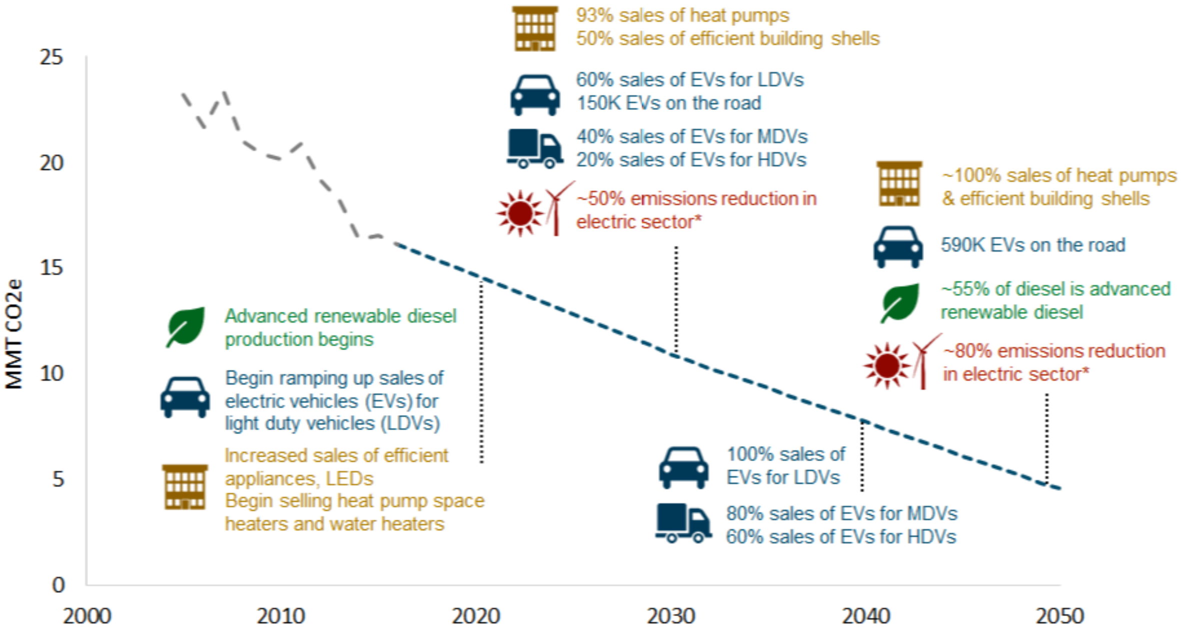


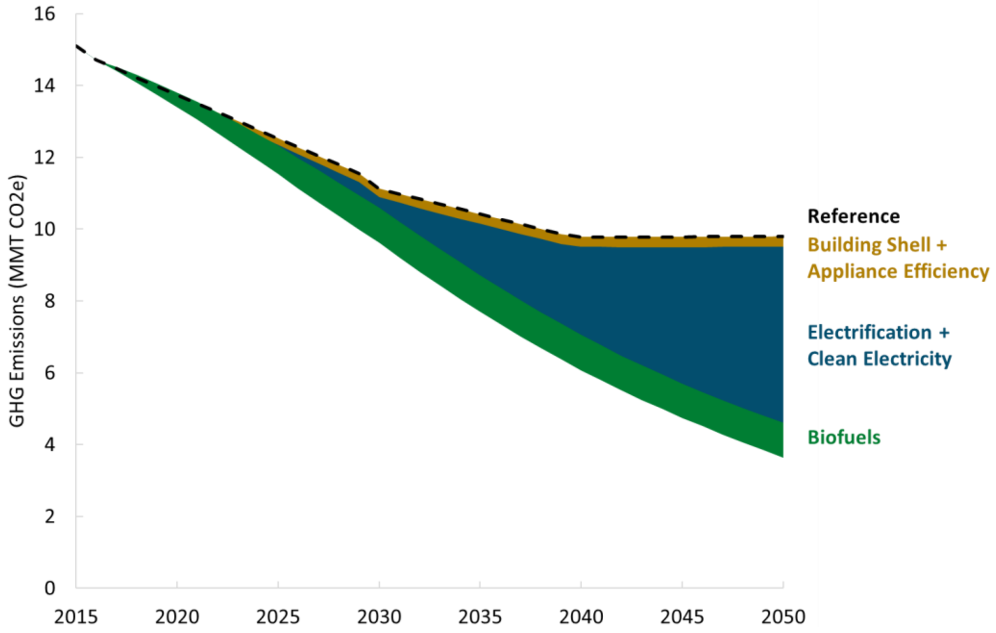
Figure 5. Nova Scotia GHG Emissions Reductions Milestones in High Electrification Scenario



**Electric sector emissions reductions relative to 2005 (10.7 MMT)*

3. **Low-carbon electricity alone is not enough to achieve 80% economy-wide reductions.** All mitigation scenarios, including E3's high electrification scenarios, require additional measures and actions beyond low-carbon electricity in order to achieve the 80% reduction target. Figure 6 below presents emissions reductions by measure for the high electrification scenario. Electrification is used to leverage low-carbon electricity to dramatically reduce emissions from transportation and buildings. Advanced biofuels were used as the main low-carbon fuel in this analysis to supplement the emissions savings needed to achieve the 2050 GHG goal, although other options like hydrogen produced with clean electricity could serve this need as well. However, these strategies will only be viable if the technologies can reach economies of scale in a global market. Nova Scotia should therefore monitor the development of these emerging energy sectors and perform more detailed assessments of their potential deployment in Nova Scotia.

Figure 6. Emissions Reduction by Strategy for the High Electrification Scenario



4. **Long lifetimes require early action.** Investments in infrastructure and equipment can last decades or more, thus having long-lasting effects on emissions. Because there are a limited number of investment opportunities to ensure low-carbon alternatives are selected over alternatives that lead to higher emissions, meeting 2050 goals may require measures to encourage early adoption of electric and/or low-emissions infrastructure and equipment where possible. Delayed action in early years may require more costly early retirements or buy-back programs closer to goal years in order to make up the difference and meet targets. In particular, E3's mitigation scenarios assume near-complete electrification of passenger vehicles by 2050, an aggressive target given there are only around 300 EVs registered in Nova Scotia today. While the costs of electric vehicles are declining quickly, complementary investments in public charging infrastructure may help enable widespread adoption. NSPI could start by defining adoption targets, determining the

infrastructure and initiatives needed to achieve those targets, and developing a strategy to support those markets.

5. **Building electrification is dependent on reducing costs and enhancing incentives, which may be facilitated by the utility and the province.** To achieve the levels of electrification modeled in the decarbonization scenarios, rapid increases in consumer adoption of more efficient and electrified equipment is required. Adoption is unlikely to meet these targets without lower capital costs and attractive rate structures. This study includes scenarios which rely on rapid and widespread adoption of cold climate heat pumps, which are a relatively new technology with significant emissions reduction potential. This technology is commercially available but not yet broadly adopted. The currently high up-front costs of this technology could be addressed with government or NSPI support. From a planning perspective, NSPI must also more thoroughly evaluate the peak electricity demand impacts associated with widespread electric space heating, which were not investigated in detail in this study. The Appendix also contains a scenario in which E3 modeled low-carbon biofuels as an alternative building decarbonization strategy.
6. **Getting to “net zero” will be an even greater challenge, requiring more direct reductions, and/or carbon removal technologies or carbon offsets.** Although this target was not modeled directly in this study, achieving “net zero” would likely require investments in negative emissions technologies such as direct air capture or carbon capture and sequestration. These technologies will be valuable in removing emissions from the hardest-to-decarbonize sectors such as industry. While not typically cost effective today, these technologies may become more feasible strategies with cost declines and performance improvements.

1 Background

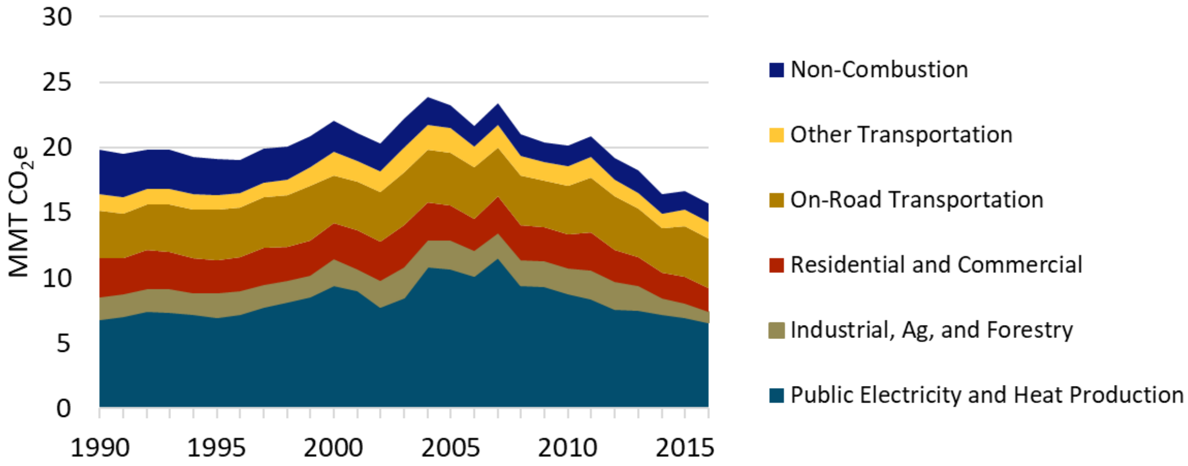
1.1 Nova Scotia Policy Landscape

Climate change threatens human health and livelihoods around the globe, including risks to Nova Scotians, particularly given the province's 7,600 km of coastline and position at the northern end of the Atlantic. In October 2019, the Nova Scotia legislature passed some of the most ambitious climate targets in North America, setting goals of reducing greenhouse gas (GHG) emissions by 53% below 2005 levels by 2030 and attaining "net zero" emissions by 2050. This legislation, the Sustainable Development Goals Act, supersedes the Environmental Goals and Sustainable Prosperity Act of 2007 (updated in 2012), which included a goal of 10 percent reductions relative to 1990 by 2020 and a goal of 40% electricity generation from renewables by 2020. This study, commissioned prior to the passage of the SDGA, evaluates pathways for Nova Scotia to achieve an 80% reduction in GHGs by 2050. This level of climate mitigation is often referred to as "deep decarbonization".

1.2 Nova Scotia Existing Greenhouse Gas Emissions

As of 2016, GHG emissions from electricity and heat production made up over 40% of Nova Scotia's GHG emissions. This portion of total emissions continues to decline given the province's transition to cleaner and renewable fuels; including the addition of Muskrat Falls energy in 2020, the share of NS Power's non-emitting sources will reach approximately 60% of the Company's electricity supply portfolio. The next largest source of emissions is on-road transportation, which makes up almost a quarter of emissions in Nova Scotia as of 2016.

Figure 7. Total GHG Emissions in Nova Scotia by Sector, 1990-2016



Source: E3 calculations based on greenhouse gas emissions inventory data and categories for Nova Scotia from Environmental and Climate Change Canada

2 Study Approach

2.1 Study Questions

This analysis investigates pathways to achieving deep decarbonization of the Nova Scotia economy, with a specific focus on electricity decarbonization and the impacts of economy-wide decarbonization on the electricity sector.

The key research questions include:

- What are viable pathways to achieve deep decarbonization in Nova Scotia?
- What level of electricity sector carbon reductions might be required as part of an economy-wide deep decarbonization strategy for Nova Scotia?
- What role might be played by electrification of vehicles and appliances, and how might that impact electric load served by Nova Scotia Power?

2.2 PATHWAYS Model Framework

This study used E3's PATHWAYS model to develop emissions projections for a reference scenario and five mitigation scenarios. The PATHWAYS model is an economy-wide representation of infrastructure, energy use, and emissions within a specific jurisdiction. E3 developed the PATHWAYS framework in 2008 to help policymakers, businesses and other stakeholders understand and compare plausible decarbonization scenarios. The model has since been modified and improved over time in projects that analyze deep decarbonization in jurisdictions across North America; recent examples include working with the California Energy Commission and with Xcel Energy in Minnesota.

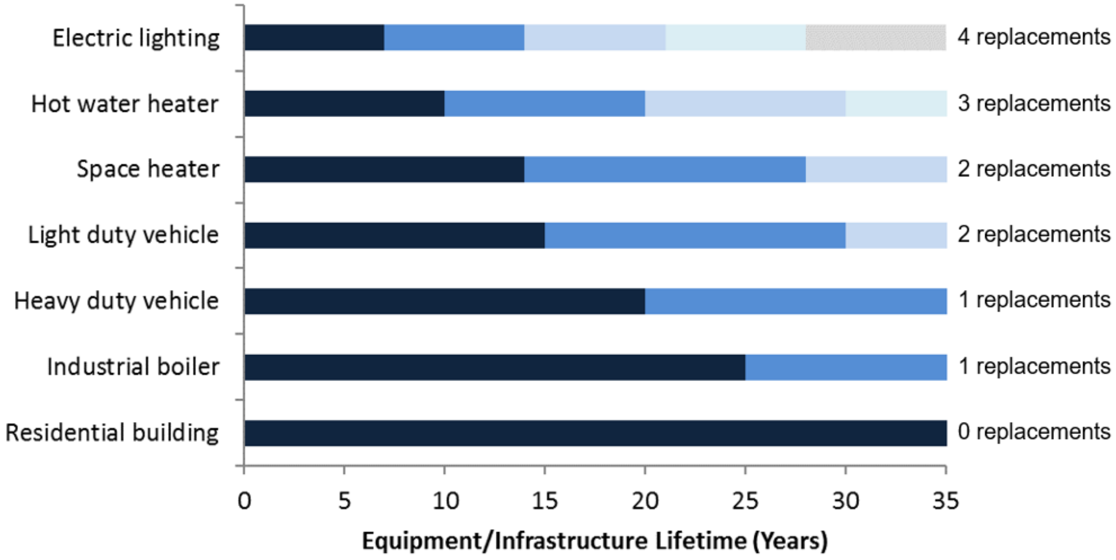
E3’s PATHWAYS modeling includes detailed information regarding energy infrastructure including power plants, trucks, cars, buses and building appliances, industrial processes, and more. Each type of infrastructure consumes energy and produces emissions differently, but they collectively determine the region’s emissions trajectory. Many of these technologies are long-lived. For instance, a home built today will likely still be in use by mid-century. Because investments made in the near-term shape the energy system of the future, the PATHWAYS model includes a detailed, “bottom-up” stock accounting of the region’s energy infrastructure on a technology-specific level (Figure 8). With detailed accounting of residential, commercial, industrial, agricultural and transportation equipment lifetimes, PATHWAYS determines the pace of change necessary to deploy decarbonization strategies while avoiding costly early retirement and captures potential path dependencies of near-term decisions.

A second key feature of the PATHWAYS model is its ability to link sectors. This enables PATHWAYS to identify where aggressive action in one sector can enable emissions reductions elsewhere. For instance, the detailed treatment of the electricity sector is explicitly tied to the carbon savings associated with electric vehicles.

Demands for energy in PATHWAYS are driven by forecasts of population, building square footage, vehicle miles traveled, and other drivers of energy services. The rate and type of technology adoption and energy supply resources are all user-defined scenario inputs. PATHWAYS calculates energy demand, GHG emissions, the portfolio of technology stocks in selected sectors, as well as capital costs and fuel costs for each year between 2015 and 2050. E3 will use the PATHWAYS model to assess the costs of alternative feasible pathways to decarbonization in Phase 2 of this study.

PATHWAYS also features representation of biofuels availability. Based on an assessment of biofuel demands, the model optimizes a biofuels portfolio based on available sustainable feedstocks and selected conversion pathways. The biofuels portfolio meets pre-defined demand for renewable jet kerosene, renewable diesel, and renewable natural gas.

Figure 8. Infrastructure Lifetimes in PATHWAYS



2.3 Nova Scotia PATHWAYS Model

E3 built a bottom-up PATHWAYS model of the Nova Scotia economy using the LEAP tool (Long-range Energy Alternatives Planning System)[2]. This modeling tool implements the framework described above and is customized to the desired region. In particular, the model quantifies the energy and emissions associated with the projected trends in consumption and production in all sectors of an economy, and also accounts for complementary policies targeting future emissions. E3 built a model of Nova Scotia's energy and non-energy emission sources, projecting them through 2050 using multiple scenarios to understand different pathways that can be reached through complementary actions across the province. E3 notes that this study does not perform detailed electricity sector modeling of the Nova Scotia system, given this modeling will

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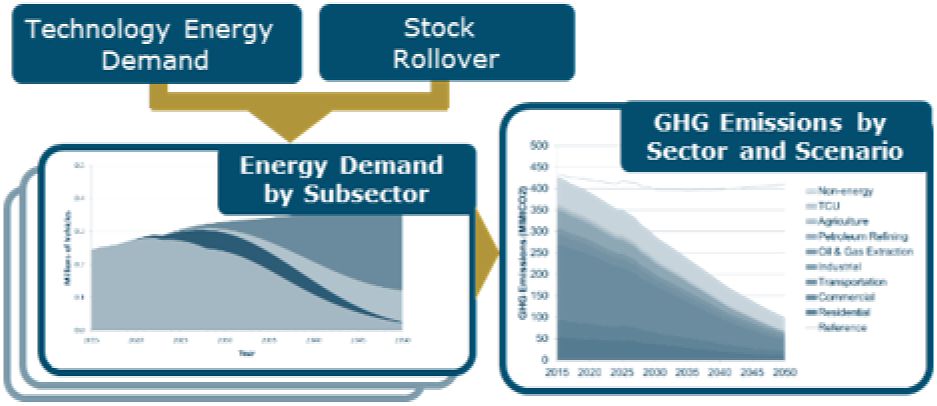
[2] LEAP is developed by the Stockholm Environment Institute. More information on the LEAP software can be found at www.energycommunity.org

occur during the 2020 IRP. Instead, E3 utilized a range of plausible carbon intensities typical of a more deeply decarbonized system, and assumed this range of emissions intensities would be associated with plausible future NPSI loads. s noted in the conclusion, more detailed electricity sector modeling should be performed within the context of the IRP or in future NSPI study

Figure 9. PATHWAYS Energy Modeling Framework Utilized for Nova Scotia Study



2.4 Scenarios

The study considers one reference scenario, which reflects the NS government's greenhouse gas reduction target in 2030 of a 45-50% GHG reduction below 2005 levels, as of the study initiation. At the time, this was more ambitious than the federal target of 30% below 2005 levels by 2030. In the Reference scenario, the 2030 target was held flat across the remaining period to serve as a baseline for comparing against the mitigation scenarios, all of which meet 80% emissions reductions by 2050. The study considers one reference and three primary mitigation scenarios.

- **Reference Scenario:** The current policy scenario includes the 2030 hard cap on emissions from the electricity sector as required by the 2009 Greenhouse Gas Emissions Regulations[3] and utility-driven energy efficiency. This scenario also assumes some improved appliance and vehicle efficiency standards and further electric sector emissions reductions in 2040-2050, beyond the 2030 hard cap as required by the 2009 Greenhouse Gas Emissions Regulation. This Reference scenario is based on current stock and sales of devices as represented by publicly available governmental data sources, and is not based on NS Power produced internal load forecasts.

- **High Electrification Scenario:** This mitigation scenario relies on significant energy efficiency, near-complete electrification of space and water heating demands by 2050, and complete electrification of light duty vehicles by 2050, with significant electrification of other transportation sectors. Some emissions reductions are achieved from advanced biofuels to displace fossil combustion, especially in freight transportation; industry; and other off-road transportation.

- **Moderate Electrification Scenario:** This mitigation scenario relies on significant energy efficiency and achieves about half of the building and transportation electrification achieved in the High Electrification Scenario. Additional emissions reductions come from use of advanced biofuels to displace fossil fuel combustion.

- **Building Electrification Only Scenario**: A mitigation scenario that relies on significant energy efficiency and achieves near-complete electrification of space and water heating demands by 2050. Because there is no transportation electrification, additional emissions reductions come from use of advanced biofuels to displace fossil fuel combustion.

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[3] The Greenhouse Gas Emissions Regulations set hard cap on electricity emissions **https://www.novascotia.ca/JUST/REGULATIONS/regs/envgreenhouse.htm**

Two additional “bookend” scenarios –one focusing on more extreme reliance on biofuels and the other focusing on more extreme reliance on electrification – were also modeled. These scenario assumptions and results are available in the report appendix. Key assumptions are also reported in Table 1 below. E3 notes that it developed its assumptions using publicly available data sources, and that these explicitly do not reflect NSPI’s assumptions.

Figure 10. Historical Greenhouse Gas Emissions and 2050 Greenhouse Gas Targets

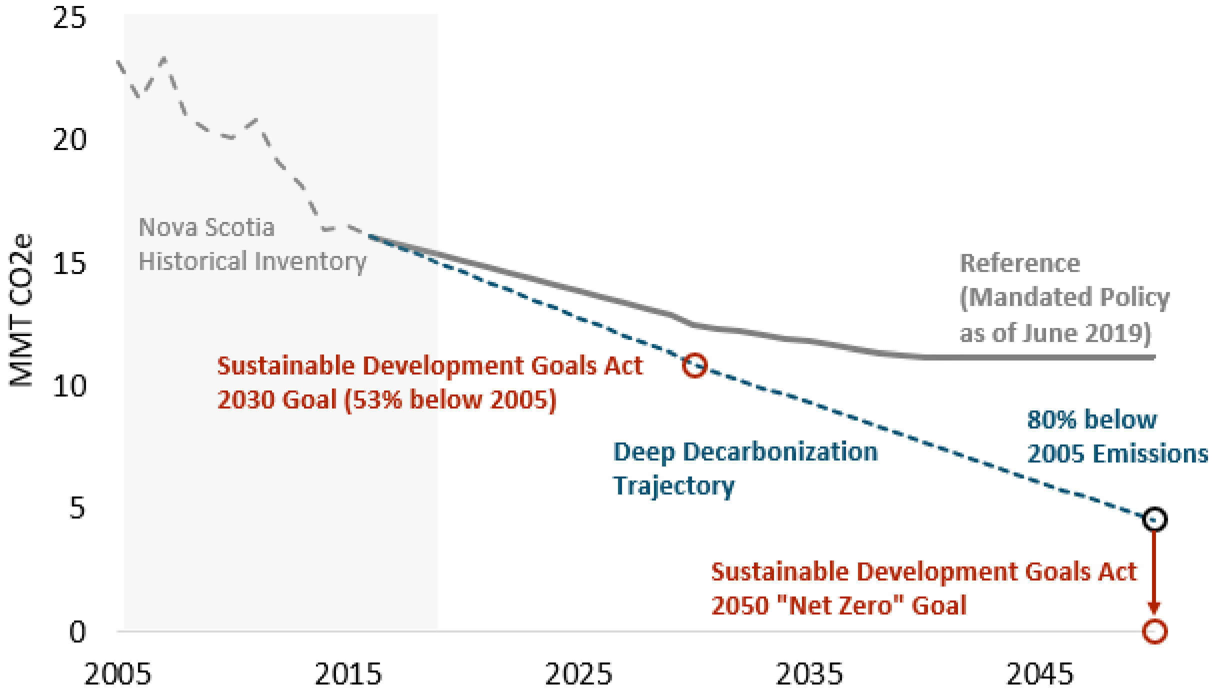

Table 1. Key Assumptions Across Scenarios

	Reference	High Electrification	Building Electrification Only	Moderate Electrification
2050 GHG emissions budget for electricity generation	3.5 MMT CO_2e	2.0 MMT CO_2e	1.5 MMT CO_2e	1.65 MMT CO_2e
Building energy efficiency	None	54% of homes are assumed to have significant weatherization upgrades by 2050, leading to a 7% reduction in space conditioning demands		
Sales of electric heat pump equipment / other appliances	25% sales of air source heat pumps for space heating by 2050	100% sales of heat pump space heaters and water heaters by 2030 in the residential sector 98% sales of heat pump space heaters and 93% sales of heat pump water heaters by 2040 in the commercial sector 100% sales of electric cookstoves by 2040		50% sales of heat pump space heaters and water heaters by 2040 in the residential and commercial sectors 50% sales of electric cookstoves by 2050
Zero-emission vehicles	LDVs: 2% Zero Emission Vehicles (ZEV*) sales by 2050 MDVs: 10% compressed natural gas sales, 2% EV sales and 1.5% H_2 fuel cell sales by 2050 HDVs: 10% compressed natural gas sales and 0.5% EV sales by 2050 Buses: 5% EV sales by 2030	LDVs: 100% ZEV sales by 2040 MDVs: 80% EV sales by 2040 and 9% diesel electric hybrid sales by 2050 HDVs: 60% EV sales and 40% diesel electric hybrid sales by 2040 Buses: 60% EV sales by 2040	Same as Reference	LDVs: 50% ZEV sales by 2040 MDVs: 90% diesel electric hybrid sales by 2050 HDVs: 100% diesel electric hybrid sales by 2050 Buses: 5% EV sales by 2030
Vehicle fuel economy	U.S. CAFE standards for LDVs through 2026			
Advanced Biofuels	None	Advanced biofuels using agricultural residues and forestry wastes assumed to be available, based on assumption of broader North American biomass feedstock market		
Non-energy	None	30% reductions relative to 2016		

*ZEV: Zero Emission Vehicles include battery electric (BEV) and plug-in hybrid electric (PHEV) vehicles.

2.5 Model Inputs

As described above, PATHWAYS is a stock rollover modeling framework which projects energy demands and the associated GHG emissions. Input data for PATHWAYS were constructed based on Canadian and United States government data. Data on device efficiencies and average lifetimes were sourced from the United States National Energy Modeling System (NEMS) as used in the Annual Energy Outlook (AEO) 2019.

2.5.1 FIRST YEAR EMISSIONS BENCHMARKING

In each sector of the economy, E3 created a representation of base year (2016) infrastructure and energy, and identified key variables that drive activity changes over the duration of each scenario (2017-2050). E3 benchmarked the Nova Scotia PATHWAYS model created for this analysis to Nova Scotia 2016 emissions from the Canadian Government 2016 GHG Inventory data for Nova Scotia.

2.5.2 KEY DRIVERS AND DEMOGRAPHICS

To project future energy use and corresponding emissions, E3 projected key macroeconomic variables that drive energy services demands. The most impactful inputs are population growth, household growth, and growth in vehicle miles traveled (VMT). For these key variables, E3 assumed flat growth from 2015-2050. This assumption is based on population trends as seen in the National Energy Board (NEB) Reference forecast, which projects slightly negative population growth through 2040. However, E3 conservatively forecasts flat population growth, indicating that fundamental demand for energy services does not change over time.

2.5.3 BUILDING SECTOR

2.5.3.1 *Base Year*

In 2016, Nova Scotia had a population of about 942,000 people residing in about 403,000 households.[4] The buildings sector includes energy usage for residential and commercial customers. In a stock rollover approach, total energy usage in buildings is decomposed into energy use per device multiplied by number of devices. In the residential subsectors, E3 performed a stock rollover of physical devices themselves (e.g. number of natural gas furnaces). Because of the more heterogenous nature of commercial buildings and the difficulty in comparing physical devices across commercial building types, in the commercial subsectors E3 abstracts stock rollover into modeling the unit of stock as a square footage of commercial building.

E3 sourced data on population and number of households from Natural Resources Canada (NRCAN) data when available, filling in gaps with the New England region of the NEMS database when NRCAN data are unavailable. To calculate the distribution of device types within a subsector (e.g., the percentage of residential space heaters which are natural gas versus electric resistance), E3 again relies on NRCAN data. Device efficiency data are sourced from the United States National Energy Modeling System (NEMS)[5]. For energy services demand per household or per commercial square foot, NEMS data are used as a default and modified to benchmark to NRCAN data. For residential subsectors, NRCAN data are available for the Nova Scotia province, and for commercial subsectors an emissions-weighted downscale of the Atlantic provinces region are used.

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[4] National Energy Use Database by Natural Resources Canada:
http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

[5] Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. Report by Navigant Consulting, Inc. and Leidos (formerly SAIC) for the US Energy Information Administration. https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf

Table 2. Representation of 2016 Building Energy Consumption by Subsector in Nova Scotia

Sector	Subsector	Modeling Approach	Energy Use in 2016 [TBtu]	Percent of 2016 Building Energy Use [%]
Residential	Central Air Conditioning	Stock Rollover	0.09	0%
	Room Air Conditioning	Stock Rollover	0.09	0%
	Building Shell+	Stock Rollover	-	0%
	Clothes Drying	Stock Rollover	0.83	1%
	Clothes Washing	Stock Rollover	0.07	0%
	Cooking	Stock Rollover	0.42	1%
	Dishwashing	Stock Rollover	0.25	0%
	Freezing	Stock Rollover	1.11	2%
	Reflector Lighting	Stock Rollover	0.24	0%
	General Service Lighting	Stock Rollover	1.05	2%
	Exterior Lighting	Stock Rollover	0.17	0%
	Linear Fluorescent Lighting	Stock Rollover	0.18	0%
	Single Family Space Heating	Stock Rollover	28.20	45%
	Refrigeration	Stock Rollover	3.22	5%
	Water Heating	Stock Rollover	6.39	10%
	Other*	Total Energy by Fuel	-	0%
Commercial	Air Conditioning	Stock Rollover	2.07	3%
	Cooking	Stock Rollover	0.35	1%
	General Service Lighting	Stock Rollover	1.38	2%
	High Intensity Discharge Lighting	Stock Rollover	0.20	0%
	Linear Fluorescent Lighting	Stock Rollover	1.44	2%
	Refrigeration	Stock Rollover	2.72	4%
	Space Heating	Stock Rollover	7.89	13%
	Ventilation	Stock Rollover	1.27	2%
	Water Heating	Stock Rollover	1.10	2%
	Other*	Total Energy by Fuel	1.88	3%
All Buildings Subsectors			**62.59**	**100%**

+Building Shell is modeled to represent potential deep home retrofits and other measures which significantly reduce space conditioning demands. By itself a Building Shell stock does not consume energy, but E3 models an Efficient building shell reducing space heating service demand by 20%.

*Residential Other includes furnace fans, plug loads (e.g. computers, phones, speakers, printers), secondary heating, fireplaces, and outdoor grills. Commercial Other includes plug loads, office equipment, fireplaces, and outdoor grills.

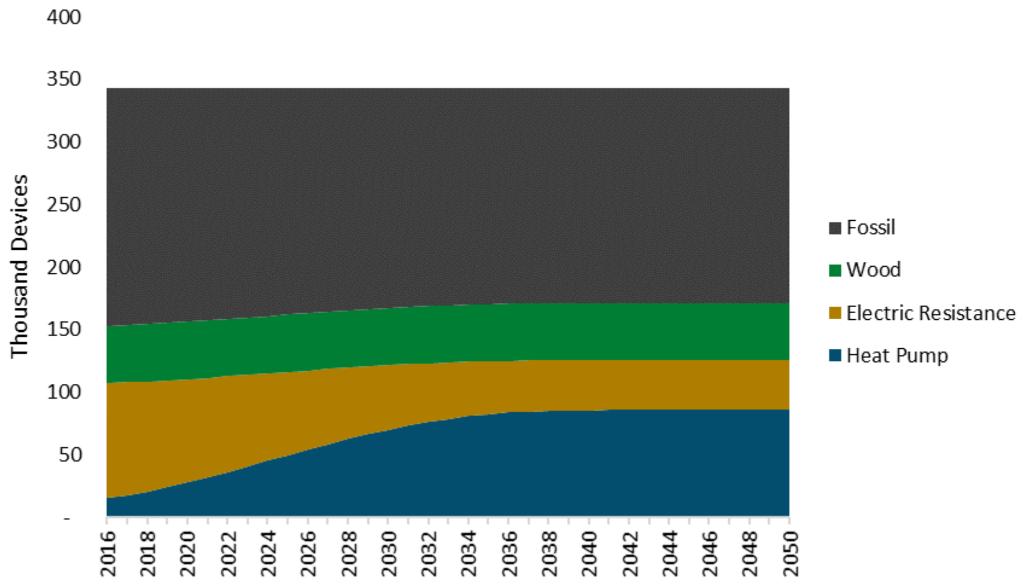
2.5.3.2 Reference Scenario

The primary measure represented in buildings for the Reference Scenario is the achievement of electric energy efficiency. Energy efficiency in buildings is implemented in the PATHWAYS model in the form of increased device efficiencies for new building devices. Specifically, E3 assumes a greater share of high efficiency appliances or lighting are purchased and therefore used in the residential and commercial sectors. New equipment is typically assumed to replace existing equipment “on burn-out”, e.g., at the end of the useful lifetime of existing equipment. Efficiency improvements in new devices are included in the NEMS forecast of device efficiency improvements. In addition, a percentage of the current stock of electric resistance space heating is swapped to heat pump space heaters as heat pump space heaters provide large efficiency improvements. Table 3 documents key assumptions for the Reference Scenario, and Figure 11 provides an example of the stock rollover assumed in the Reference Scenario, showing residential space heating stock.

Table 3. Reference Scenario Assumptions for Building Energy Efficiency

Category of Building Measures	Reference Scenario Assumption
Device efficiencies	NEMS reference technology efficiency improvements
Building electrification	20% of space heater sales are heat pumps by 2020

Figure 11. Stock Rollover from the Reference Case: Residential Space Heating



Since the model is based on a bottom-up forecast of technology stock rollover in the residential and commercial sectors, the model does not use a single load forecast or energy efficiency savings forecast as a model input. It is important to note that the modeling assumptions used in this analysis may not reflect specific future energy efficiency programs or activities.

2.5.3.3 Mitigation Scenarios

The mitigation scenarios include varying levels of aggressive energy efficiency and building electrification measures. These mitigation scenarios are designed to test a range of future outcomes for building electrification, which in practice, will depend on the availability of incentives for building electrification as well as future technology trends and fuel cost trajectories. The scenarios are not attempting to predict future consumer adoption based on economics alone. Three major mitigation categories are modeled in the Buildings sector:

1. **Building retrofits for high efficiency building shells**: Deep home retrofits of existing buildings are performed when space conditioning appliances are replaced, in addition to mandating ultra-efficient building shells for new homes and commercial buildings. These efficient building shells reduce the demand for space conditioning by up to 20% over a Reference building shell.
2. **New appliance sales:** In addition to the efficiency of conventional devices improving over time, new appliance sales begin switching over to efficient alternatives, such as EnergyStar appliances.
3. **Building electrification:** As discussed in the Reference scenario, heat pump space heaters have significant GHG mitigation benefits since heat pumps are significantly more efficient than conventional fossil or electric alternatives over an annual energy basis.

Table 4 documents the key building mitigation measure utilized in the modeling, while Figure 12 and Figure 13 show a stock rollover of residential space heating in the Moderate and Building/High Electrification scenarios respectively.

Table 4. Building Mitigation Measures

Category of Building Measures	Building Electrification Only	Moderate Electrification Scenario	High Electrification Scenario
Building retrofits for high efficiency building shells	100% adoption of efficient building shell and weatherization measures by 2040		
New appliance sales	100% of new sales of all appliances are assumed to be efficient (e.g. EnergyStar) by 2030 (except space heaters, which are considered below).		
Building electrification	100% sales of electric heat pumps by 2030	50% sales of electric heat pumps by 2030	100% sales of electric heat pumps by 2030

Figure 12. Stock Rollover in the Moderate Electrification Scenarios: Residential Space Heating

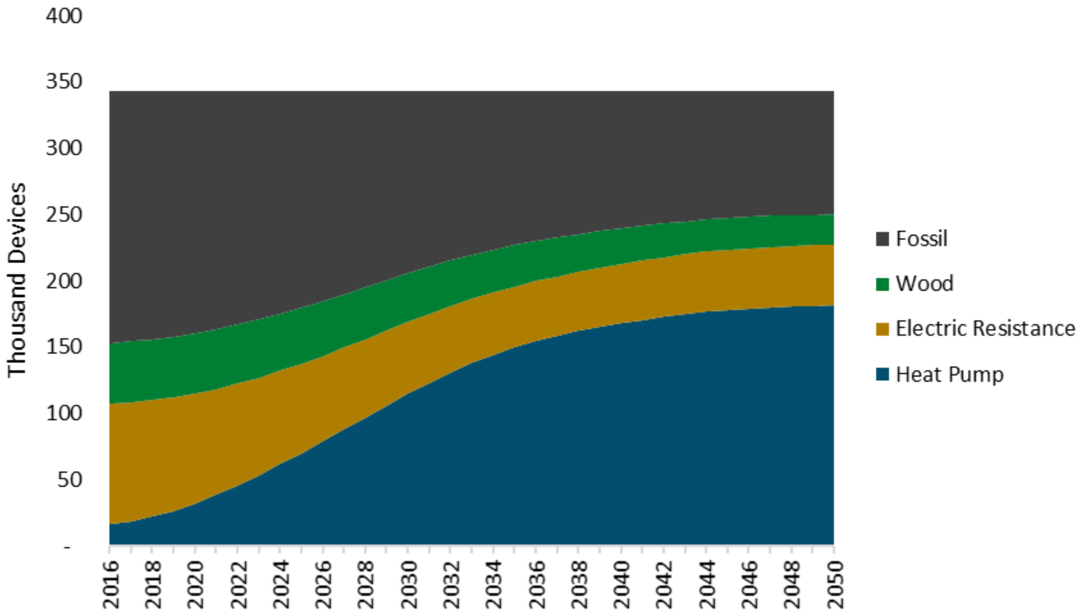
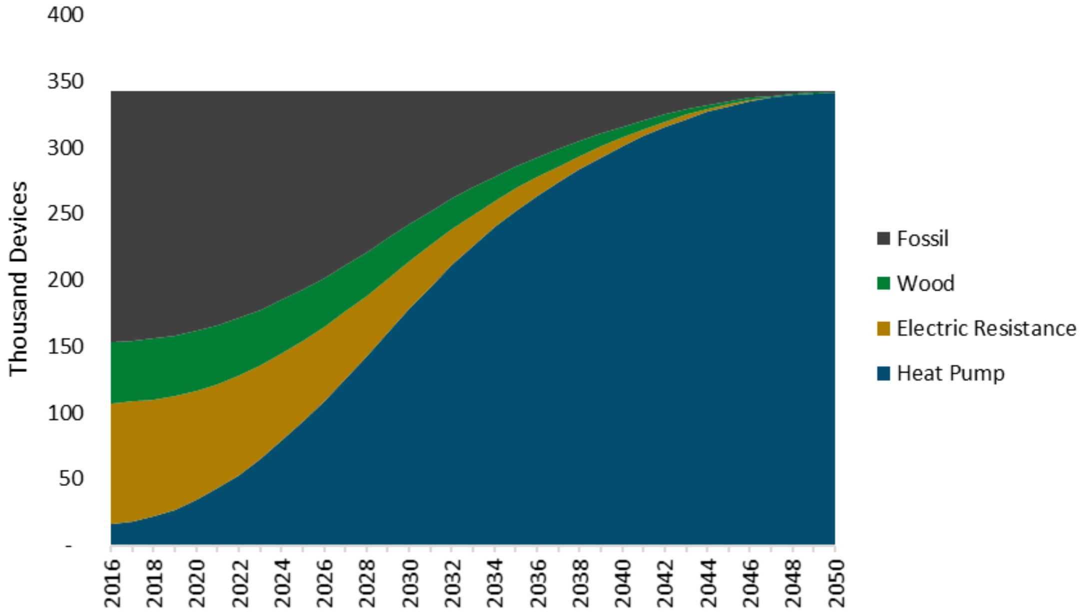


Figure 13. Stock Rollover in the Building Electrification and High Electrification Scenarios: Residential Space Heating



2.5.4 TRANSPORTATION SECTOR

2.5.4.1 Base Year

The Nova Scotia PATHWAYS model includes a stock-rollover representation of five transportation sectors and an energy representation of seven subsectors. Sectoral energy demand is benchmarked to energy consumption from the Nova Scotia GHG Inventory for 2016 and is disaggregated by subsector based on the EIA National Energy Modeling System (NEMS) technology characterization and additional data from Nova Scotia GHG Inventory and federal Canadian data on vehicle miles traveled (VMT) by vehicle class. All subsectors represented in the transportation sector are listed in Table 5.

Table 5. Representation of 2016 Transportation Energy Consumption by Subsector in Nova Scotia

Subsector	Modeling Approach	Energy Use in 2016 [TBtu]	Percent of 2016 Transportation Energy Use [%]
Long Wheelbase Light Duty Vehicle (Long LDV)	Stock Rollover	25.81	35%
Short Wheelbase Light Duty Vehicle (Short LDV)	Stock Rollover	17.13	23%
Heavy Duty Trucks	Stock Rollover	13.67	18%
Other (all other transportation energy to benchmark to the GHG Inventory, including shipping; rail; other non-road and off-road vehicles)	Total Energy by Fuel	11.67	16%
Aviation	Total Energy by Fuel	2.87	4%
Medium Duty Trucks	Stock Rollover	2.61	4%
Buses	Stock Rollover	0.73	1%
All Transportation Subsectors		**74.48**	**100%**

2.5.4.2 Reference Scenario

The main driver of energy reductions in the Reference scenario are continued federal Light Duty Vehicle (LDV) Corporate Average Fuel Economy (CAFE) Standards. While there is continued policy uncertainty in the US around CAFE standard implementation, E3 understanding is Canada has pledged to continue following CAFE standard improvements through model year 2026, and as such those improvements are modeled within this analysis. In addition, a nominal amount of electric passenger vehicles (codified as short and long wheelbase light duty vehicles in the table above), and a small amount of electric bus sales are modeled. Figure 15 presents the reference case stock rollover graph for light duty electric vehicles.

While freight trucks as a whole consume less energy and emit fewer emissions than passenger vehicles, the energy and emissions demands from freight trucking are not insignificant. There are currently a small amount of compressed natural gas (CNG) vehicle sales in Nova Scotia, and a small market for CNG trucks continues to be modeled in the Reference scenario.

Figure 14: Fuel Economy for New Light Duty Vehicles (LDVs)

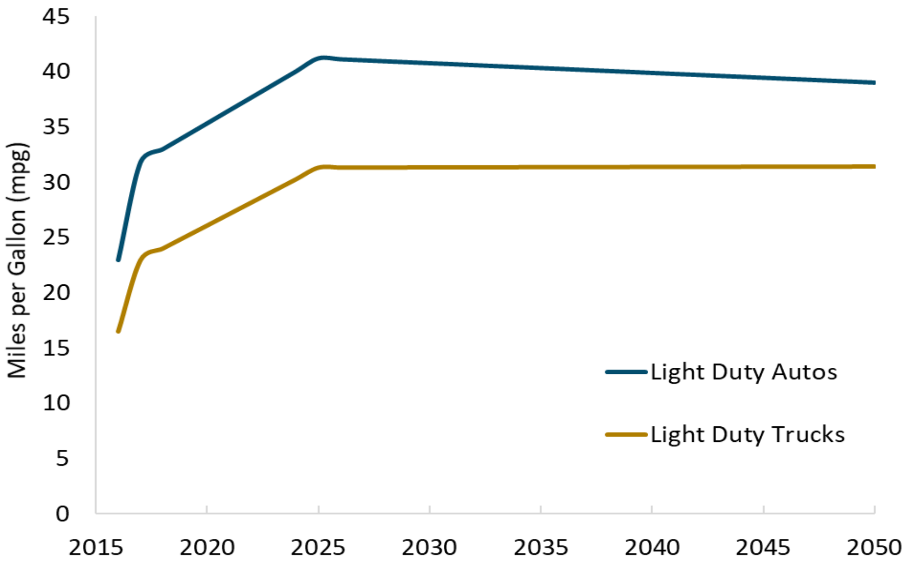
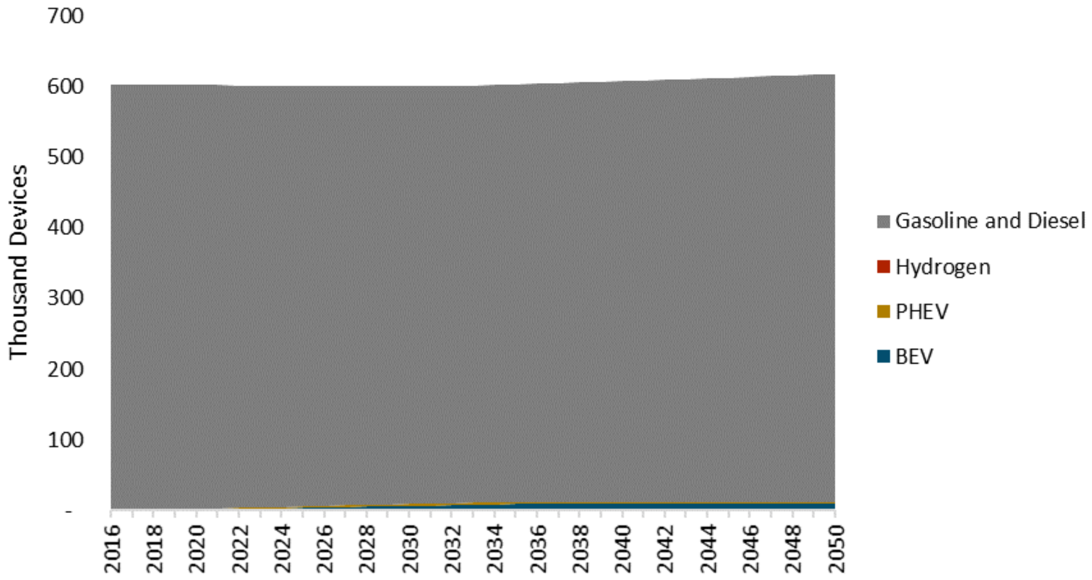


Figure 15. Stock Rollover from the Reference Scenario and Building Electrification Scenario: Light Duty Vehicles



2.5.4.3 Mitigation Scenarios

The main vehicle decarbonization measure in the mitigation scenarios is electrification of internal combustion engine vehicles to electrified alternatives; these alternatives range from hybrid-electric vehicles to zero emission vehicles (ZEV) such as battery electric (BEV) and plug-in hybrid electric (PHEV). Table 6 below documents the main mitigation measures used in constructing the three mitigation scenarios.

Table 6. Transportation Mitigation Measures

Category of Transportation Measures	Building Electrification	Moderate Electrification Scenario	High Electrification Scenario
Zero-emission Light Duty Vehicle (LDV) sales	Same as Reference (2% by 2020, flat at 2% after)	Reach 50% annual sales by 2040 (15% of the ZEV are PHEV)	100% annual sales by 2040 (20% of ZEV are PHEV by 2050)
Zero-emission Medium Duty Vehicle (MDV) sales	None	By 2050 achieve 90% sales of Diesel Hybrids	By 2040 assume 80% annual sales of ZEV MDVs
Zero-emission Heavy Duty Vehicle (HDV) sales	None	By 2050 achieve 100% sales of Diesel Hybrids	By 2040 assume 60% annual sales of ZEV HDVs
Zero-emission Bus sales	Same as Reference (5% by 2030, flat at 5% after)	Same as Reference (5% by 2030, flat at 5% after)	By 2040 assume 60% annual sales of ZEV Buses.

Note: The Very High Electrification Scenario (provided in the Appendix) includes some electrification of the Transportation Other subsector. That means 60% of all other transportation fuels which are uncategorized or unknown are electrified.

Figure 16. Stock Rollover from the Moderate Electrification Scenario: Light Duty Vehicles

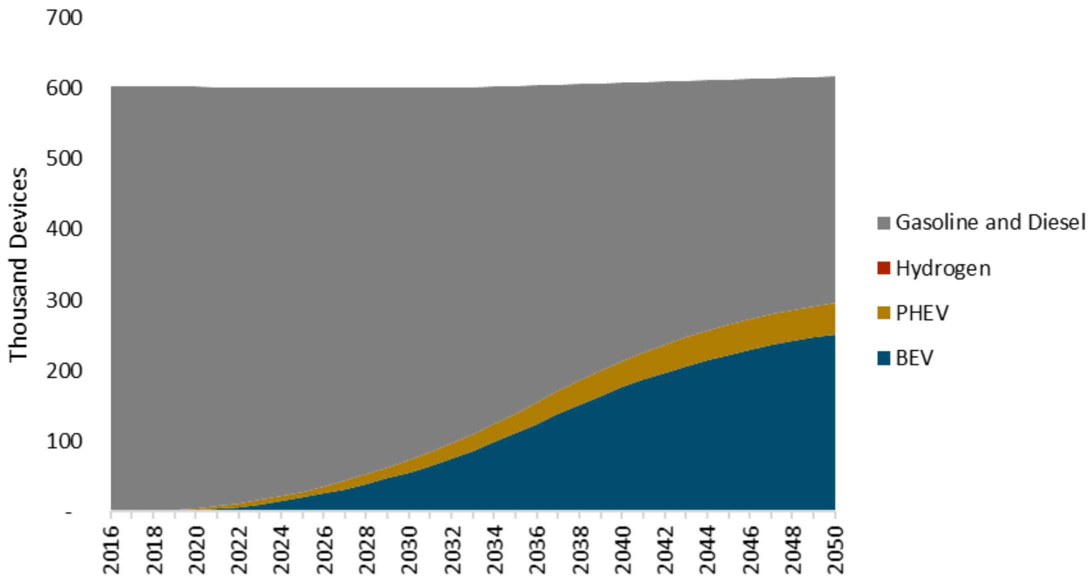
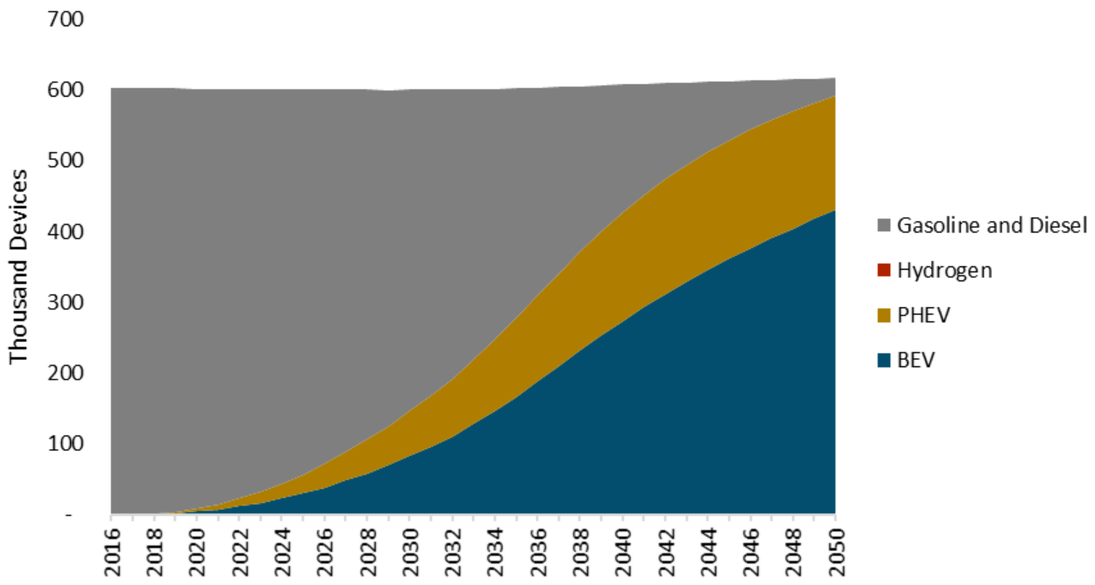


Figure 17. Stock Rollover from the High Electrification Scenario: Light Duty Vehicles



2.5.5 ELECTRICITY SECTOR

To assess potential decarbonization in the electricity sector, E3 identified a range of emissions intensities associated with deeply decarbonized electricity systems and developed a trajectory for NSP to attain an emissions intensity within this range. E3 did not perform detailed electricity dispatch modeling, recognizing that this would be performed in the upcoming IRP. In particular, E3 recognizes that a more detailed assessment of integrating renewables, primarily wind, will include evaluating the variability of wind output; grid strength and stability; seasonal energy requirements; and reduced capacity contribution of wind when replacing firm thermal units. This modeling assumes that NSPI can achieve a reduction in emissions intensity of at least 80% relative to 2005 levels. E3 recommends further study on the cost, reliability, and potential of electricity sector decarbonization under deep decarbonization and load growth scenarios.

2.5.6 OTHER ENERGY (INDUSTRIAL) SECTOR

The "other energy" category mainly consists of industrial energy activities. Because energy emissions from the industrial sector are relatively low compared to buildings and transportation, efficiency or electrification measures for industry are not modeled in the main mitigation scenarios. However, emissions do decline in industry in all three main mitigation scenarios due to biofuels replacing up to 72% of diesel consumption.

2.5.7 NON-ENERGY SECTOR

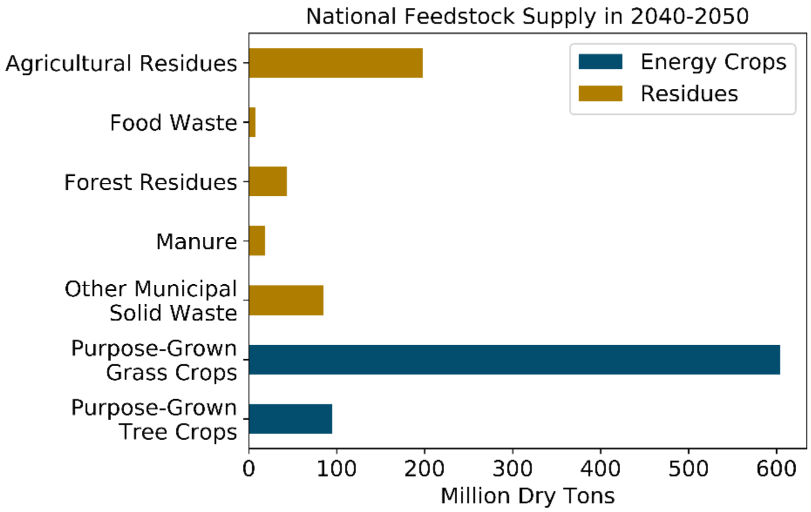
Non-energy greenhouse gas emissions include methane and other high global warming potential gases from agriculture, waste, and industrial processes. By 2050, all mitigation scenarios are assumed to achieve 30% reductions in non-energy emissions relative to 2006. These reductions could be achieved by changes in agricultural practices, increased methane control and treatment for municipal solid waste, and the phase down of (hydrofluorocarbons) HFCs. For HFCs in particular, Canada's ratification of the Kigali Amendment in 2017 established a nationwide target of 85% reduction in HFC consumption by 2036, relative to 2016 levels.

2.5.8 BIOFUELS SECTOR

Advanced renewable biofuels, i.e., drop-in fuels which are chemically indistinguishable from the conventional fossil alternative, are a potentially important resource option when decarbonizing certain subsectors, particularly those which are difficult to electrify or otherwise convert to other low-carbon alternatives. These advanced renewable fuels are modeled as carbon neutral from a life cycle emissions perspective. There is a limited supply of appropriate biomass feedstock which can be used to produce biofuels, and the competing demands for biofuels are contingent on a regional biofuels market to incentivize the appropriate capital investments into biofuel conversion refineries.

Due to limited data regarding the biomass resource potential for biofuel production in Canada, E3 used the United States Department of Energy Billion Ton Study (BTS) dataset to calculate feedstock availability and costs for biofuels produced from US feedstocks, and then converted this amount to an estimate of the amount of available feedstocks expected to be available in Canada**.** The BTS dataset was updated in 2016, and its base assumptions include over one billion tons of biomass potential by 2040, incremental to resources currently utilized. However, most of this resource is new purpose-grown crops and forests, which E3 excludes from this analysis due to concerns about their sustainability. The advantage of using the BTS data is that it includes biomass supply curves that account for the costs of reserving, collecting, and transporting the raw biomass for central processing. Conversion efficiencies and costs and long-distance transport are layered on top of the raw feedstock costs. Detailed conversion assumptions for biofuels are available in Appendix Table 12.

Figure 18. US Billion Ton Study (BTS) National Feedstock Supply



Using population data and United Nations Food and Agriculture Organization (FAO) data on acreage of various agricultural resources within Canada, E3 estimated the Canadian biomass potential at 128 million dry tons by 2040 excluding purpose-grown crops. E3 considered modifying some of the crop and tree feedstock categories to be more representative of Canadian resources, such as by replacing corn with colder climate grains like barley and replacing hardwood (deciduous trees) with softwood (coniferous). However, the results are not especially sensitive to the particular feedstock and conversion assumptions, because Canada's supply is likely many times greater on a per capita basis than in the US. Although there is a potentially large supply of biofuels, if these resources were developed for commercial use, it may be feasible for Canada to export these biofuels into a global market as decarbonization proceeds elsewhere. While it is technically feasible for Nova Scotia to rely exclusively on Canadian biomass feedstocks and produce biofuels, such a strategy would be inconsistent with the global action necessary to achieve deep decarbonization and limit warming to below 2 degrees Celsius. Given this, these scenarios do not rely exclusively on domestic biomass feedstocks to produce biofuels, instead considering mitigation measures such as efficiency, electrification, and other types of fuel switching.

As noted above, E3 modeled a "bookend" scenario in which Nova Scotia pursues deep decarbonization using solely biofuels, which is presented in the appendix. Biomass is not used for electricity generation in this study. This might be a lower cost solution than using biomass for biofuel production and direct end-uses, but there may be other constraints limiting the ability to use biomass for electric generation.

Table 7. US 2040 Biomass Feedstock and potential Canadian equivalent with appropriate scaling factor

Feedstock	US Potential (Million Tons)	Scaling factor to convert US potential to estimated Canadian potential	Estimated Canadian Potential (Million Tons)
Ag Residues	198	Cropland	62
Purpose-Grown Grasses	604	Cropland	189
Food Waste	8	Population	1
Forest Residues	44	Forest	49
Manure	18	Cropland	6
Other MSW	85	Population	10
Purpose-Grown Trees	95	Forest	106
Total	1,051		423
Total Excl. Purpose-Grown	**352**		**128**

3 Results

The results in this section demonstrate the transformative change that must occur in order to achieve 80% GHG reductions (relative to 2005) by 2050. The Reference scenario reflects projected economic activity without an economy-wide emissions budget, while the three mitigation scenarios reflect a target economy-wide 2050 emissions budget of 4.6 MMT, utilizing the PATHWAYS model and assumptions outlined in Section 2.

3.1 Economy-wide GHG Emissions

While all three of the mitigation scenarios achieve 80% reductions by 2050, the scenarios diverge in their allocation of emissions across sectors. Figure 19 represents the total emissions allowed (and projected to be achieved) in each sector of the economy. In scenarios with greater electrification, E3 allocated additional emissions budget to the electricity sector in order to accommodate the greater portion of energy demand met by the electricity sector. E3 notes that detailed electricity sector modeling was not done for this PATHWAYS study. Rather, E3 determined electricity sector emissions budgets with implied emissions intensities that fell within a range of electricity sector emissions intensities that were consistent with a deeply decarbonized NSP system. This was done as a preliminary step in order to assess the feasibility of a given budget, and the utility's ability to reduce emissions to a given level while meeting growing demand, ensuring reliability, and maintaining reasonable costs.

Across the three mitigation scenarios, the High Electrification scenario assumes the highest level of building and transportation electrification. The Moderate Electrification scenario, alternately, assumes end-use electrification in the building and transportation sectors is slower and thus more emissions remain in those sectors. The Building Electrification Only scenario looks at a hypothetical future in which aggressive building electrification occurs, but no similar vehicle electrification; thus, most transportation sector emissions persist. This demonstrates that a range of electrification levels are possible while still meeting the 80% reduction, as shown in Figure 19 below.

E3 does not model the detailed changes that may occur in non-energy emissions, which include agriculture, waste, and some industrial processes. Rather, E3 assumes all mitigation scenarios achieve 30% reduction in non-energy emissions relative to 2016. The “other energy” category mainly consists of industry energy activities for which E3 do not model any efficiency or electrification measures, since emissions are relatively low compared to buildings and transportation. Across the sectors, remaining emissions include emissions from hard-to-electrify end-uses, such as long-haul trucks, aviation, shipping and industrial activities.

Figure 19. Nova Scotia 2050 Mitigation Scenario Sectoral Share of Carbon Emissions Budget (4.6 MMT)

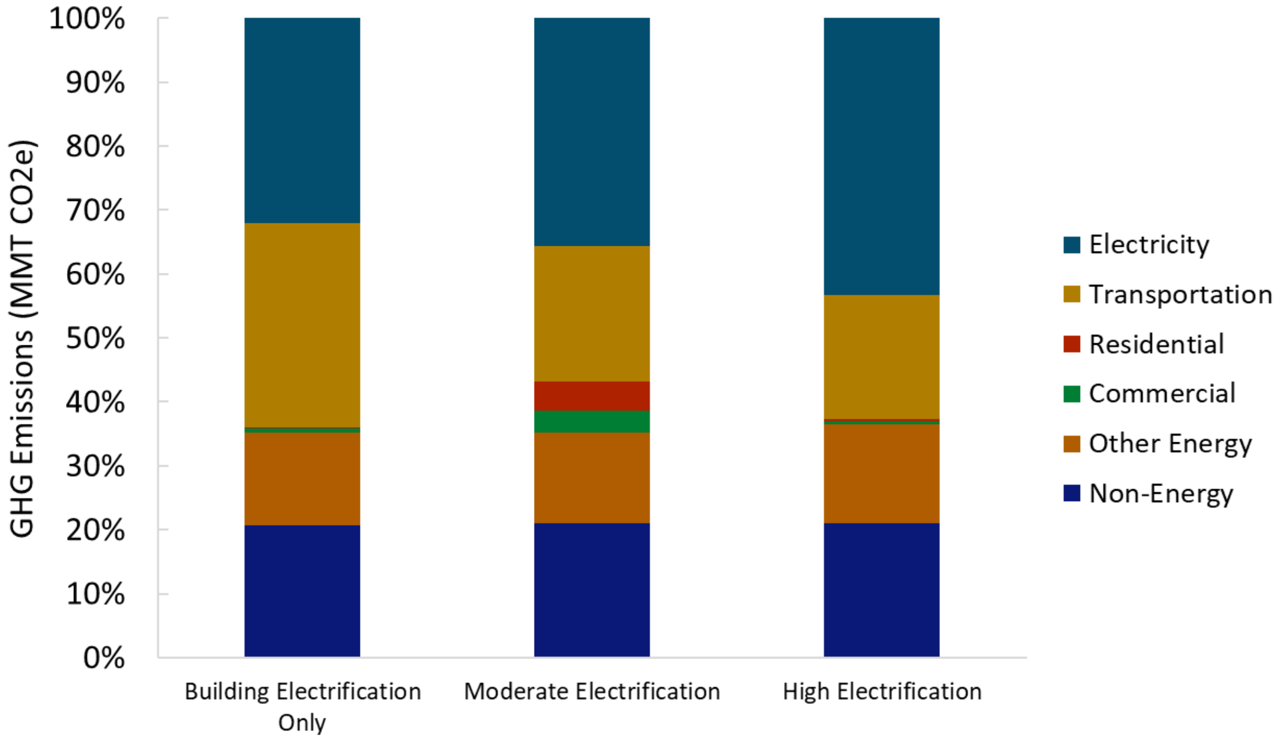
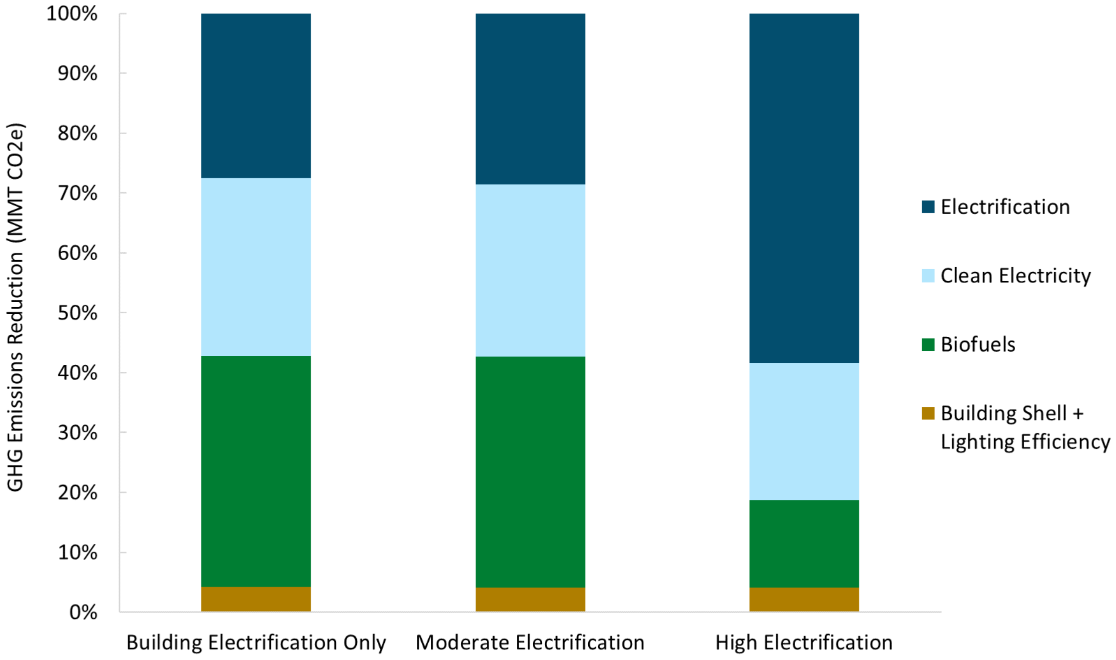


Figure 20. Share of Greenhouse Gas Reductions by Measure in 2050 (6.5 MMT, Relative to Reference)



Note: Emissions reductions from Electrification and Clean Electricity measures are interdependent and were not modeled separately in this analysis. Thus, allocations to these two categories are preliminary approximations.

3.2 Final Energy Demand

Final energy demand includes demand for energy of all forms across sectors. Final energy demand falls over time as a result of the combined impact of energy efficiency in all sectors (buildings, industry and transportation), as well as the efficiency savings associated with electrification. Improvement in new appliance efficiency, on-road vehicle efficiency, and building shells are among the energy efficiency measures that contribute to reductions in final energy demand. Electrification also contributes significant reductions in final energy demand. For example, heat pumps are assumed to have an average efficiency of 350% in delivering space heating, almost four times as efficient as even a high-efficiency furnace with 90% efficiency. In transportation, electrification lowers total energy demand given the relatively greater efficiency from switching from internal combustion engines in vehicles (~40 MPG) to electric motor drivetrains in the transportation sector (~150-180 MPGe).

Final energy demand in the High Electrification scenario is about 20% lower than in the other two mitigation scenarios, thanks to the efficiency gains from high levels of electrification. Building and transportation electrification, together with building shell improvements, reduce final energy demand by ~60 TBtu, ~40% below the Reference scenario.

Figure 21. Nova Scotia Final Energy Demand

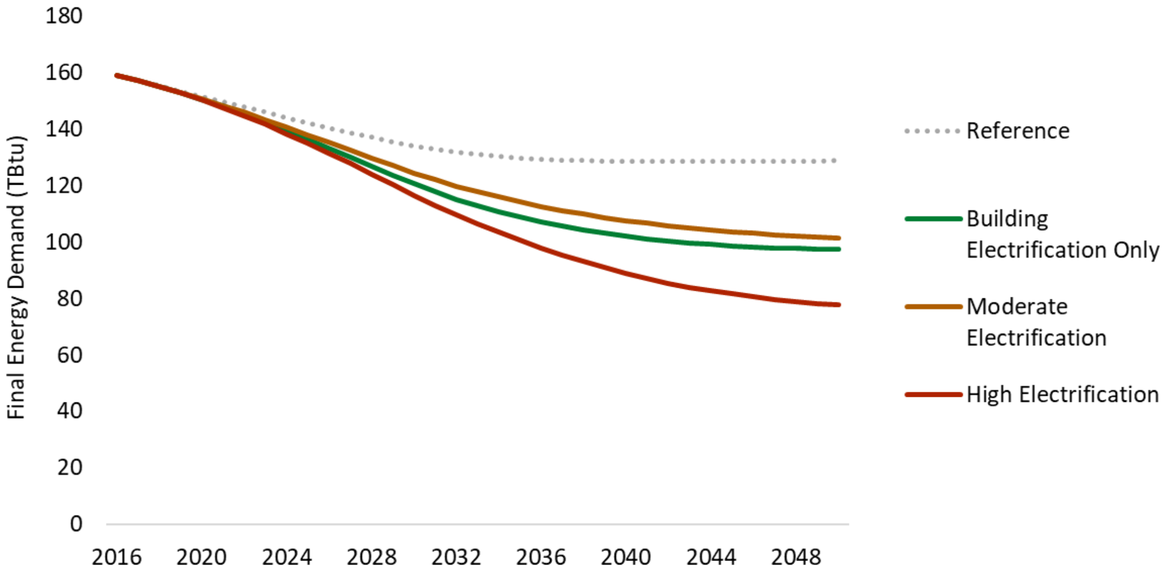
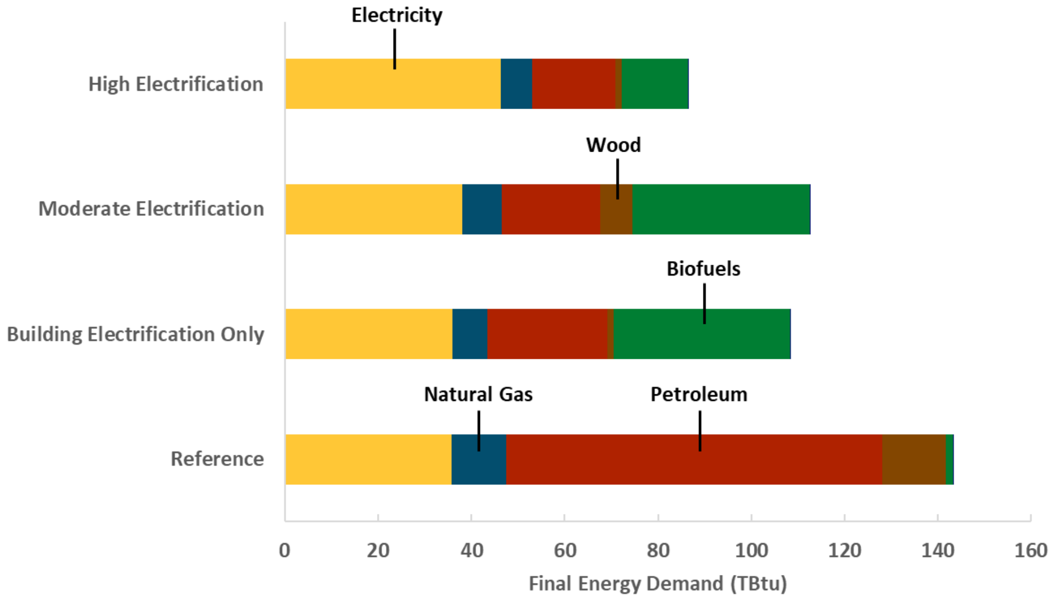


Figure 22. Final Energy Demand by Fuel Type and Scenario in 2050



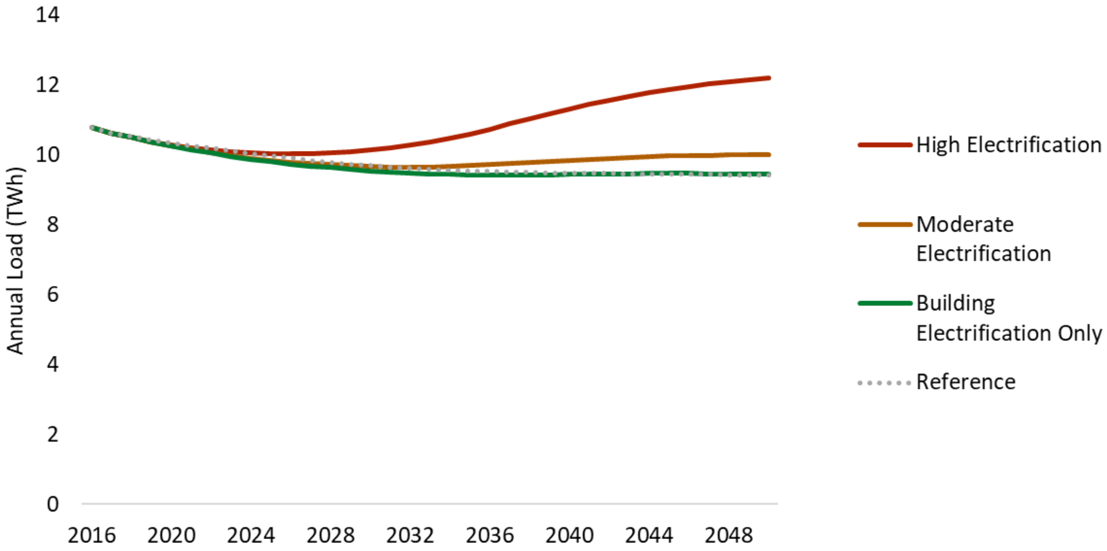
3.3 Electricity Sector

3.3.1 ELECTRIC LOAD

PATHWAYS generates electric load by aggregating the electricity demand of end-use appliances, devices and activities in all sectors (buildings, transportation and industry). The change in electric load is determined by the level of electrification and the magnitude of energy efficiency measures (such as device-level efficiency gain and behavioral conservation). Our analysis determines a budget for the electricity sector based on our estimates of feasible emissions intensities for a deeply decarbonized system, the emissions reductions in the other sectors, and the economy-wide emissions reduction goal.

This study's results show that the High Electrification Scenario projects electric load growth due to increasing level of transportation and building electrification. In contrast, the Moderate Electrification scenario projects moderate load growth because increased heat pump and EV load is offset by reduced load from conversion of resistance heaters to more efficient heat pumps, and from decreased space heat demands due to highly efficient building shell measures. The Building Electrification Only scenario has similar annual load as the Reference scenario due to a larger effect of heat pump load offset by building shell improvement.

Figure 23. Annual Electricity Demand (excluding losses) by Scenario, 2015-2050



As Table 8 shows below, in all mitigation cases the electric sector achieves over 80% emissions reductions relative to 2005 levels. Even in the High Electrification scenario in which E3 have significant vehicle and building electrification (and corresponding load growth), the electric sector must hit an 80% by 2050 decarbonization target. If transportation electrification is not included and only building electrification occurs, the burden is much greater on electricity as it must hit an 87% emissions reduction relative to 2005 levels. As noted in Section 2.5.5 above, this analysis relies on assessed bounds of feasible electric sector emissions intensities. More detailed electric sector simulation with increased loads is necessary to more completely evaluate costs and reliability, as well as considering the different resource constraints and peak load impacts of various electrification technologies.

Table 8. Electricity Sector Demand and Emissions

	2005	2016	Reference (2050)	Building Electrification Only (2050)	Moderate Electrification (2050)	High Electrification (2050)
Electricity Demand (TWh)	11.08	10.80	9.67	9.44	10.00	12.20
Emissions (MMT CO_2e)	10.77	6.58	3.5	1.5	1.65	2.0
Percent Reduction relative to 2005 emissions (%)	n/a	39%	68%	87%	85%	81%
Emissions Intensity (MMT/TWh)	0.972	0.609	0.362	0.158	0.165	0.163
Percent Reduction relative to 2005 intensity (%)	n/a	37%	63%	84%	83%	83%

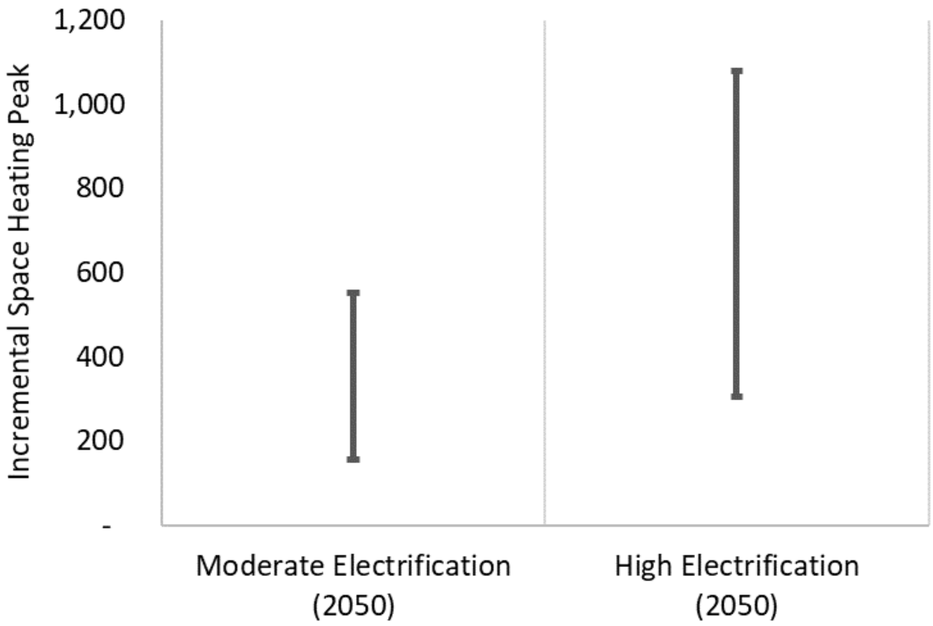
3.3.2 PEAK IMPACTS

Nova Scotia is a winter peaking electricity system, driven by electric resistance space heating. E3's modeling indicates that this winter peak may increase as a result of electrified space heating, driven by customers switching away from oil furnaces, the most prevalent heating appliances in Nova Scotia, to heat pumps. E3 notes, however, that as temperature drops, heat pump efficiencies decline until, in very cold conditions, heat pumps revert to electric resistance mode as back-up heat. Because heat pumps might operate in electric resistance mode during the coldest winter hours in Nova Scotia, there would be no reduction in peak load impact from switching from electric resistance units to heat pumps, even though switching from electric resistance units to heat pumps would provide efficiency gains for most of the year.

In this analysis, E3 estimated a range of heat pump impacts on peak demand by assuming a range of heat pump performance and weather conditions. Results show that the High Electrification scenario could have a peak impact between 304 MW and 1080 MW, depending on the temperature of the coldest day and the efficiency of the heat pump technology (Figure 24). The Moderate Electrification case could generate a smaller peak impact of between 155 MW and 552 MW.

This analysis shows the impact of heat pump electrification on peak loads could be a significant driver of peaking capacity requirements and reliability impacts on the electricity sector, and merits further investigation. However, note that that while a range of heat pump peak impacts were modeled, other measures can reduce this peak impact. These measures include, for example, using ground source heat pumps, which operate a thermal loop using underground pipes and are less affected by ambient temperature conditions. Another method to reduce electrified space heating peak effects is to pair a new heat pump space heater with an existing thermal backup (such as an oil furnace) for very cold hours. In this way the heat pump space heater allows for the majority of space heat demands to be met with decarbonized electricity throughout the year, but during peak cold hours the thermal furnace provides supplemental heat. Since a majority of Nova Scotian households currently have some type of oil furnace or wood stove, this might be a significantly more effective cost mitigation strategy than building electricity capacity to meet space heat peak impacts from electrified space heaters with no thermal backup source.

Figure 24. Estimated Space Heating Incremental Peak in 2050* (MW)

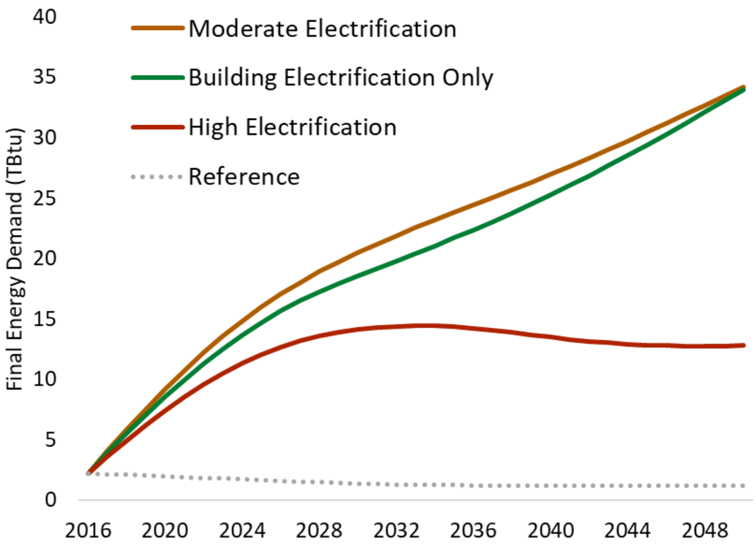


*Note: These ranges estimate the impact of electrifying fossil furnaces with air source heat pumps. The ranges estimate the impacts of different types of air source heat pump technologies, but do not account for other measures which might reduce peak impacts. As discussed in the text above, using a ground source heat pump, or using air source heat pumps with thermal backups, would cause smaller incremental peak impacts from space heat electrification.

3.4 Biofuel Demand

Biofuels are utilized as a carbon-neutral source of energy. Biofuel demand in the High Electrification Scenario peaks at 14 TBtu in 2030 and slightly decreases after 2030 due to highly electrified end-uses and cleaner electricity to meet the GHG reduction goals (Figure 25). Biofuel is used mainly in the hard-to-electrify sectors such as long-haul trucks, aviation, shipping and industry. The Moderate Electrification and the Building Electrification Only scenarios have increasing biofuel demand through 2050 using biofuels for all types of end-uses but primarily for vehicles to meet the increasingly stringent economy-wide GHG goals.

Figure 25. Final Energy Demand by Scenario



4 Conclusions

This climate pathways analysis illustrates that achieving deep decarbonization will require tremendous shifts within the energy sector in just over 30 years. Efficiency and conservation, electrification, low carbon electricity, and low carbon fuels are all “no regrets” strategies that can help Nova Scotia to achieve economy-wide deep decarbonization. The section below discusses these key findings, implications for NSPI, and areas for future research.

4.1 Key Findings and Implications for NSPI

This report illustrates several key findings related to how to make this transition in Nova Scotia, and the actions NSPI can take to support this transition.

1. **Synergistic action is required across sectors.** Figure 5 in the Executive Summary lays out a set of strategies and milestones that will enable the province to reach 80% reductions by 2050. This timeline demonstrates the need for broad and integrated effort across the power, transportation, and building sectors. Complementary efforts would also be required in industrial and non-combustion energy sectors, though these efforts were not modeled in detail in this study. The initial stages of transformation have begun but would need to be accelerated to achieve the 2050 target.

2. **Low-carbon electricity is essential to achieving decarbonization by enabling emissions reductions in the electricity sector as well as complementary reductions in buildings and transportation.** Over the last decade, the electricity sector in Nova Scotia has reduced emissions by more than 30% relative to 2005 levels, thanks to a transition to cleaner and renewable energy

sources. Maintaining this momentum would require continuing to integrate low-carbon resources like wind and hydro into its portfolio, while ensuring reliability and affordability. This transition would enable NSPI to meet energy demand from existing electric load as well as new load growth from space and water heating and transportation, without emitting more carbon.

3. **Low-carbon electricity alone is not enough to achieve 80% economy-wide reductions.** All mitigation scenarios, including E3's high electrification scenarios, require additional measures and actions beyond low-carbon electricity in order to achieve the 80% reduction target. Figure 6 in the Executive Summary presents emissions reductions by measure. Electrification can also leverage low-carbon electricity to dramatically reduce emissions from transportation and buildings. That said, in the scenarios modeled here, other low-carbon fuels are still needed to provide incremental carbon-neutral energy services after all economic clean energy and electrification measures are implemented. Advanced biofuels were used as the main low-carbon fuel in this analysis, although other options like hydrogen produced with clean electricity could serve this need as well. However, these strategies will only be viable if the technologies can reach economies of scale in a global market. Nova Scotia should therefore monitor the development of these emerging energy sectors and perform more detailed assessments of their potential deployment in Nova Scotia.

4. **Long lifetimes require early action.** Investments in infrastructure and equipment can last decades or more, thus having long-lasting effects on emissions. Because there are a limited number of investment opportunities to ensure low-carbon alternatives are selected over alternatives that lead to higher emissions, meeting 2050 goals may require measures to encourage early adoption of electric and/or low-emissions infrastructure and equipment where possible. Delayed action in early years may require more costly early retirements or buy-back programs closer to goal years in order to make up the difference and meet targets. In particular, E3's mitigation scenarios assume near-complete electrification of passenger vehicles by 2050, an aggressive target given there are only around 300 EVs registered in Nova Scotia today. While the costs of electric vehicles

are declining quickly, complementary investments in public charging infrastructure may help enable widespread adoption. NSPI could start by defining adoption targets, determining the infrastructure and initiatives needed to achieve those targets, and developing a strategy to support those markets.

5. **Building electrification is dependent on reducing costs and enhancing incentives, which may be facilitated by the utility and the province.** To achieve the levels of electrification modeled in the decarbonization scenarios, rapid increases in consumer adoption of more efficient and electrified equipment is required. Adoption is unlikely to meet these targets without lower capital costs and attractive rate structures. This study relies on rapid and widespread adoption of cold climate heat pumps, which are a relatively new technology with significant emissions reduction potential. This technology is commercially available but not yet broadly adopted. The currently high up-front costs of this technology should be addressed with government or NSPI support. From a planning perspective, NSPI must also more thoroughly evaluate the peak electricity demand impacts associated with widespread electric space heating, which were not investigated in detail in this study. The Appendix also contains a scenario in which E3 modeled low-carbon biofuels as an alternative building decarbonization strategy.

6. **Getting to “net zero” will be an even greater challenge, requiring more direct reductions, and/or carbon removal technologies or carbon offsets.** Although this target was not modeled directly in this study, achieving “net zero” would likely require investments in negative emissions technologies such as direct air capture or carbon capture and sequestration. These technologies will be valuable in removing emissions from the hardest-to-decarbonize sectors such as industry. While not typically cost effective today, these technologies may become more feasible strategies with cost declines and performance improvements.

4.2 Recommendations for Additional Analysis

The scenarios evaluated in this analysis represent an initial modeling assessment of strategies to decarbonize, focusing on emissions in electricity generation, buildings, and transportation. Additional modeling in the context of NSPI's IRP planning process will be necessary to better understand the potential for decarbonization in the electricity sector, and the implications of economy-wide decarbonization on electricity system operability and reliability. In addition, this report does not assess the costs of different decarbonization pathways, which will be important for prioritizing strategies for decarbonization. Finally, while these sectors will continue to be the most important sectors for achieving decarbonization goals in Nova Scotia, additional modeling may also be valuable to investigate the emissions reduction potential of industrial and non-energy sectors. This report is a first step to understand the pathways to economy-wide decarbonization; E3 recommends future research efforts consider:

- **Cost Modeling:** This study does not report the economy-wide or sector-level costs associated with each of the mitigation scenarios. In order to fully assess trade-offs among different decarbonization pathways, it will be essential for NSPI to investigate the costs associated with the different potential pathways. At a minimum, this assessment would include the direct costs of energy infrastructure, the associated operations and maintenance costs, and fuel costs. E3 will undertake a more detailed review of costs in Phase 2 of this analysis.

- **Electricity Sector Modeling:** This study did not perform detailed dispatch or capacity expansion modeling. Efforts to more completely characterize potential electricity system impacts, including operability and reliability, should be performed in future work. For example, as discussed above, cold climate heat pumps are anticipated to have significant impacts on peak load. More detailed evaluation of peak impacts and potential mitigation strategies (e.g., flexible load) will be particularly valuable to resource planning. Moreover, given Nova Scotia's exposure to extreme weather, electrifying more sectors of the economy will require utility planners to think more carefully about the resilience and reliability of the electric grid.

- **Consumer Adoption Modeling:** As noted above, the PATHWAYS modeling assumes the ability for rapid adoption of several low/no carbon technologies, including but not limited to high-efficiency appliances, cold-temperature heat pumps, and electric vehicles. Valuable future work should evaluate the consumer economics and choices that may drive the adoption of more efficient, lower emitting technologies, such as cold climate heat pumps and electric vehicles.

- **Technical Feasibility:** This study includes scenarios that rely significantly on adoption of cold climate heat pumps. Research to understand heat pump technology feasibility and costs specifically within Nova Scotia will be valuable, in particular to assess the potential for performance degradation in cold temperatures.

5 Appendix

5.1 Mitigation Scenario Results

Table 9. 2050 Results for Reference and Mitigation Scenarios

Category	Reference	Building Electrification Only	Moderate Electrification	High Electrification
Electric Sector Emissions (MMT CO2e)	3.5	1.6	1.6	2.0
Non-Electric Emissions (MMT CO2e)	7.7	3.2	3.0	2.6
Total Emissions (MMT CO2e)	11.2	4.8	4.6	4.6
Total Final Energy Demand (TBtu)	143	108	113	86
Electric Load (TWh)	13	13	14	17
Electricity Share of Final Energy Demand (%)	25%	33%	34%	54%
Biofuels Demand (TBtu)	1	38	38	14
Biofuels Share of Final Energy Demand (%)	1%	35%	34%	16%

5.2 Additional Scenarios

Table 10. 2050 Results for Reference Scenario and Additional Scenarios

Category	Reference	Very High Electrification	High Biofuels
Electric Sector Emissions (MMT CO2e)	3.5	2.0	1.1
Non-Electric Emissions (MMT CO2e)	7.7	2.8	3.9
Total Emissions (MMT CO2e)	11.2	4.8	5.0
Total Final Energy Demand (TBtu)	143	84	131
Electric Load (TWh)	13	20	11
Electricity Share of Final Energy Demand (%)	25%	64%	23%
Biofuels Demand (TBtu)	1	0	48
Biofuels Share of Final Energy Demand (%)	1%	0%	37%

Table 11. Key Assumptions for Reference Scenario and Additional Scenarios

	Reference	Very High Electrification	High Biofuels
GHG emissions budget for electricity generation	3.5 MMT CO2e	2.0 MMT CO2e	1.0 MMT CO2e
Building energy efficiency	None	50% of building shell sales are efficient by 2030 (20% reduction in space heating demand and 12% reduction in air conditioning demand), and 100% by 2040	None
Sales of electric heat pump equipment	25% sales of air source heat pumps for space heating	100% sales of heat pump space heaters and water heaters by 2040 in the residential sector and 90% by 2040 in the commercial sector; 80% sales of electric cookstoves and clothes dryers by 2050	Same as Reference
Zero-emission vehicles	LDVs: 2% EV sales by 2050 MDVs: 10% compressed natural gas sales, 2% EV sales and 1.5% H_2 fuel cell sales by 2050 HDVs: 10% compressed natural gas sales and 0.5% EV sales by 2050 Buses: 5% EV sales by 2030	LDVs: 100% EV sales by 2050 MDVs: 95% EV sales and 5% diesel electric hybrid sales by 2050 HDVs: 60% EV sales and 40% diesel electric hybrid sales by 2050 Buses: 95% EV sales by 2040	Same as Reference
Other transportation	None	60% of total energy is electrified by 2050 including rail, domestic navigation and off-road vehicles	None
Vehicle fuel economy	US CAFE standards for LDVs by 2026		
Advanced Biofuels	None	None	Advanced biofuels using agricultural residues and forestry wastes assuming there is a broader North American biomass feedstock market
Industry	None	20% liquid fuel consumption is electrified by 2050	None
Non-energy	None	30% reductions relative to 2016	30% reductions relative to 2016

5.3 Biofuels Tables

Table 12. 2050 Biomethane Conversion Inputs

Feedstock Type (Disaggregated)	Feedstock Category	Conversion Process	Efficiency (GJ/dry ton)	Process Costs (2012$/dry ton)
Barley straw	Ag Residues (Cellulose)	gasification	14.001	80.65
Biomass sorghum	Ag Residues (Cellulose)	gasification	13.864	79.28
CD waste	Other MSW (Wood)	gasification	13.985	80.59
Citrus residues	Ag Residues	gasification	13.744	79.21
Corn stover	Ag Residues	gasification	13.535	78.10
Cotton gin trash	Ag Residues	gasification	14.884	85.97
Cotton residue	Ag Residues	gasification	13.190	76.53
Energy cane	Purpose-Grown Grasses	gasification	13.623	78.26
Eucalyptus	Purpose-Grown Trees	gasification	15.141	87.15
Food waste	Other MSW	gasification	11.487	66.41
Hardwood, lowland, residue	Forest Residues	gasification	14.700	84.63
Hardwood, lowland, tree	Purpose-Grown Trees	gasification	14.700	84.63
Hardwood, upland, residue	Forest Residues	gasification	14.700	84.63
Hardwood, upland, tree	Purpose-Grown Trees	gasification	14.700	84.63
Hogs, 1000+ head	Manure	anaerobic digestion	7.415	79.81
MSW wood	Other MSW (Wood)	gasification	14.346	82.76
Milk cows, 500+ head	Manure	anaerobic digestion	8.096	87.13
Miscanthus	Purpose-Grown Grasses	gasification	14.346	82.41
Mixed wood, residue	Forest Residues	gasification	14.700	84.63
Mixed wood, tree	Purpose-Grown Trees	gasification	14.700	84.63
Non-citrus residues	Ag Residues	gasification	13.655	77.95
Oats straw	Ag Residues	gasification	13.663	78.25
Other	Other MSW	gasification	12.852	73.55
Other forest residue	Forest Residues	gasification	13.655	77.95
Other forest thinnings	Forest Residues	gasification	13.655	77.95

Feedstock Type (Disaggregated)	Feedstock Category	Conversion Process	Efficiency (GJ/dry ton)	Process Costs (2012$/dry ton)
Paper and paperboard	Other MSW (Cellulose)	gasification	15.824	91.34
Pine	Purpose-Grown Trees	gasification	15.021	86.29
Plastics*	Other MSW	gasification	28.460	163.12
Poplar	Purpose-Grown Trees	gasification	15.085	86.84
Primary mill residue	Other MSW (Wood)	gasification	15.342	88.15
Rice hulls	Ag Residues	gasification	12.210	69.84
Rice straw	Ag Residues	gasification	12.266	70.38
Rubber and leather*	Other MSW	gasification	21.367	122.27
Secondary mill residue	Other MSW (Wood)	gasification	15.342	88.15
Softwood, natural, residue	Forest Residues	gasification	14.860	85.41
Softwood, natural, tree	Purpose-Grown Trees	gasification	14.860	85.41
Softwood, planted, residue	Forest Residues	gasification	14.860	85.41
Softwood, planted, tree	Purpose-Grown Trees	gasification	14.860	85.41
Sorghum stubble	Ag Residues	gasification	11.808	66.87
Sugarcane bagasse	Ag Residues	gasification	13.623	78.26
Sugarcane trash	Ag Residues	gasification	13.382	77.04
Switchgrass	Purpose-Grown Grasses	gasification	13.471	77.75
Textiles*	Other MSW	gasification	14.095	80.52
Tree nut residues	Ag Residues	gasification	15.294	87.75
Wheat straw	Ag Residues	gasification	15.704	89.80
Willow	Purpose-Grown Trees	gasification	14.796	85.26
Yard trimmings	Other MSW (Cellulose)	gasification	13.688	78.61

Notes: Ag residues are classed as cellulosic for liquid biofuel conversions below. Food waste, manure, and other MSW not categorized as wood or cellulose is not considered to be convertible into liquid fuels.

*These feedstocks are included in BTS but typically contain petroleum-based content so are excluded from the renewable biomass potential.

Table 13. 2050 Conversion Inputs for Liquid Biofuels

Feedstock Type (Aggregated)	Fuel	Conversion Process	Efficiency (GJ/dry ton)	Process Costs (2012$/dry ton)
Cellulose	renewable gasoline	hydrolysis	10.101	175.74
Cellulose	renewable gasoline	pyrolysis	8.088	206.49
Cellulose	renewable ethanol	hydrolysis	6.328	86.71
Cellulose	renewable diesel	pyrolysis	8.949	228.48
Cellulose	renewable diesel	biomass to liquids*	10.705	126.43
Cellulose	renewable jet fuel	pyrolysis	8.682	221.65
Wood	renewable gasoline	pyrolysis	10.784	206.49
Wood	renewable ethanol	hydrolysis	7.838	92.57
Wood	renewable diesel	pyrolysis	11.933	228.48
Wood	renewable diesel	biomass to liquids*	10.705	126.43
Wood	renewable jet fuel	pyrolysis	11.576	221.65

*Biomass to liquids refers to thermochemical conversion using gasification plus Fisher-Tropsch synthesis of drop-in synthetic fuels.

6 References

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