Appendix G: Integration Analysis Technical Supplement New York State Climate Action Council Scoping Plan

Integration Analysis Technical Supplement

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Abstract

This technical supplement summarizes, reports, and documents the findings, results, and methodology of the Integration Analysis developed to support the Climate Action Council in its development of the Final Scoping Plan pursuant to the Climate Act. The Integration Analysis evaluates strategies to achieve the Greenhouse Gas (GHG) mitigation aims of the Climate Act and assesses the resulting benefits and costs. Benefits of avoided GHG are assessed based on Value of Carbon Guidance developed by the New York State Department of Environmental Conservation (DEC) pursuant to the Climate Act. Additional public health benefits were assessed, as well as societal costs.

The technical supplement is organized as follows:

Section I. Techno-Economic Analysis
Section II. Health Co-Benefits Analysis

Additional data are available for download at https://climate.ny.gov/:

Annex 1. Techno-Economic Analysis Inputs and Assumptions
Annex 2. Techno-Economic Analysis Key Drivers and Outputs
Annex 3. Health Co-Benefits Analysis Supplemental Data

Section I. Techno-Economic Analysis defines the Integration Analysis scenarios, GHG mitigation pathways, and strategies across sectors. This section describes the physical basis for decarbonization and assesses societal benefits and costs. Section II. Health Co-Benefits Analysis describes the methods and results of the public health benefits analysis of the Integration Analysis scenarios. Annexes 1–3 compile a range of supplemental data.

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Section I. Techno-Economic Analysis

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Acronyms and Abbreviations

AEO	Annual Energy Outlook
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
ASHP	Air source heat pump
Btu	British thermal unit
CCS	Carbon capture and storage
CH_4	Methane
CJWG	Climate Justice Working Group
Climate Act	Climate Leadership and Community Protection Act
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COBRA	CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool
DEC	New York State Department of Environmental Conservation
DOE	Department of Energy
DOT	New York State Department of Transportation
EIA	Energy Information Administration
FHWA	Federal Highway Administration
g	Gram
GHG	Greenhouse gas
GSHP	Ground source heat pump
GSP	Gross state product
GW	Gigawatt
GWh	Gigawatt-hour
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
MMBtu	Million British thermal units
MMT	Million metric ton
MW	Megawatt
MWh	Megawatt-hour
NET	Negative emissions technologies
NPV	Net present value
NYC	New York City
NYISO	New York Independent System Operator
NYS	New York State
NYSDPS	New York State Department of Public Service
NYSDEC	New York State Department of Environmental Conservation

NYSERDA	New York State Energy Research & Development Authority
SEDS	State Energy Data System
TBtu	Trillion British thermal units
ZEV	Zero emission vehicle
VMT	Vehicle miles traveled

Summary

The results of the Scoping Plan Integration Analysis show that achieving the emissions reductions limits in the Climate Leadership and Community Protection Act (Climate Act) will require aggressive action across all sectors of New York's economy but that the achievement of these targets is technically feasible and would have societal net benefits when accounting for avoided GHG emissions and the health benefits of reduced fuel combustion.

Figure 1. Gross Greenhouse Gas Emissions by Scenario

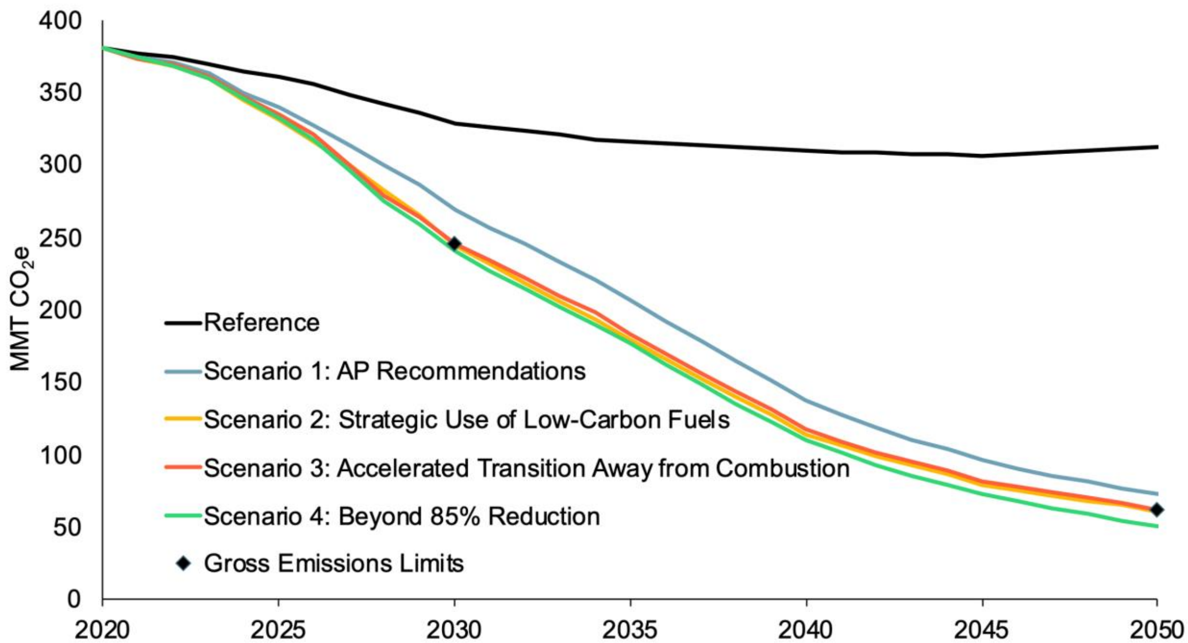
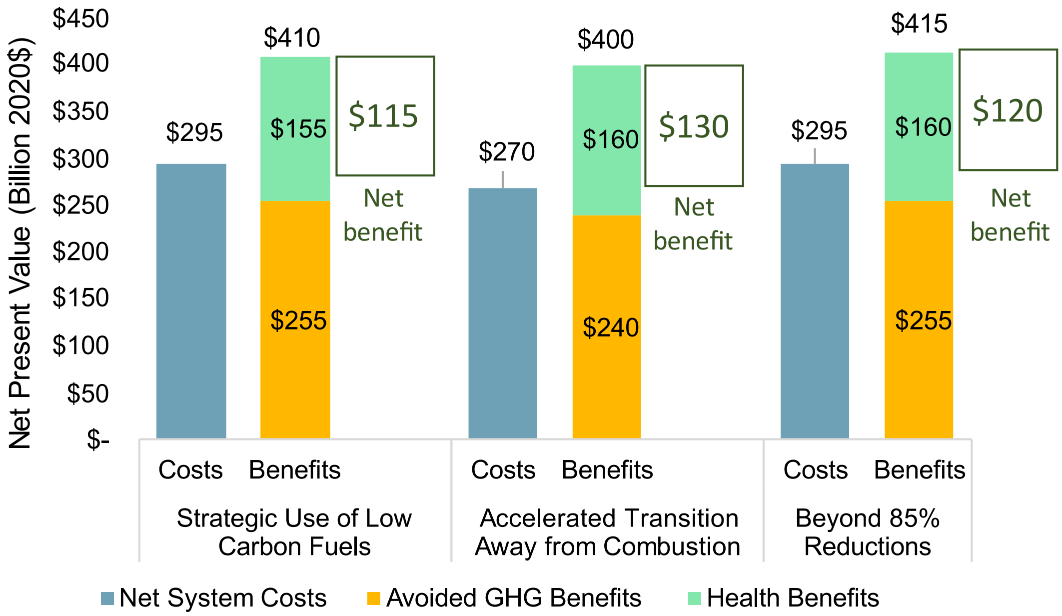


Figure 1 above shows gross GHG emissions over time in New York for the five core scenarios modeled in the integration analysis. While emissions are projected to slightly decline in the Reference case (which demonstrates how existing policies and programs have decoupled GHG emissions from economic growth in New York), significant additional reductions would be achieved by implementing the recommendations of the Climate Action Council Advisory Panels (Scenario 1: AP Recommendations). However, further action is still needed to achieve the Climate Act gross emissions limits, and three additional scenarios were modeled that demonstrate various technical pathways to achieving these targets. Many of the strategies needed to achieve significant emissions reductions are common to all scenarios (e.g., aggressive energy efficiency, building and transportation electrification, decarbonized electricity), but there remains some optionality in terms of the exact level of ambition and timing that is explored by these scenarios.

Although the investments required to achieve Climate Act emissions limits are significant, they are small relative to the size of New York's economy (net annual costs for Scenarios 2 through 4 are equivalent to roughly 1% of gross state product in 2050) and are outweighed by the net benefits of avoided GHG emissions, public health improvements, and reduced fuel combustion (Figure 2). Furthermore, the level of investment needed results in an increase in system spend of just 10% relative to the Reference Case. Because significant infrastructure investment will be needed to maintain business as usual infrastructure within the state irrespective of further climate policy, redirecting investment away from status quo energy expenditures and toward decarbonization is key to realizing the aims of the Climate Act. While there is significant uncertainty to any projection of energy demands, energy infrastructure turnover, and greenhouse gas emissions that extends three decades into the future, this Integration Analysis finds that achieving New York's aggressive emissions targets is technically achievable, and that the costs of inaction exceed the costs of mitigation across all scenarios and sensitivities.

Figure 2. Net Present Value of Benefits and Costs by Scenario (2020–2050)



Key findings from the Integration Analysis:

- **Achieving deep decarbonization is feasible by mid-century**. Achieving the GHG emission limits **requires action in all sectors**, especially considering the Climate Act's emissions accounting. Every sector will see high levels of transformation over the next decade and beyond, requiring critical investments in New York's economy
- **Together, the benefits of avoiding economic impacts of damages caused by climate change and the improvements in public health total $400 – 415 billion**. Realizing these benefits will require an incremental investment over the 30-year transition of approximately 10 percent in additional spending, or $270 – 295 billion, in addition to redirecting the approximately $2.7 trillion in expected system spending under the reference case towards New York's low carbon future.
- **Energy efficiency and end-use electrification are essential parts of any pathway that achieves New York State emission limits**. Approximately 1 to 2 million efficient homes are electrified with heat pumps by 2030 across compliant scenarios. Approximately 3 million zero-emission vehicles (predominantly battery electric) are sold by 2030.
- **Consumer and community decision-making is key, and especially important for the purchase of new passenger vehicles and heating systems for homes and businesses through the next decade.** In all scenarios modeled, zero emission vehicles and heat pumps become the majority of new purchases by the late 2020s, and fossil-emitting cars and appliances are no longer sold after 2035. This represents an unprecedented rate of adoption of novel and potentially disruptive technologies and measures.
- **New York will need to substantially reduce vehicle miles traveled while increasing access to public transportation**. This should include expansion of transit service structured around community needs, smart growth inclusive of equitable transit-oriented development (E-TOD), and transportation demand management.
- **Wind, water, and sunlight power most of New York's economy in 2050 in all pathways**. Even with aggressively managed load, electric consumption doubles and peak nearly doubles by 2050, and NYS becomes a winter peaking system by 2035, with offshore wind on the order of 15 GW, solar on the order of 60 GW, and 4- and 8-hour battery storage on the order of 20 GW by 2050. Firm, zero-emission resources, such as green hydrogen or long-duration storage, will play an important role to ensure a reliable electricity system beyond 2040.
- **Low-carbon fuels such as bioenergy or hydrogen may help to decarbonize sectors that are challenging to electrify.** By 2030, scenarios include initial market adoption of green hydrogen in several applications (including medium and heavy-duty vehicles and high-temperature industrial).

Additional promising end-use applications include district heating and non-road transportation such as aviation and rail.

- **Large-scale carbon sequestration opportunities include lands and forests and negative emissions technologies.** Protecting and growing New York's forests is required for carbon neutrality. Negative emissions technologies (e.g., direct air capture of CO_2) may be required if the State cannot exceed 85% direct GHG emissions reductions. Strategic land-use planning will be essential to balance natural carbon sequestration, agriculture activities, new renewables development, and smart urban planning (smart growth).
- **Necessary methane emissions mitigation in waste and agriculture will require transformative solutions.** Diversion of organic waste and capture of fugitive methane emissions are key in the waste sector. Alternative manure management and animal feeding practices will be critical in reducing methane emissions in agriculture.
- **Continued research, development, and demonstration (RD&D) is key to advancing a full portfolio of options.** Additional innovation will be required in areas such as carbon sequestration solutions, long-duration storage, flexible electric loads, low-GWP refrigerants, and animal feeding.
- **Although benefits and costs are in the same range across mitigation scenarios, risk levels differ by scenario**. Although all scenarios involve a high degree of transformation across strategies and sectors, very high levels of transformation increase risk of delivering GHG emission reductions. Types of risk include reliance on technologies in early stages of development which require substantial innovation (e.g., negative emission technologies, carbon capture and storage, advanced low-carbon fuels), reliance on widespread adoption of technologies that are in the early stages of deployment (e.g., zero-emission vehicles, heat pumps), and reliance on strategies that require the highest levels of transformation of social institutions and business models (e.g., land use patterns, mobility practices, waste management).
- **The Inflation Reduction Act will meaningfully reduce net direct costs**. New York could realize up to $70 billion of federal resources in support of the Scoping Plan initiatives through 2050, which would reduce incremental costs to New Yorkers by up to 19%.

Chapter 1. Introduction

As part of the Scoping Plan development, NYSERDA commissioned Energy and Environmental Economics, Inc. (E3)[1] to model technical pathways for New York to achieve the ambitious climate targets set in the Climate Act and evaluate the implications of these pathways on energy demand, GHG emissions, and benefits and costs to New York's economy. This work is referred to as the "Integration Analysis." This technical supplement provides additional detail on the modeling performed as part of the Integration Analysis. The Analytic Approach chapter provides a high-level overview of the modeling framework used for this analysis; the Results chapter provides both detailed economy-wide and sector-specific model outputs for multiple scenarios; and the Key Findings chapter summarizes the highest profile findings of the study. Finally, the Methods and Data chapter provides greater detail on the modeling methodology, input data and data sources, and scenario assumptions that were used to develop the technical pathways. The model inputs and assumptions are compiled in greater detail in Annex 1, and the key drivers of GHG emission reductions, benefits, and costs, as well as key outputs are compiled in detail in Annex 2.

Chapter 2. Analytic Approach

The objective of the Integration Analysis is to develop GHG mitigation scenarios for the Scoping Plan that capture and account for how various strategies interact across sectors and evaluate the benefits and costs of the suite of strategies for achieving the Climate Act's GHG emissions reduction requirements and goals. These mitigation scenarios incorporate Advisory Panel and Working Group recommendations, feedback from the Climate Action Council, and CJWG input. The Integration Analysis is built within the New York Pathways Model[2], which is a multi-model framework that includes a representation of all categories of GHG emissions in New York and takes as inputs relevant complementary analyses, including the 2021 New York Power Grid Study[3], building and transportation road mapping efforts, oil

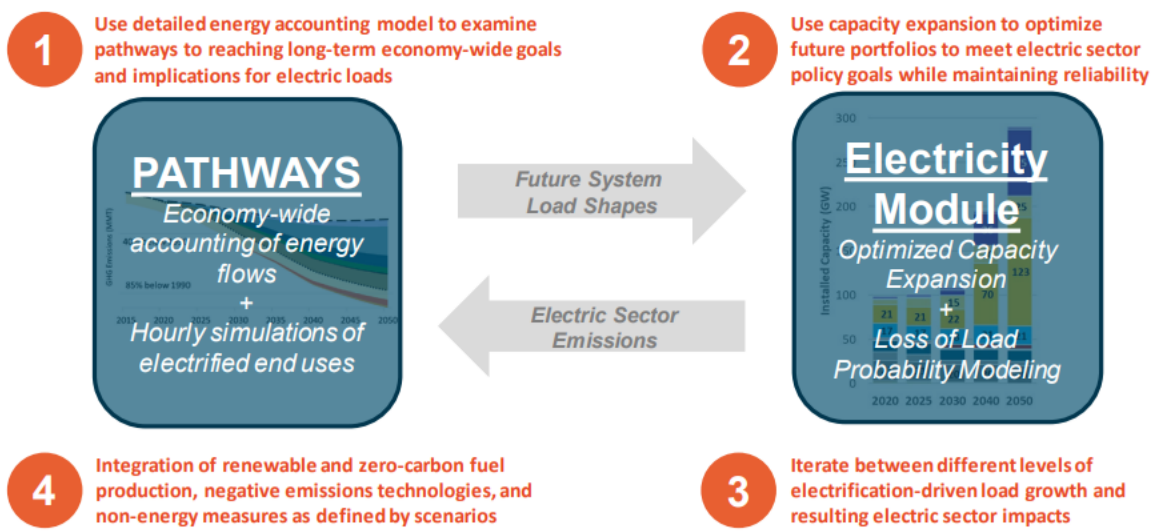
[1] For more about E3, see: www.ethree.com.

[2] The New York Pathways model was developed by E3. More detail on the NY Pathways model can be found in Chapter 5.

[3] https://www.nyserda.ny.gov/About/Publications/New-York-Power-Grid-Study, accessed January 2021

and gas system analysis, and refrigerant management analysis.[4] A diagram of this multi-model framework is presented in Figure 3.

Figure 3. Economy-wide energy model linked to electricity module



This chapter contains a high-level summary of the results of the Integration Analysis. Detailed technical information on the mitigation scenarios presented in this chapter can be found in Chapter 3. Detailed information on the proposed strategies to realize the levels of transformation included in the Integration Analysis scenarios can be found in the Sector Strategies sections of the Plan.[5]

2.1 Scenario Design

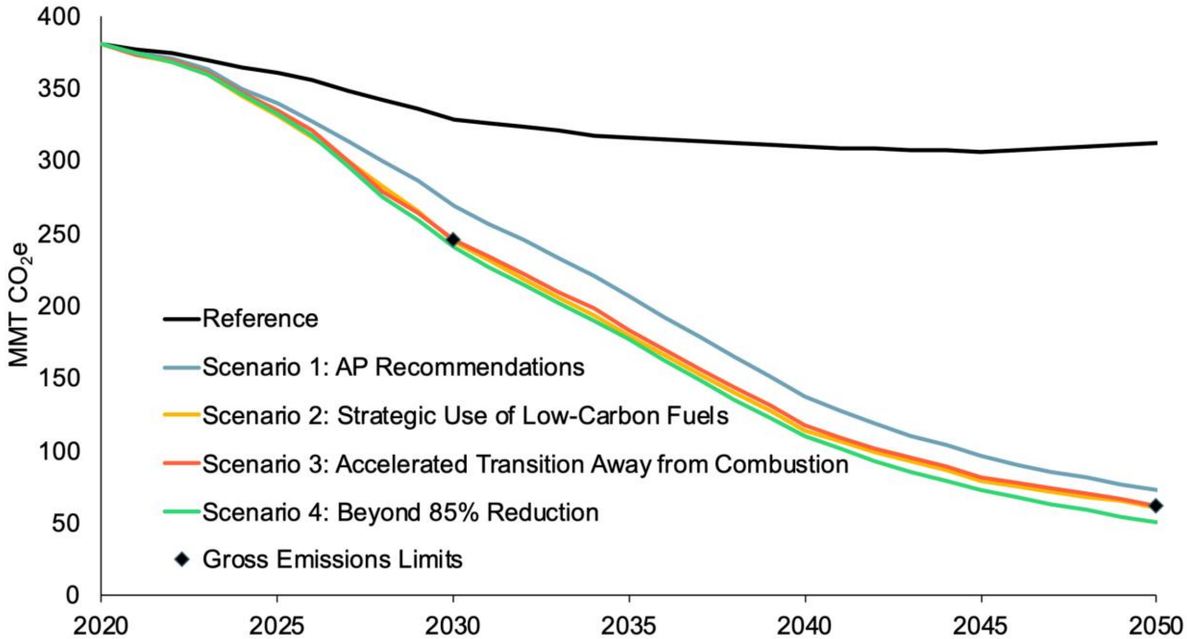
The initial runs of the Integration Analysis evaluated a future that represents business-as-usual inclusive of implemented policies (Reference Case) and a representation of a future based on the recommendations from the Council's Advisory Panels (Scenario 1). Analytical results indicated that the Advisory Panel recommendations alone were not sufficient to achieve the Climate Act emissions limits (Figure 4). These results were presented to the Council in July 2021 and initiated a scenario design planning exercise by the

[4] NYSERDA conducts research and analysis to support the development and improvement of the statewide Greenhouse Gas Emissions Report, statewide planning and policy development, implementation of the Climate Leadership and Community Protection Act, and greenhouse gas emissions mitigation. Relevant studies produced with this research and analysis can be found here: https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Greenhouse-Gas-Emissions

[5] See https://climate.ny.gov/

Council, facilitated by the analytical team and informed by feedback from the Climate Justice Working Group (CJWG) on the advisory panel recommendations, to develop scenarios with additional emissions reductions. This exercise resulted in three additional scenarios designed to meet or exceed GHG limits and achieve carbon neutrality (Scenarios 2 through 4). Scenarios 2, 3, and 4 all carry forward foundational themes based on findings from Advisory Panels and supporting analysis but represent different approaches based upon Council feedback and CJWG input. For more detailed scenario parameters, see Chapter 5.3. Results of Scenarios 2, 3, and 4 were presented to the Council in October - December 2021 and again with refreshed input data and additional sensitivities in September-October 2022. The Council continued deliberations on these scenarios in 2022, informed by public comment on the draft Plan, as they worked to develop the final Scoping Plan.

Figure 4. Gross Greenhouse Gas Emissions by Mitigation Scenario



- **Reference Case**: Business as usual plus implemented policies [6]

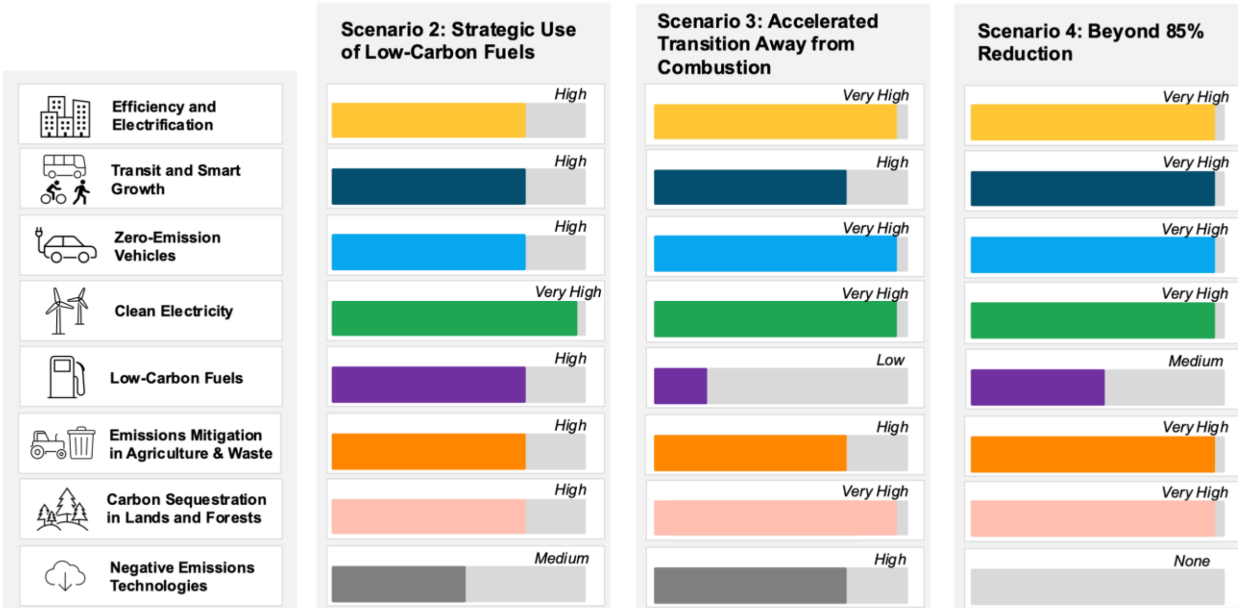
[6] The Reference Case is used for evaluating incremental societal costs and benefits of GHG emissions mitigation. The Reference Case includes a business as usual forecast plus implemented policies, including but not limited to federal appliance standards, energy efficiency achieved by funded programs (Housing and Community Renewal, New York Power Authority, Department of Public Service, Long Island Power Authority, NYSERDA Clean Energy Fund), funded building electrification, national Corporate Average Fuel Economy standards, a statewide Zero-emission vehicle mandate, and a statewide Clean Energy Standard including technology carveouts. For more details see Chapter 5.3.

- **Scenario 1: Advisory Panel Recommendations**: Representation of the Advisory Panel recommendations,[7] which provide a foundation for all scenarios through rapid electrification of buildings and transportation, decarbonization of the power sector, and ambitious reductions in non-combustion emissions; however, scenario modeling shows that additional effort is needed to meet Climate Act emissions limits.
- **Scenario 2: Strategic Use of Low-Carbon Fuels:** Advisory Panel recommendations adjusted for strategic use of bioenergy derived from biogenic waste, agriculture and forest residues, and limited purpose grown biomass, as well as a critical role for green hydrogen for difficult-to-electrify applications. This scenario includes a role for negative emissions technologies to reach carbon neutrality.
- **Scenario 3: Accelerated Transition Away from Combustion:** Advisory Panel recommendations adjusted to include accelerated electrification of buildings and transportation and a very limited role for bioenergy and hydrogen combustion. This scenario includes a role for negative GHG emissions technologies to reach carbon neutrality.
- **Scenario 4: Beyond 85% Reduction:** Advisory Panel recommendations adjusted to reflect accelerated electrification and targeted use of low-carbon fuels. This scenario includes additional reductions in VMT and innovation in methane abatement. This scenario reduces gross GHG emissions beyond the 2050 limit and avoids the need for negative emission technologies.

Figure 5 highlights the key differences in assumptions across the three scenarios that meet or achieve New York’s GHG emissions limits and achieve carbon neutrality by 2050. All scenarios share common foundational themes of decarbonization, including a zero-emission power sector by 2040, enhancement and expansion of transit, unprecedented rapid and widespread efficiency and electrification, electric end-use load flexibility, and methane mitigation in agriculture and waste.

[7] More information on the relationship between the Advisory Panel recommendations and the Integration Analysis assumptions can be found in Annex 2.

Figure 5. Level of Transformation by Mitigation Scenario



More detailed scenario assumptions are available in Chapter 3 and in Annex 2

Transformative, challenging, and potentially disruptive levels of effort are required across all sectors, and all three scenarios include high levels of electrification, including Scenario 2, which also incorporates strategic use of low-carbon fuels. Scenario 3 pushes harder on accelerated electrification to meet the emission limits using a very low-bioenergy and low-combustion mix of strategies. Scenario 4 pushes beyond 85% direct reductions in 2050 by including use of some low-carbon fuels, examining very high VMT reductions, and assuming high (but also highly uncertain) levels of innovation in the waste and agriculture sectors. Scenario 4 is the only evaluated scenario that achieves carbon neutrality without the use of negative emissions technologies like direct air capture of CO_2, which is also subject to high uncertainty, but is required in Scenarios 2 and 3 to address the gap between remaining gross emissions in 2050 and the ambitious assumed projections of natural sequestration. Additional documentation of scenario assumptions can be found in Chapter 3 and 5.3. Key assumptions for Scenarios 2, 3, and 4 are shown in Figure 6, Figure 7, and Figure 8.

Figure 6. Key Assumptions in Scenario 2: Strategic Use of Low-Carbon Fuels

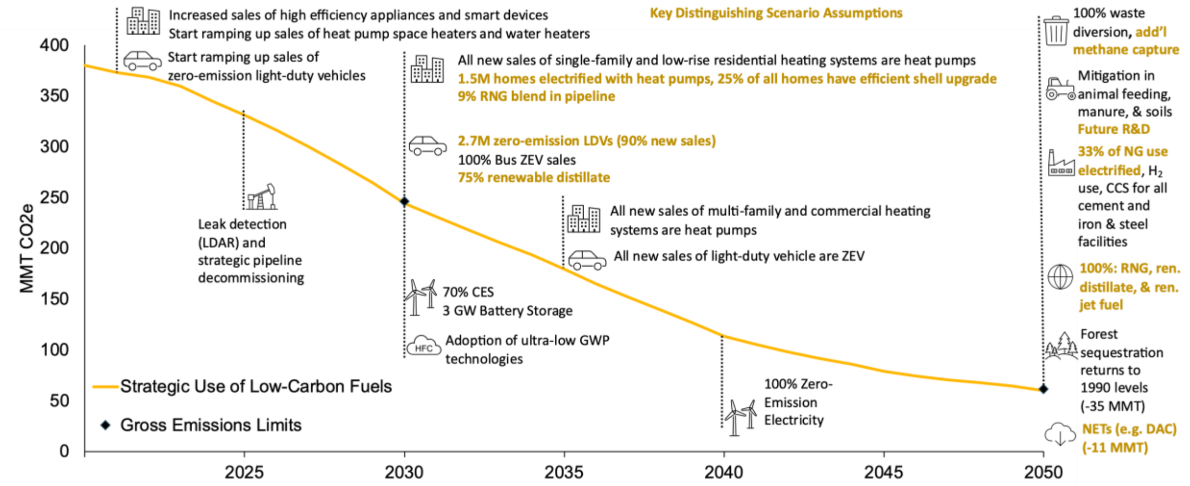


Figure 7. Key Assumptions in Scenario 3: Accelerated Transition Away from Combustion

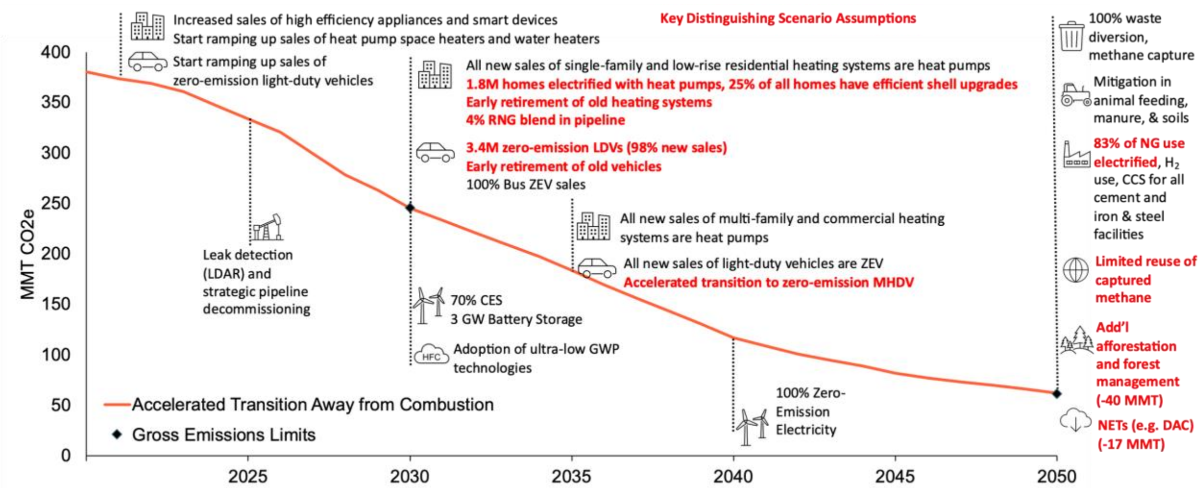
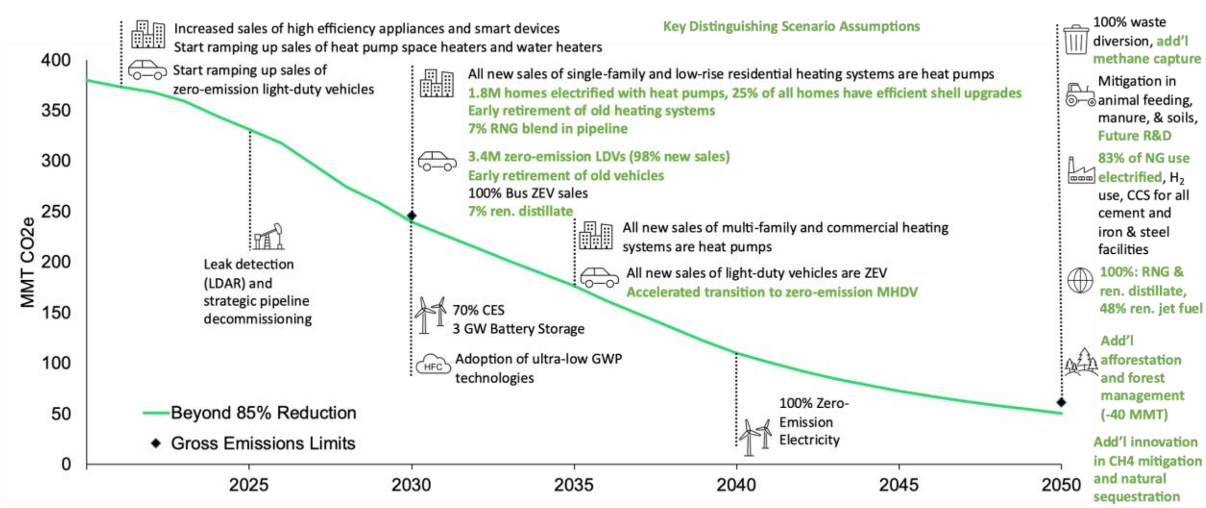


Figure 8. Key Assumptions in Scenario 4: Beyond 85% Reduction



Chapter 3. Results

3.1 Underlying Pillars of Decarbonization

New York's transition to net-zero emissions by 2050 in Scenarios 2 through 4 can be observed through key sustainability metrics that account for the expected changes in New York's population and economy over this period. Even in the Reference scenario, final energy demand and GHG emissions are expected to decline even as population and gross state product (GSP) grow at 0.2%/year and 1.9%/year (Figure 9). However, as shown in Figure 10 and Figure 11, the transformational mitigation measures implemented in Scenarios 2 through 4 lead to final energy intensity and GHG emissions intensity declining much sooner and much farther than in the Reference Case.

Figure 9. Statewide Population and Gross State Product (GSP) Forecasts

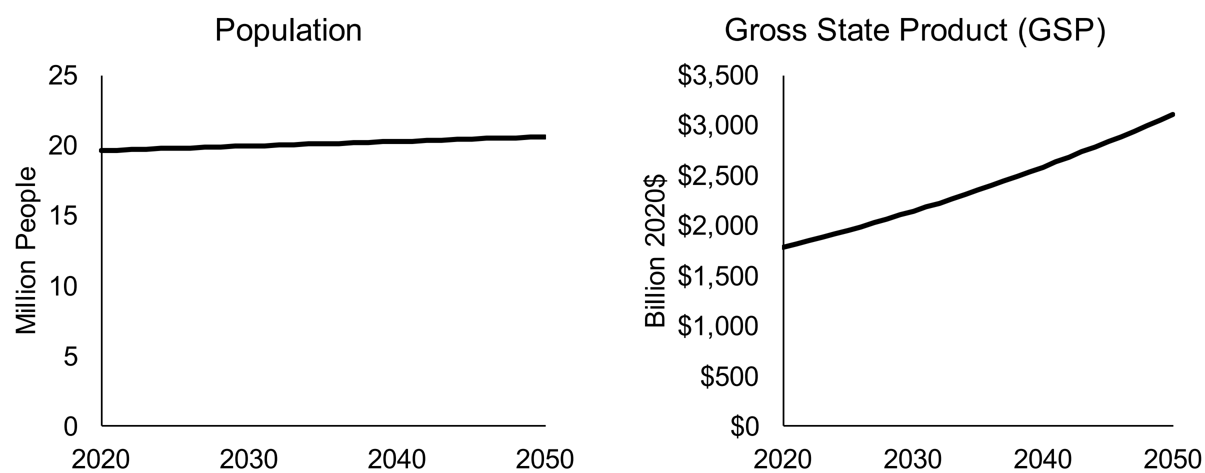


Figure 10. GHG Intensity per Capita and per unit of GSHP by Scenario in New York

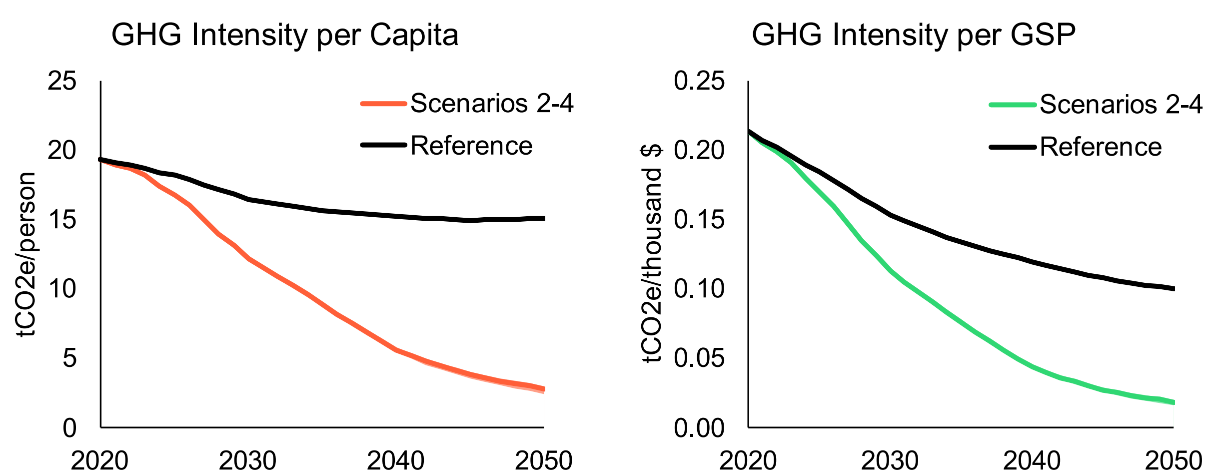
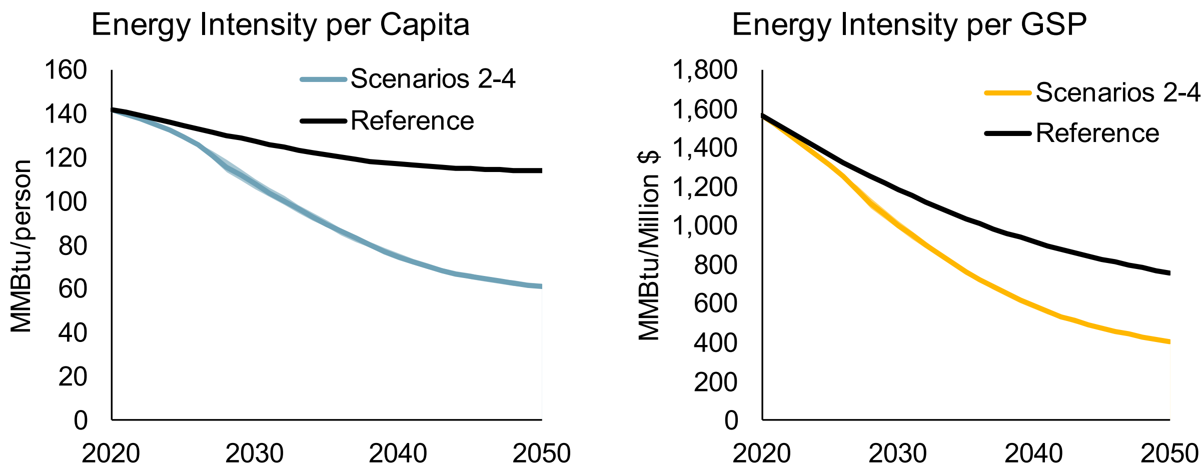


Figure 11. Energy Use Intensity per Capita and per unit of GSHP by Scenario in New York



3.2 Economy-Wide Results

Greenhouse Gas Emissions

Greenhouse gas emissions decline gradually in the Reference Case and decline dramatically in all other scenarios. Scenarios 2 through 4 all meet or exceed Climate Act GHG emission limits and achieve carbon neutrality by 2050 (Figure 12, Table 1, Figure 13, Figure 14)[8]. Annual GHG emissions data at the subsector level for all scenarios are reported in Annex 2.

[8] Detailed results can be found in Annex 2

Figure 12. GHG Emissions by Mitigation Scenario

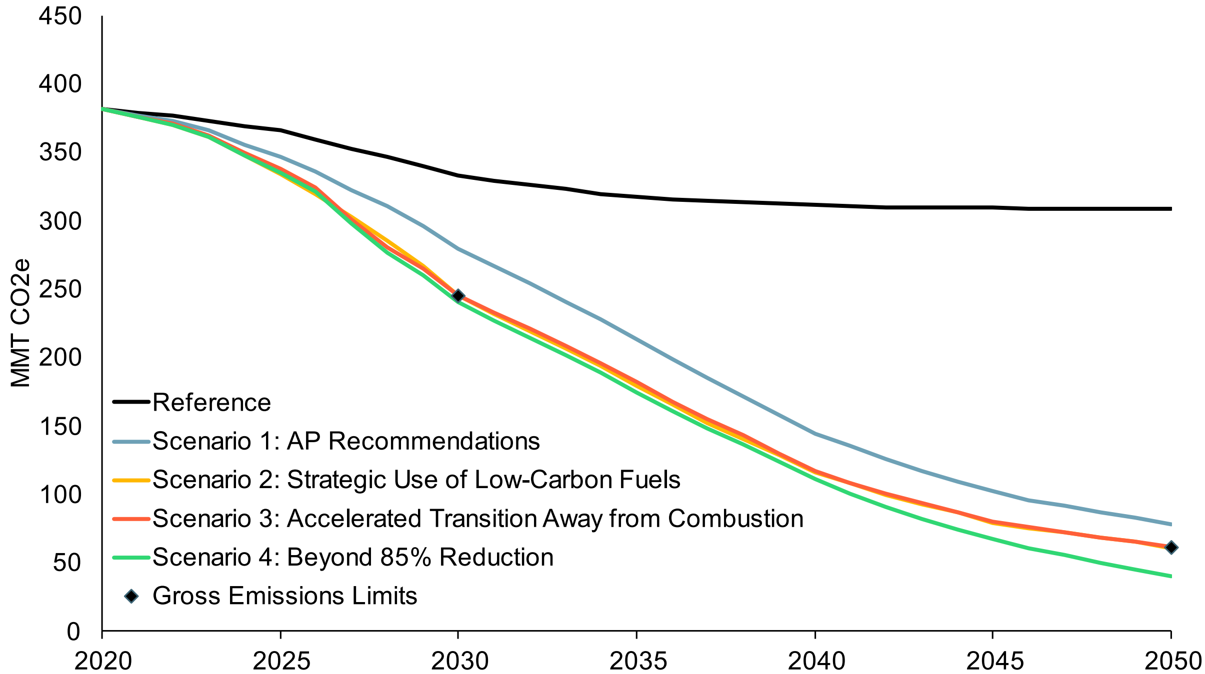


Table 1. GHG Emissions and Percent Reductions by Scenario

Scenario	**2030** MMT CO_2e	**2050** MMT CO_2e
Reference Case	329	311
Scenario 1: AP Recommendations	268	72
Scenario 2: Strategic Use of Low-Carbon Fuels	244	60
Scenario 3: Accelerated Transition Away from Combustion	245	62
Scenario 4: Beyond 85% Reductions	240	51
Climate Act Gross Emissions Limits	*246*	*62*

Figure 13. 2030 GHG Emissions by Scenario

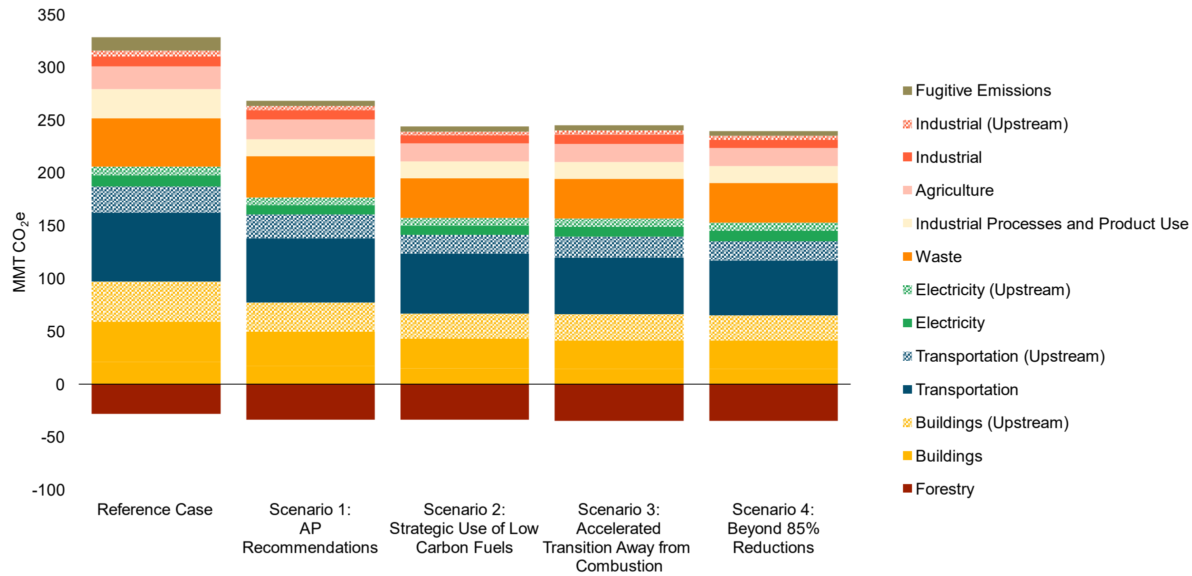
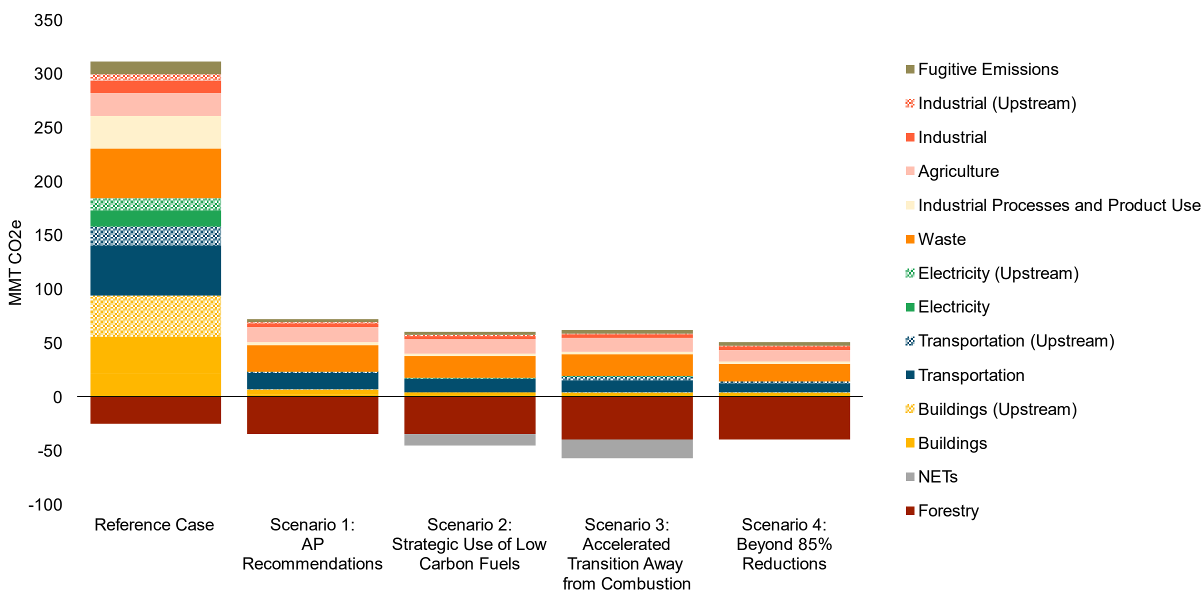


Figure 14. 2050 GHG Emissions by Scenario

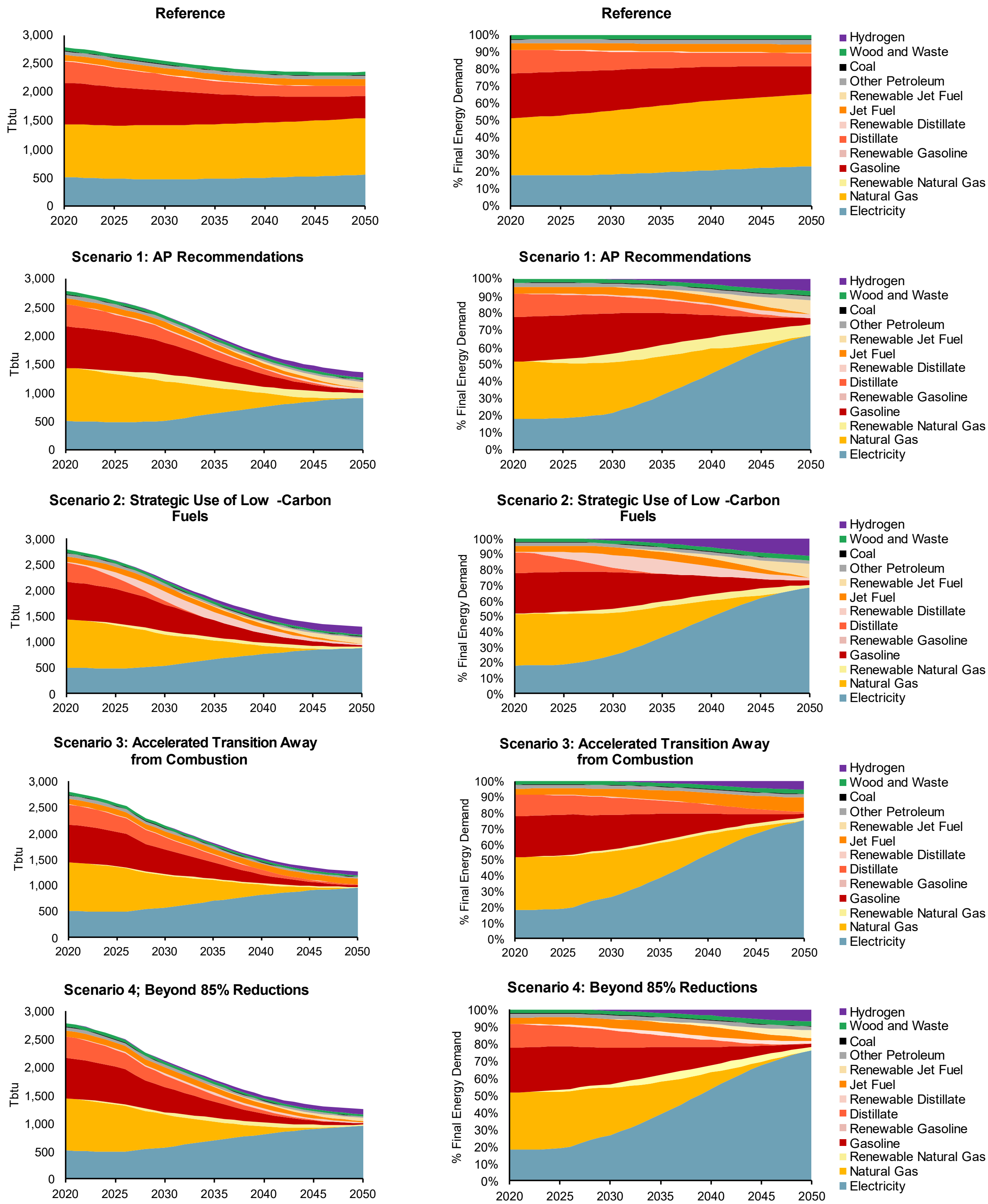


Final Energy Demand

Across Scenarios 2 through 4 there is a nearly 50% decline in total final energy demand by 2050 relative to today due to efficiency and electrification measures (Figure 15).[9] The electricity share of final energy demand grows from less than 20% today to 68%–76% by 2050. Low-carbon fuels have a targeted role that varies by scenario, with biofuels accounting for 2–13% of final energy demand and green hydrogen accounting for 5-11% of final energy demand by 2050. After electricity and green hydrogen, jet fuel has the largest share of remaining final energy demand across scenarios in 2050. Annual final energy demand by fuel type and sector for all scenarios is reported in Annex 2.

[9] Note that while liquid and gaseous fuel use declines dramatically over the study period, reductions in wood combustion are more modest at around 40%.

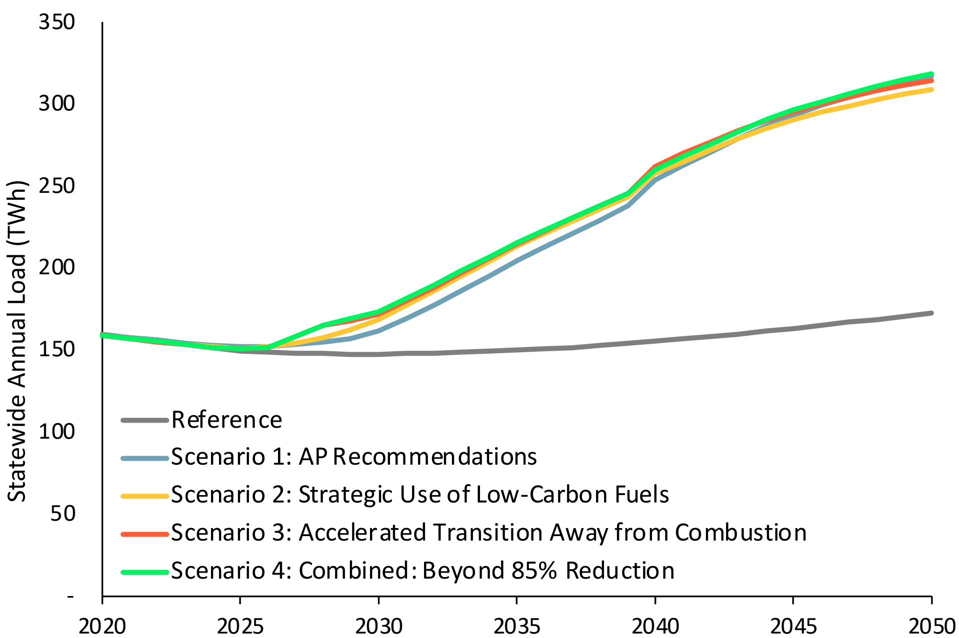
Figure 15. Final Energy by Fuel by Scenario: Absolute (left) and % Share (right)[10]



Electricity Demand

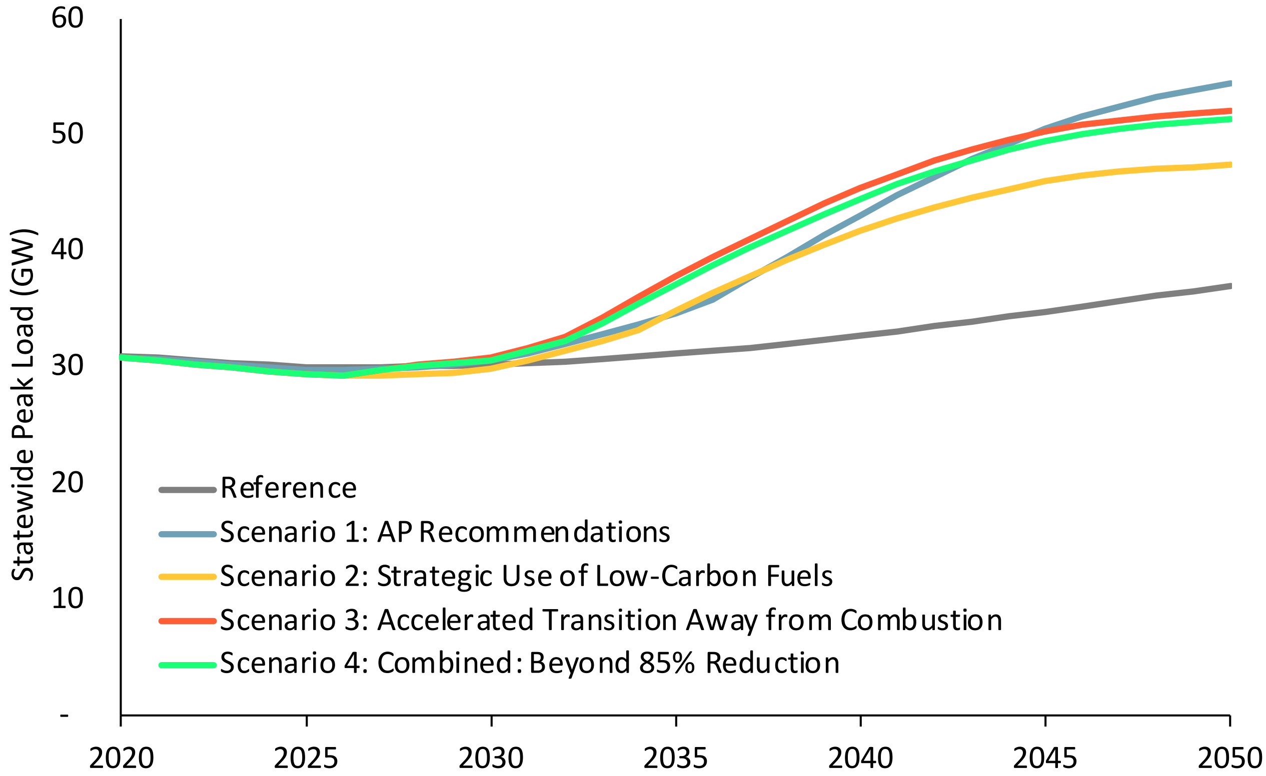
Across all pathways, clean electricity is a central pillar of New York's strategies to meet the Climate Act targets, with electricity meeting the majority of energy demand (68-76 percent) in the New York State economy by 2050. Driven by the electrification of end-uses where fossil fuels are consumed today, electricity demand is projected to double – with peak loads also nearly doubling – by 2050, even with aggressively managed loads (Figure 16 and Figure 17). As building heating needs are electrified, both the magnitude and timing of electricity loads will change rapidly, and New York will transition to a winter-peaking system by 2035. The impacts of electrification-driven changes in loads on system reliability needs are described in more detail in Chapter 5. Additional electricity demand will also result from the build-out of electrolyzers necessary to supply the state with green hydrogen.

Figure 16. Statewide Annual Electric Load[11]



[11] This chart includes electrolysis loads to produce hydrogen, assuming that 50% of New York's hydrogen demand is produced in-state. This chart includes line losses and represents total electricity demand at the generator level. The values in this chart do not account for behind-the-meter solar resources, which are included as a source of electricity supply in this modeling.

Figure 17. Statewide Peak Load Growth[12]



Gas Demand

As New York's economy becomes more efficient and electrified, end-use gas demand declines significantly, with reductions ranging from 84–94%[13] by 2050. The small amount of remaining gas demand is entirely met with renewable natural gas and green hydrogen across all scenarios by 2050.

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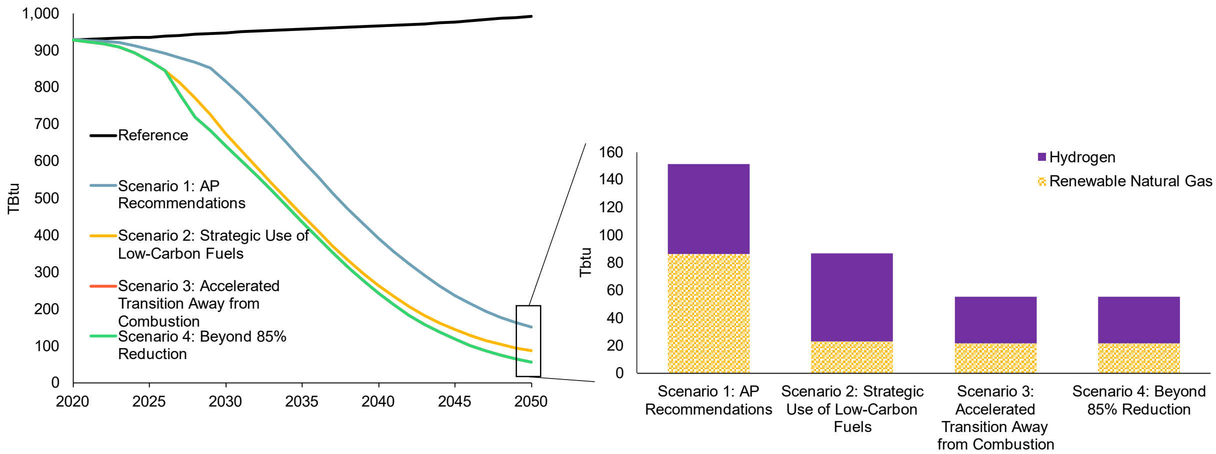
[12] Figure 17 represents the median (1-in-2) coincident peak for the New York Control Area. The sum of non-coincident local peaks (occurring during different hours) may be higher. The median peak was determined by assessing hourly loads over 40 years (1979-2018) of weather data.

[13] Mitigation scenarios that achieve Climate Act emissions requirements by 2050 (Scenario 2, Scenario 3, Scenario 4) achieve 90-95% reductions in end-use gas demand by 2050

Figure 18. Annual End-Use Gas Demand by Scenario (left) and 2050 End-Use Gas Demand by Fuel (right)[14]



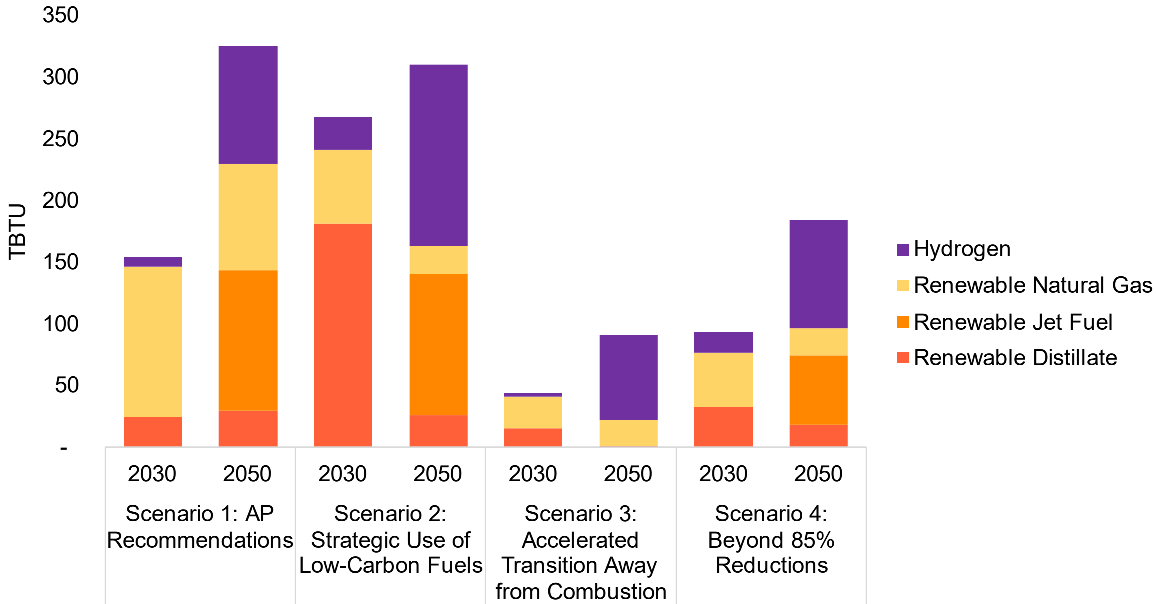
Alternative Fuels

The Reference Case includes the use of conventional biofuels such as wood, ethanol, and biodiesel. In addition to these conventional biofuels, all mitigation scenarios utilize a range of additional alternative fuels, such advanced biofuels (renewable natural gas (RNG), renewable distillate, renewable jet fuel) and green hydrogen, produced via electrolysis of zero-carbon electricity. Conventional biofuels are not chemically equivalent to their fossil counterparts so can be used in fuel blends but cannot be used in pure form with existing fossil engines and infrastructure. Advanced biofuels are chemically equivalent to existing fossil fuels and can be used as drop-in replacements of their fossil counterparts. In this analysis, the term "low-carbon fuels" refers to advanced renewable biofuels, green hydrogen, and the share of conventional biofuels (biodiesel) which are produced from waste biomass feedstocks.[15] The range of total demand for low-carbon fuels is approximately 40–270 TBtu in 2030 and approximately 90–310 in 2050 (Figure 19).

[14] Includes gas demand in buildings industry, and transportation. Excludes gas burned in electric generating units and hydrogen for fuel cell vehicles

[15] The definition of low-carbon fuels is more restrictive than that of all biofuels to attempt to exclude those fuels for which the supply feedstocks used to generate those fuels may have significant environmental externalities or which there are limits on usage throughout the economy due to end use demand constraints, such as wood and ethanol.

Figure 19. Biofuels and Green Hydrogen Utilization[16]



Note: In this figure, Renewable Distillate includes both advanced renewable diesel and a small quantity of conventional biodiesel which is blended into heating and transportation fuels.

Allocation of feedstocks to advanced biofuel production is determined by production cost, projected fossil fuel demands, fossil fuel prices, and emissions abatement potential. As a result, the allocation optimization prioritizes the production of renewable natural gas and renewable distillate, with remaining feedstocks allocated to renewable jet fuel. Biofuel feedstock supply was sourced from the 2016 US Department of Energy (US DOE) Billion Ton Report[17], the NYSERDA Potential of Renewable Gas report,[18] and the NYSERDA Energy Efficiency and Renewable Energy Potential Study[19] with additional input from Advisory Panel discussions with academic partners. Scenario 2 included a regional supply of wastes, residues, and purpose grown biomass (Figure 20), while Scenario 3 included only targeted in-state methane abatement (e.g., landfills), and Scenario 4 assumed an in-state supply of wastes and residues.

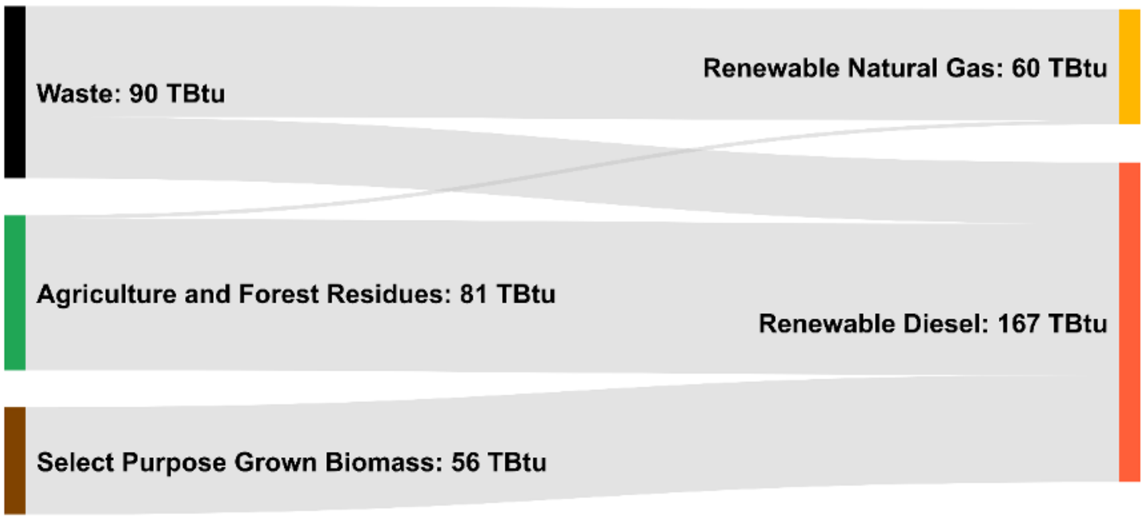
[16] Includes hydrogen demand for transportation and industry but not electricity generation. Wood continues to be used across all scenarios (~30 TBtu in 2050)

[17] https://www.energy.gov/eere/bioenergy/2016-billion-ton-report, accessed February 2021

[18] https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Greenhouse-Gas-Emissions, accessed December 2021

[19] https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Technical-Reports-and-Studies/EERE-Potential-Studies, accessed December 2022

Figure 20. Advanced Biofuels by Feedstock Category and Final Fuel in 2030, Scenario 2: Strategic Use of Low-Carbon Fuels



Attribution Analysis

The relative impacts of different emissions mitigation measures were explored through an attribution analysis. The attribution or "wedge" analysis models the emissions reductions that result from the implementation of specific measures, providing an understanding of the relative impact of each measure, or group of measures, on emissions. It also provides another view of key differences between scenarios.

The wedge analysis was performed by modeling sensitivity scenarios to determine the incremental emissions reduction from each set of measures. Individual wedges correspond to the emissions reduction achieved by a set of measures. Each wedge layers additional mitigation measures on top of those included in previous wedges, building to a complete view of the GHG reductions achieved in each scenario. Many measures are interactive, and so the order in which wedges are implemented impacts the emissions reductions attributed to each measure. Table 2 provides a description of the measures included in each wedge.

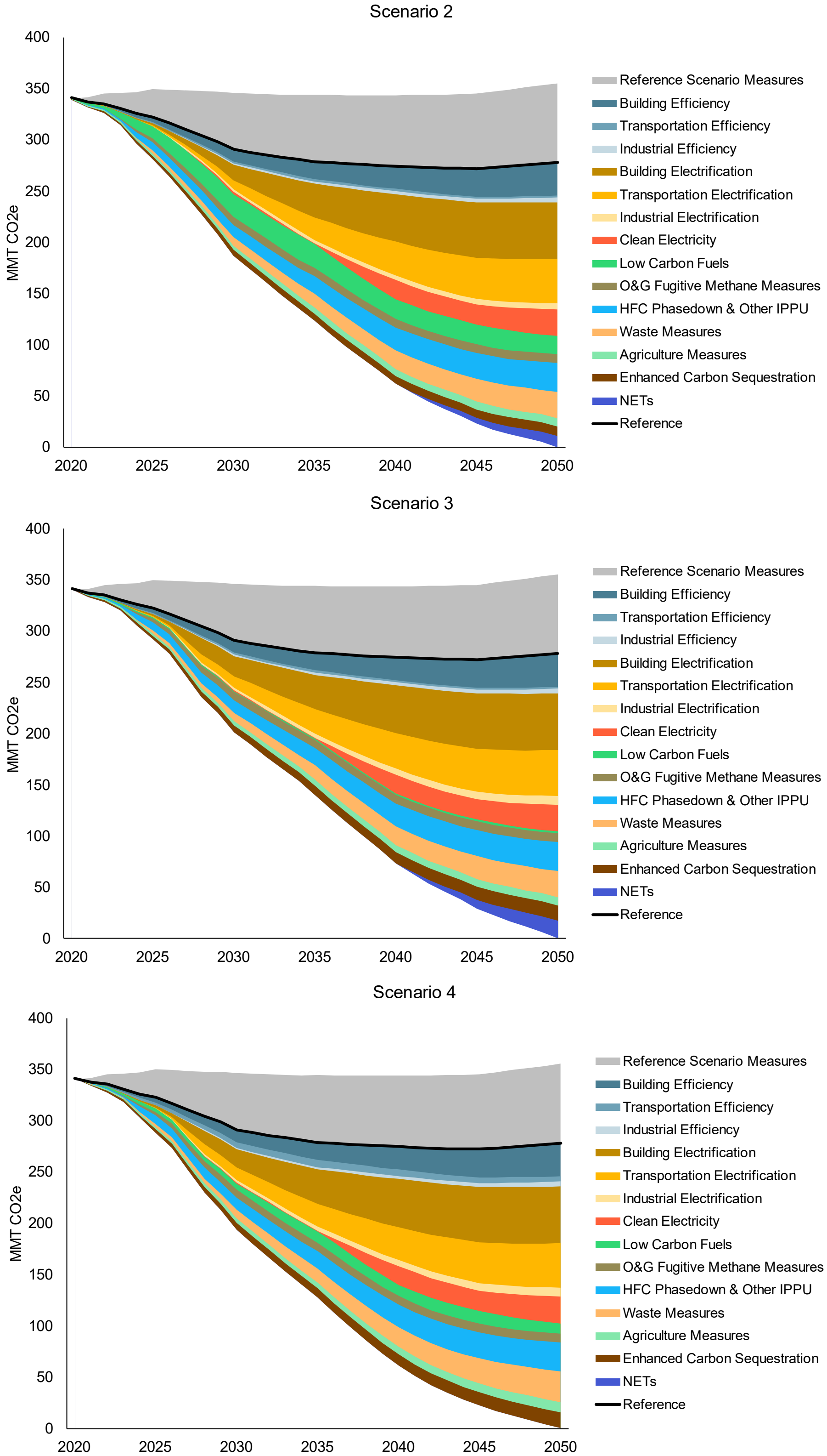
Table 2. Description of Measures Included in Attribution ("Wedge") Analysis

Wedge	Description
Building Efficiency	Includes all incremental efficiency measures in the scenarios beyond New Efficiency NY policies, including efficient appliances and improved building shells.
Transportation Efficiency	Includes all VMT reductions relative to the Reference Case.
Industrial Efficiency	Includes incremental manufacturing efficiency measures beyond those identified in the 2014 NYSERDA Energy Efficiency and Renewable Energy Potential Study.
Building Electrification	Includes the impacts of electrifying building end uses that have existing fossil fuel use, such as space heating, water heating, cooking, and clothes drying.
Transportation Electrification	Includes emissions reductions from deployment of ZEVs*, as well as non-road electrification (such as rail).
Industrial Electrification	Includes reductions due to electrification of industrial natural gas and petroleum fuels use.
Clean Electricity	Includes reductions from 100x40 policy relative to 70x30, along with associated resource-specific carve-outs for offshore wind, battery storage.
Low Carbon Fuels	Includes reductions due to the replacement of remaining fossil fuel demand (after efficiency and electrification measures) with renewable liquid and gaseous fuels.
Oil & Gas Fugitive Methane	Includes reductions in fugitive methane emissions from in-state gas facilities and equipment.
HFC Phasedown	Includes reductions in HFCs and other IPPUs.
Waste	Includes reductions in methane emissions from landfills and wastewater treatment plants.
Agricultural Measures	Includes all reductions in agriculture emissions, such as from animals and soils.
Enhanced Carbon Sequestration	Includes all reductions from increased carbon sequestration in lands and forests, relative to those included in the Reference Case.
Negative Emissions Technologies (NETs)	Includes all reductions from NETs (modelled as direct air capture [DAC])

**Hydrogen fuel cell vehicles included with ZEVs in Transportation Electrification wedge as policies driving ZEV adoption would lead to the same direct emissions reductions regardless of ZEV technology and to make a distinction between hydrogen use for fuel cell vehicles, where the motor is ultimately powered by electricity, and hydrogen combustion used as a direct replacement for natural gas*

Figure 21 shows the results of the attribution analysis. Wedges are layered from top to bottom, so the first set of measures considered are the efficiency measures, and the last measures are carbon sequestration and negative emission technologies. In all scenarios, the largest reductions are achieved through building and transportation electrification. Because of the extremely clean power sector in New York, even in the Reference Case, electrification of fossil fuel consuming devices has a large GHG reduction benefit, both due to increased efficiency of electric devices and due to a fuel switch from fossil combustion to relatively clean electric generation. Even in Scenario 2, the reductions achieved by low carbon fuels are relatively small, due to the treatment of low-carbon fuels in the Climate Act gross emissions accounting framework. In Scenario 3, the electrification wedges are significantly larger in the 2025-2030 period than in Scenario 2, which reflects the early retirement of fossil fuel consuming devices that enables greater reductions before 2030. In Scenario 3, the increased reductions from carbon sequestration allow for a reduction in required NETs to reach net zero emissions in 2050. In Scenario 4, incremental emissions reductions due to hydrogen aviation, smart growth, and intra-state rail increase the size of the electrification and efficiency wedges, while additional agriculture and waste mitigation increase the size of the agriculture and waste wedges; both of these combined result in enough emissions reductions to eliminate the need for NETs to achieve net-zero emissions by 2050. Annual emissions reductions by individual wedge for Scenarios 2-4 are reported in Annex 2.

Figure 21. Wedge Analysis for Scenarios 2-4



3.3 Sectoral Results

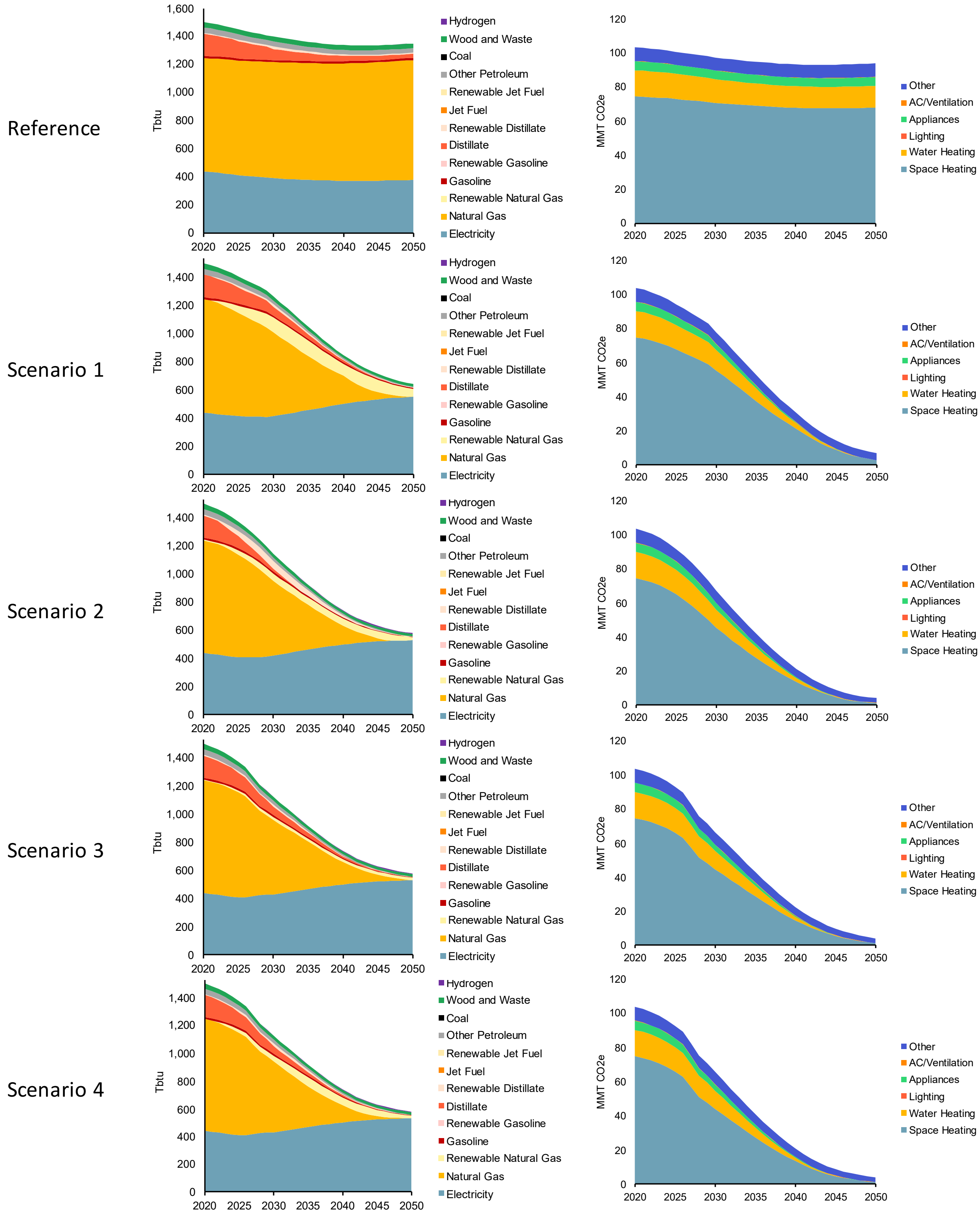
Buildings

Direct emissions in the buildings sector are dominated by emissions from space and water heaters (note that indirect emissions associated with electricity generated to power electric appliances are captured under electricity generation). Although population and households are expected to grow in New York, all scenarios see a significant decline in building sector emissions through energy efficiency, rapid electrification, and improved building shells.[20]

To achieve the reductions in energy use and emissions shown in Figure 22, rapid adoption of new technologies will be required. In all scenarios, electric heat pump space heating technology systems become the majority of new purchases by the late 2020s and no fossil-emitting appliances are sold after 2035. As a result, the electricity share of final energy demand increases from 30% in 2020 to 89%-92% by 2050 across Scenarios 2-4. Base year equipment characteristics and device populations are available in Annex 1, while annual sales and stocks of devices are reported in Figure 23 and Figure 24 below as well as in Annex 2 along with annual sectoral energy demand and GHG emissions.

[20] Adoption of energy efficiency measures, efficient building shell measures, and heat pump systems affects all existing fuels used for primary heating in buildings (e.g., natural gas, petroleum fuels, and wood)

Figure 22. Buildings Final Energy Demand by Fuel (left) and Emissions by Subsector (right)



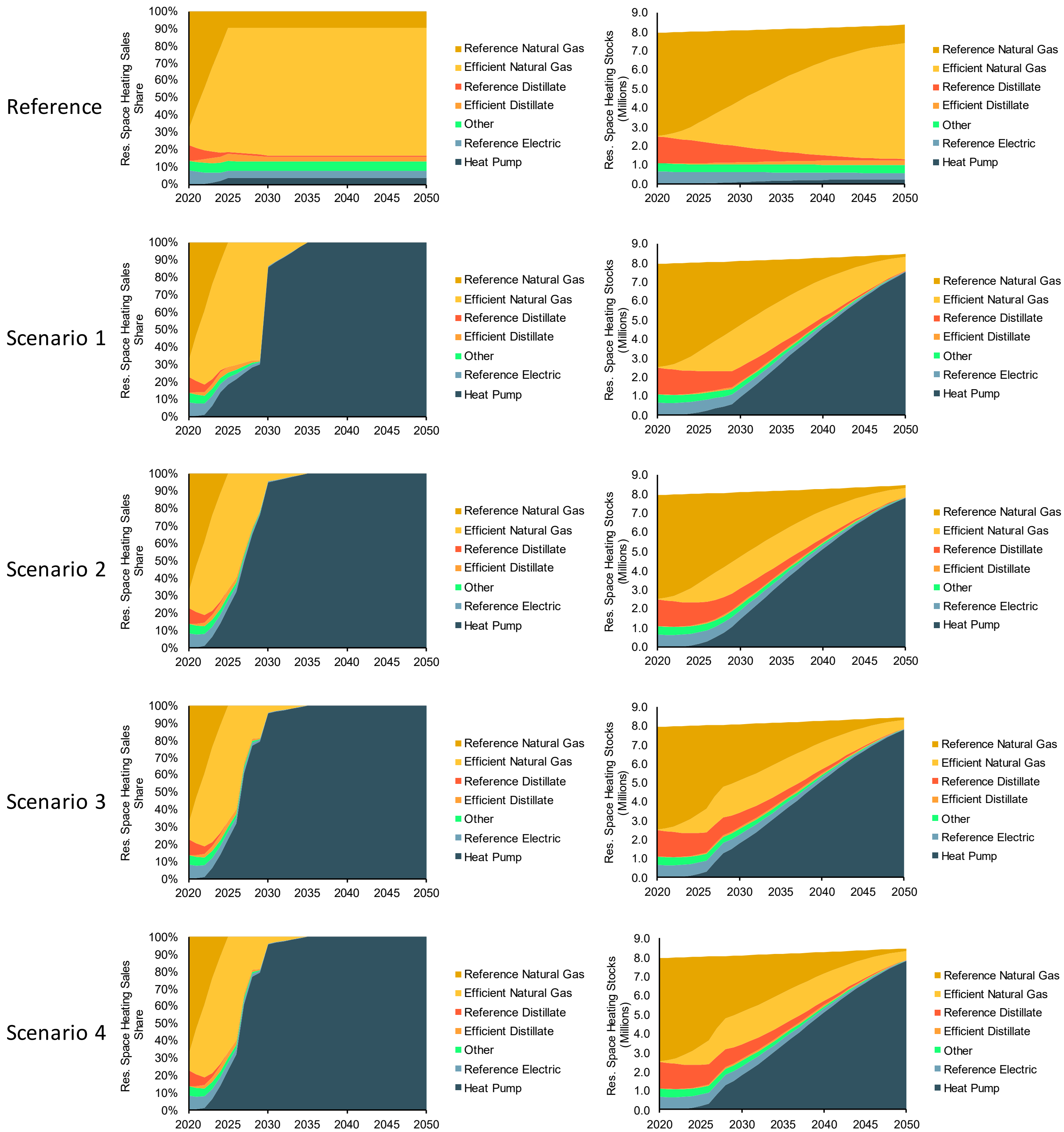
In all scenarios electric heat pump space heating technologies are predominantly cold climate air source heat pumps (ASHPs) with electric backup and a significant role for ground source heat pumps (GSHPs). ASHPs are significantly more efficient than electric resistance heaters during most heating load conditions but lose efficiency during the coldest hours of the year and require some backup heat source. ASHPs with electric backup use electric resistance as the backup heat source, resulting in increased electric system peak impacts (but generally lower than purely resistance heaters alone), whereas ASHPs with fuel backup use combustion or thermal heat sources to provide backup heat while ground source heat pumps operate with little to no performance degradation in cold conditions (Table 3). To represent a lower range of electric peak system impacts, Scenario 2 includes a small share of ASHPs with fuel backup. Scenarios 3 and 4 also include a role for early retirements of least efficient and most polluting space heaters. We also include sensitivities with higher ground source / district heating loop adoption, which are described in more detail in Chapter 3.5.

Table 3. Residential Single Family Heat Pump Annual and Peak Coefficient of Performance (COP)[21]

Technology	Annual COP	Peak COP
Air Source Heat Pump with Electric Resistance Backup	2.41	1.6
Air Source Heat Pump with Fuel Backup	2.65	n/a
Ground Source Heat Pump	3.44	3.44
Ground Source / District Loop Heat Pump Deployment Sensitivity	3.44 [rising to 4.5 by 2030]	3.44 [rising to 4.5 by 2030]

[21] COP varies slightly for multi-family and commercial heating technologies, but peak to average COP relationship is consistent to the residential single family shown here

Figure 23. New Sales Share (left) and Total Stocks (right) of Residential Space Heating Systems[22]

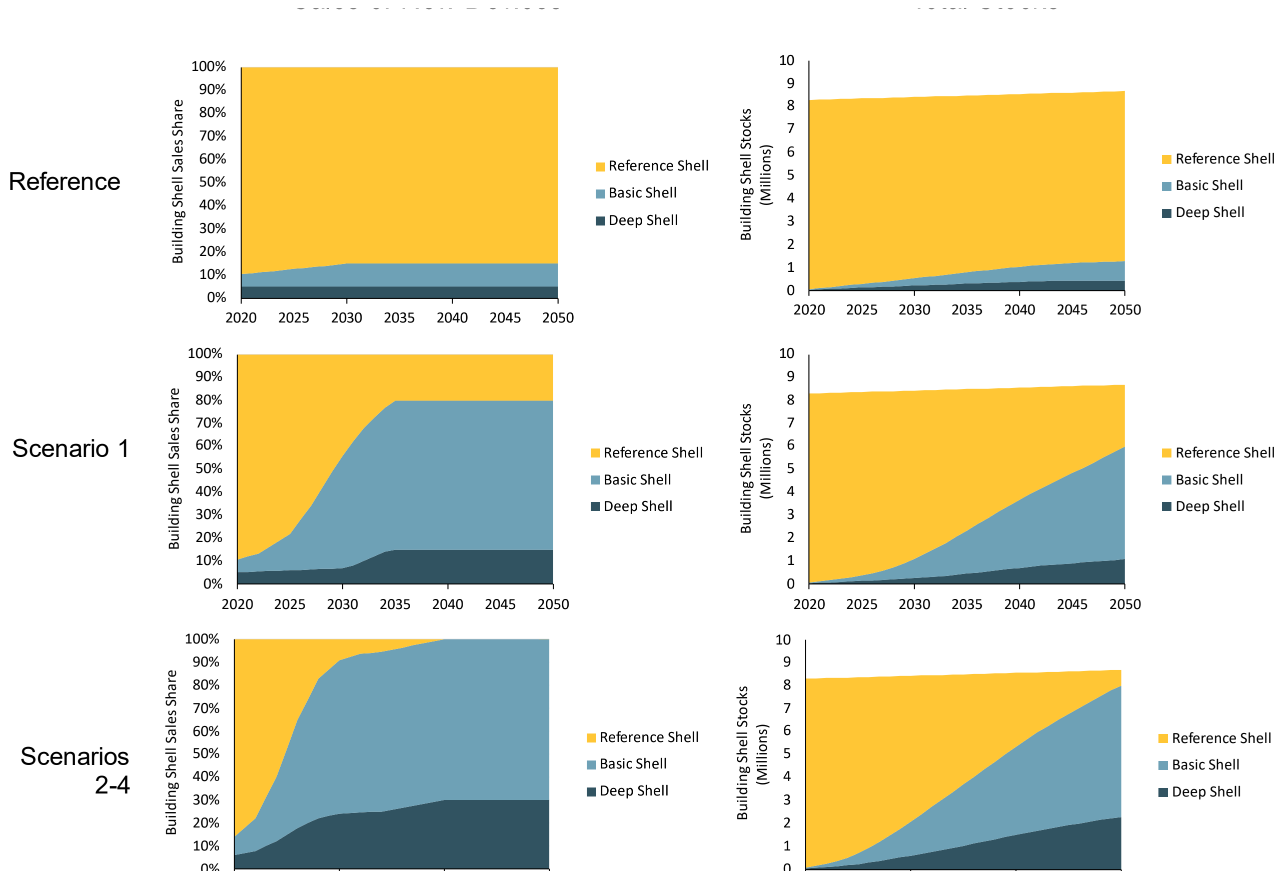


Building shell improvements (such as improved insulation, window treatments, or deep home retrofits) are modeled as reducing service demand for HVAC devices. Improvements to buildings incur costs but improve home and office comfort in addition to reducing energy bills. Two bundles of building shell improvements have been included: a basic shell upgrade and a deep shell upgrade. Basic and deep shell upgrades include a variety of measures focused on reducing energy use and increasing occupant comfort; these measures include, for example, varying levels of roof and wall insulation improvements, window treatments such as double or triple paned windows and infiltration improvements. Space heating demands are reduced by 27-44% with the basic shell package and 57-90% with the deep shell package, depending on building type. Air conditioning demands are reduced 14-27% with the basic shell package and 9-57% with the deep shell package. The total impact of building shell improvements on total HVAC service demand in buildings is a function of the market penetration of each package and distribution of building types. Building shell improvements include both retrofits and new construction, although all new construction in residential and commercial is assumed to be code-compliant and therefore has lower HVAC service demands relative to the existing building stock.[23]

[22] Scenario 4 adoption is the same as Scenario 3

[23] E3 calculated the stock rollover of building shells with a 20-year lifetime to reflect improvements in new construction and opportunities for home retrofits.

Figure 24. New Sales Share (left) and Total Stocks (right) of Residential Building Shell



Hydrofluorocarbon (HFCs) use has grown from near zero in 1990 to over 20 MMT CO_2e in 2020, driven by the use of HFCs to replace other refrigerants (CFCs/HCFCs) over that time period. HFCs are a potent greenhouse gas but a critical part of the building electrification transition in New York. All scenarios include maximum adoption of ultra-low-GWP technologies for building, transportation, and industrial HVAC and refrigeration systems with maximum possible service reclaim at product end of life (90% recover rates).[24]

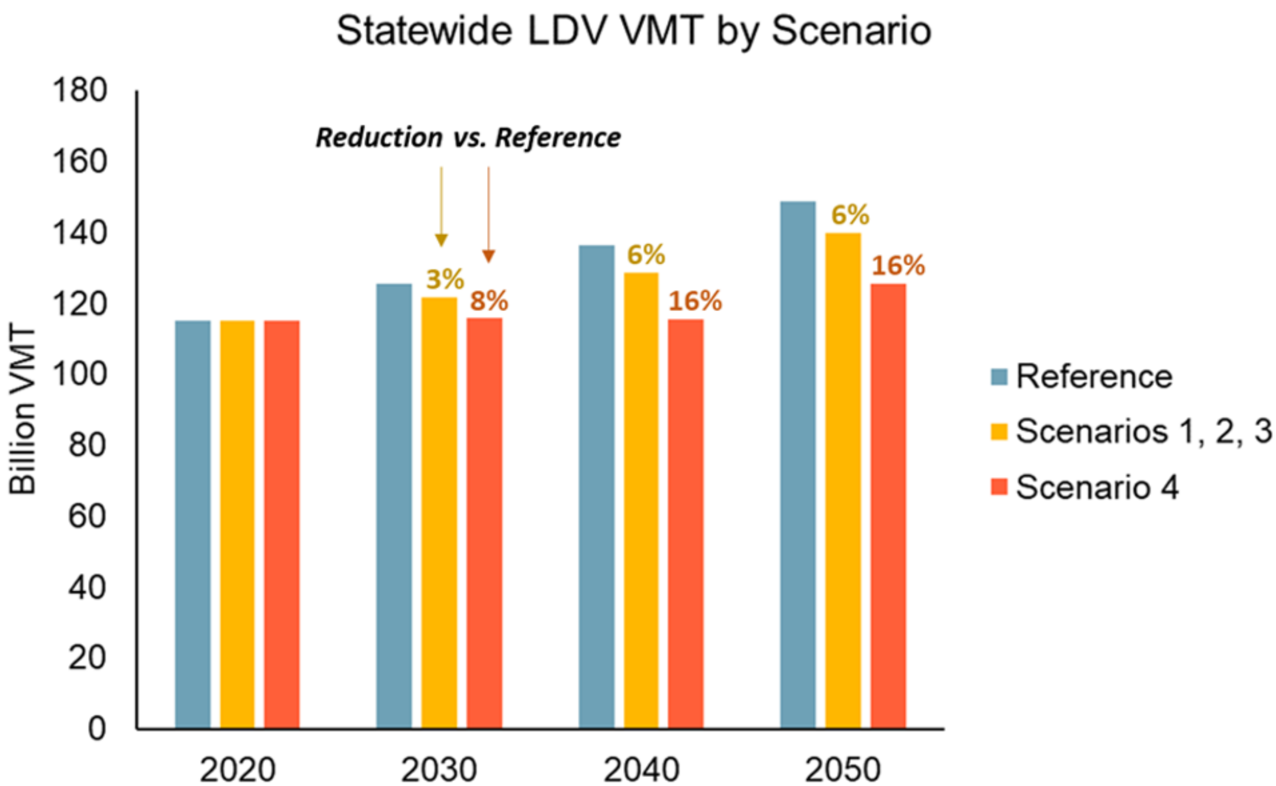
Transportation

Vehicle ownership and VMT are expected to grow in all scenarios, with the highest growth occurring in the Reference Case. As shown in Figure 25 below, growth in LDV VMT in the Reference scenario, and corresponding increase in energy demand and emissions attributed to transportation, are mitigated

[24] Note that the greenhouse gas emissions associated with refrigerants are captured in the Industrial Product and Product Use (IPPU) sector, but the analysis captures interaction effects with adoption of heat pump space heating systems and adoption of refrigerant products.

somewhat by VMT-reduction measures in all mitigation scenarios. All mitigation scenarios include a key role for VMT reduction using smart growth, expanded public transit, telework and demand management programs. In addition, all scenarios include key role for zero-emission vehicle adoption, electrification of non-road sectors, and targeted low-carbon fuel use. These actions collectively reduce total final energy consumption and GHG emissions within the transportation sector (Figure 26).

Figure 25. Statewide LDV Vehicle Miles Traveled (VMT) by Scenario



All scenarios include a core focus on VMT-reduction due to transit, transportation demand management (TDM), telework, mixed-use development, and complete streets policies. Scenario 4 includes greater ambition in these categories, such as by including congestion pricing and other TDM policies in New York City leveraging data from the 2021 Pathways to Carbon-Neutral NYC report (Carbon Neutral NYC)[25], additional ambition in transportation-oriented development where public transit and other low or zero-carbon transportation modes like biking and walking are highly accessible, as well as strategic

[25] https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/Carbon-Neutral-NYC.pdf, accessed May 2021

investments in regional rail to increase ridership and reduce statewide VMT. For more details on VMT Reductions, see Table 12 and Table 13 in Chapter 5.

To decarbonize the remaining transportation energy services demand, zero-emissions vehicles have a central role in all scenarios, with a rapid increase in customer adoption of battery electric and hydrogen fuel cell vehicles. As shown in Figure 26, the electricity share of final energy demand increases from approximately 1% in 2020 to 51%-60% by 2050 for Scenarios 2-4. Across all scenarios, sales of internal combustion engine vehicles are phased out by 2035 for light-duty vehicles and by 2045 for medium and heavy-duty vehicles (Figure 27 and Figure 28). Scenario 2 includes significant vehicle electrification and a greater focus on low-carbon fuels, in particular advanced renewable diesel and renewable jet kerosene that are utilized to decarbonize trucking and aviation, respectively. Scenario 3 includes accelerated vehicle electrification relative to Scenario 2 with some early retirements of the oldest vehicles on the road. This greater pace of electrification goes in hand with greater pace of charging infrastructure investments needed to ensure New Yorkers can charge vehicles at home, at work, and using public charging points as needed. Scenario 4 includes a greater level of vehicle electrification consistent with Scenario 3, and goes further in tackling non-road emissions by including an innovation perspective on the use of electric and hydrogen aviation; Scenario 4 leverages analysis from the Transportation Roadmap which suggests feasibility of including a small role for electric aviation in decarbonizing short distance flights by 2050, and hydrogen aviation to decarbonize medium distance flights; together, hydrogen and electric aviation displace 33% of remaining aviation fuel demand in Scenario 4. Detailed annual final energy demand and GHG emissions for all scenarios are reported in Annex 2, while base year vehicle characteristics and vehicle populations are detailed in Annex 1.

Figure 26. Transportation Final Energy Demand by Fuel (left) and Emissions by Subsector (right)

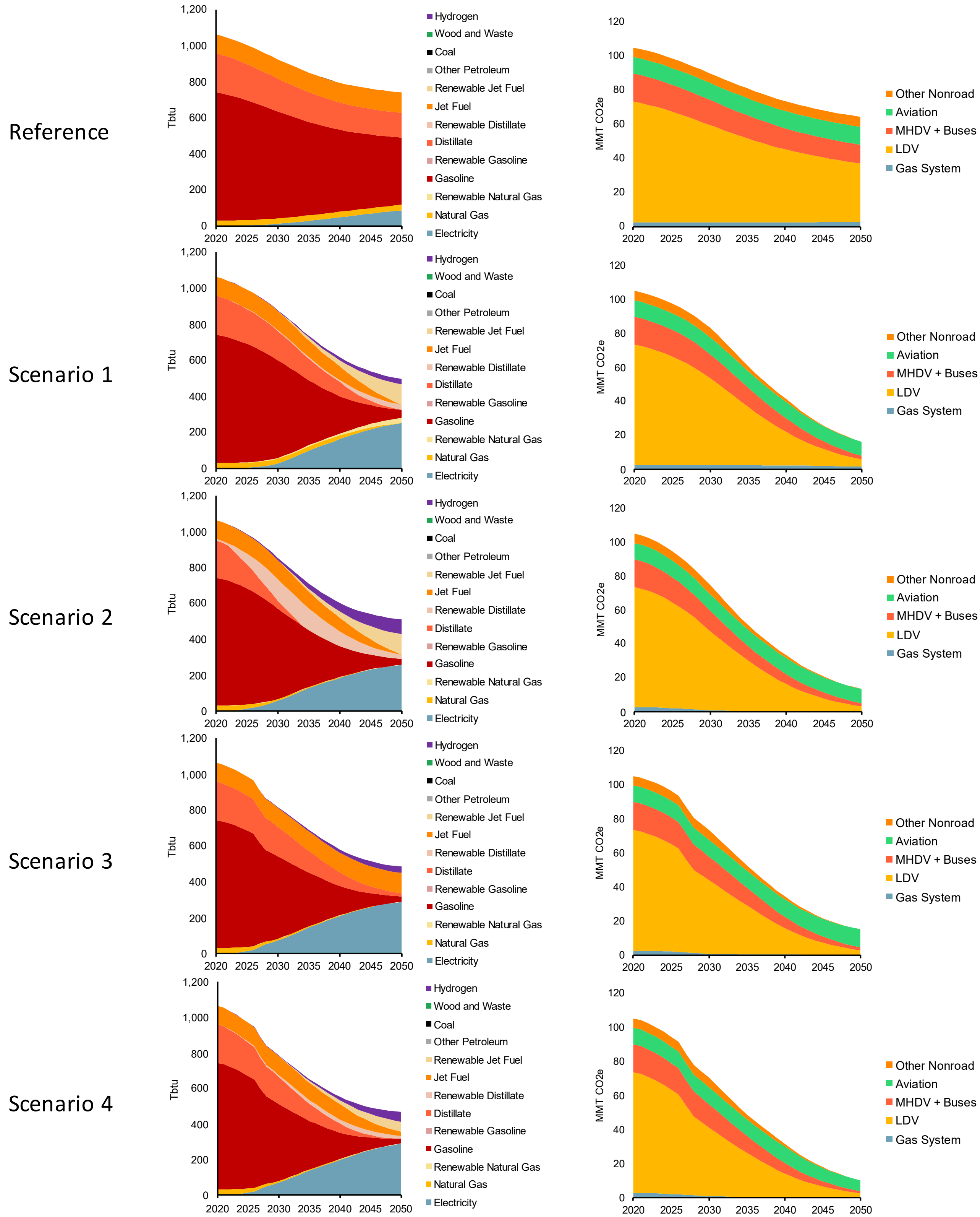
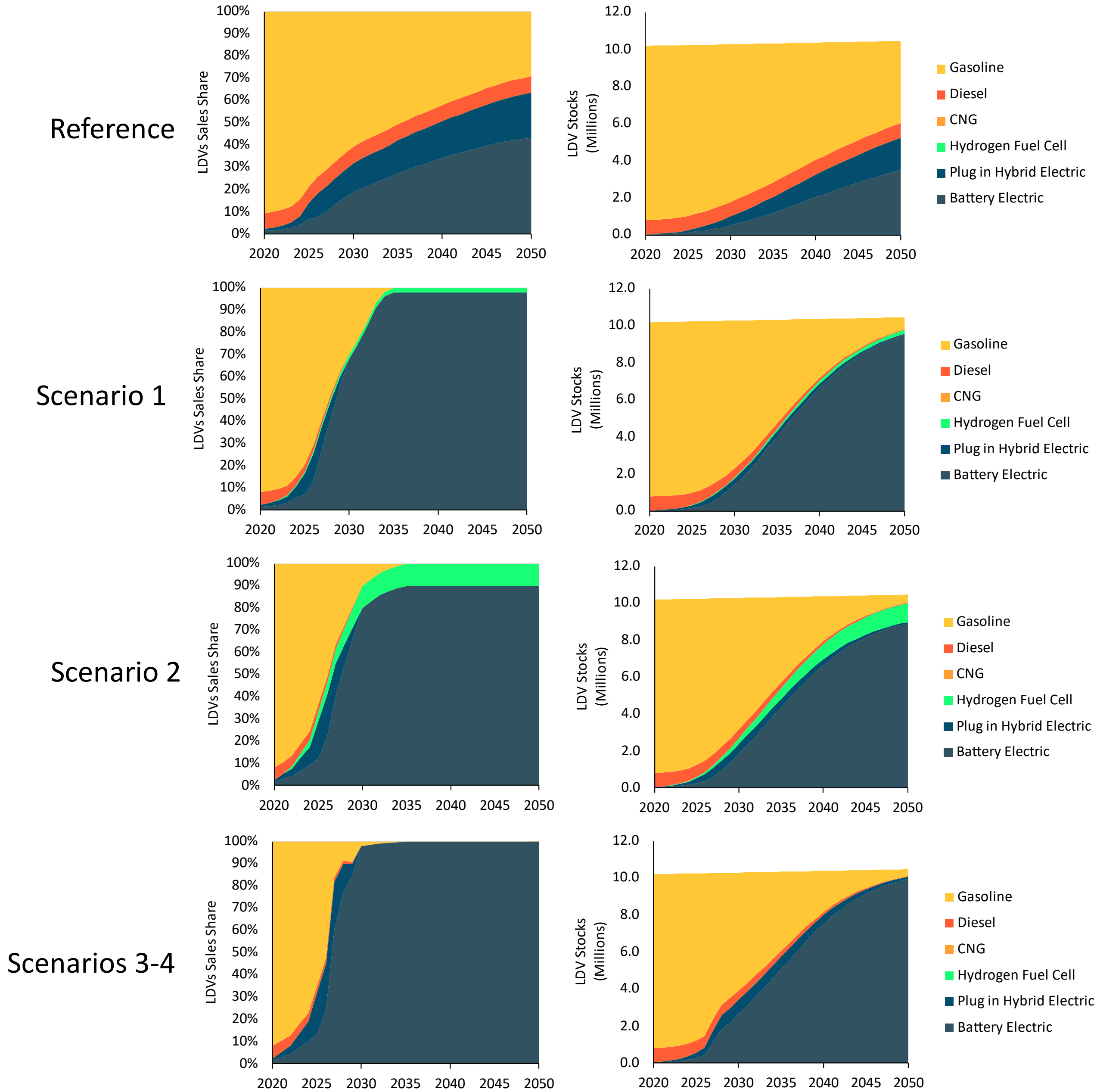


Figure 27. New Sales Share (left) and Total Stocks (right) of Light-Duty Vehicles[26]



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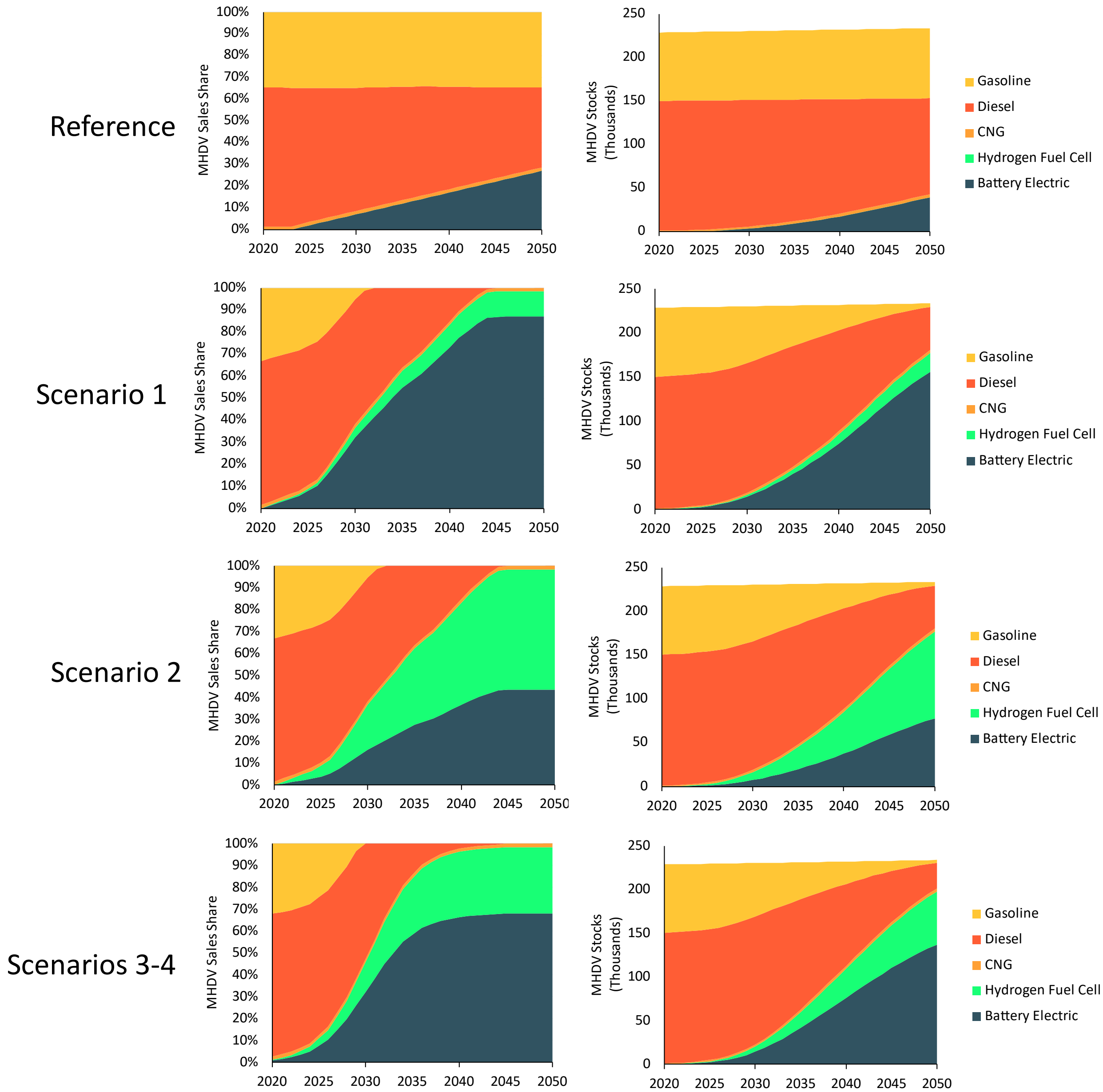
[26] Scenario 4 adoption is the same as Scenario 3

Figure 28. New Sales Share (left) and Total Stocks (right) of Medium- and Heavy-Duty Vehicles



Electricity

For electricity to become the main source of final energy for New York's carbon-neutral economy, the state must tackle a two-pronged challenge over the coming decades: (1) generation and transmission and distribution capacity must dramatically expand to reliably serve increased demand from electrification; and (2) the current mix of generating resources must transition to a carbon-free system, primarily powered by wind, water, and sunlight.

Energy Efficiency and Managed Electrification

Energy efficiency and managed electrification strategies will be critical to the achievement of New York's emission reduction goals. In each of the pathways modeled, New York makes significant investments in energy efficiency and pursues aggressive strategies to offset the impacts of electrification and mitigate the "peak heat" challenge.[27]

Strategies to manage the impacts of electrification can be broken into three broad categories: Managed Infrastructure, Managed Usage, and Dynamic Usage. Each strategy can play a critical role in successfully limiting growth in system peak loads.

Under the Managed Infrastructure category, all scenarios include significant investments in building shell and a diverse mix of heat pump technologies that mitigate the impacts of electrified heating. Building shell improvements play a critical role in reducing building heating needs and thus reducing the amount of electricity required to power heat pumps. The adoption of efficient heat pump technologies, such as ground-source heat pumps, as well as installation of heat pumps with fuel backup, further reduce the amount of electricity needed on the coldest days of the year, relative to air-source heat pumps with electric resistance backup. In the Transportation sector, all scenarios implicitly include the development of workplace charging infrastructure that is critical to reducing the peak impacts of electric vehicle charging. If drivers are able to plug in their vehicles while at work, then they may not need to charge for as long (or at all) when they get home each evening.

The Managed Usage category represents relatively "low-hanging fruit" to shift customer demand away from times of system peak. This analysis focused on opportunities in the Transportation sector, and all scenarios include moderate shifting of electric vehicle charging loads towards day-time and overnight charging, under an implicit assumption that there is both workplace charging infrastructure and time-of-use incentives in place.

Without investments in infrastructure and implementation of rate designs to manage the impacts of electrification, load growth and peak impacts would be substantially higher, which would in turn increase the amount of new electricity infrastructure, and associated costs, that would be required to reliably meet demand with zero-carbon generation. Analysis performed for the 2021 Carbon Neutral Buildings

[27] Peak heat refers to increases in winter peak electricity demand as a result of the electrification of building heating needs.

Roadmap found that managed infrastructure in buildings could reduce overall system peaks by up to 34%.[28]

Dynamic Usage represents more aggressive and innovative load management, in which customer demand interacts with signals from grid operators and dynamically responds to changing prices and system conditions. This type of highly flexible customer load can be particularly valuable in a highly renewable system in which static time-of-use rates may no longer accurately reflect real-time grid conditions (e.g., grid operators may want customers to shift loads to mid-day during sunny days but to evenings or mornings during windy, cloudy days). This analysis conservatively uses a central assumption that a portion of electric vehicle loads (25% of LDV loads) become capable of real-time grid interactivity, but that other end uses in buildings do not.

In this analysis, all scenarios include achievement of Managed Infrastructure and Managed Usage; sensitivity analysis was performed to explore the impacts of varying levels of Dynamic Usage. The results of the sensitivity analysis are detailed in Section 3.5.

Carbon-Free Electric Supply

To meet rapidly growing electricity demand while decarbonizing electricity supply, New York must significantly expand its generation and transmission infrastructure. Coupled with New York's existing clean firm resources, all pathways require major investments in wind, solar, and battery storage, which serve as the foundational resources to achieve New York's 70x30 and 100x40 goals.

To achieve 70% renewable electricity by 2030, New York must continue to increase its Clean Energy Standard procurements for large-scale renewables, part of which involves scaling up Offshore Wind procurements on the path to the 9 GW target by 2035. Although partially offset by investments in the New Efficiency: New York program, the large increases in electricity demand by 2030 and beyond will place additional pressure on the amount of new renewable resources needed to meet, maintain, and exceed the 70% target over time. Behind-the-meter solar resources play a critical role in meeting the

[28] *See* New York Carbon Neutral Buildings Roadmap, Chapter 5, https://www.nyserda.ny.gov/All-Programs/Programs/Carbon-Neutral-Buildings, accessed October 2021.

70x30 targets, and the modeled pathways include the achievement of the 10 GW BTM PV goal by 2030.[29]

New transmission infrastructure is also expected to be an important part of the State's 70x30 and 100x40 goals. The pathways reflect contracted Tier 4 transmission projects, which consist of a 1250 MW line from Hydro-Quebec to New York City, as well as a 1300 MW line from upstate New York to New York City representing the Clean Path New York project, both of which support the State's decarbonization efforts and in particular help reduce the need for fossil generation in Zone J.[30] The analysis also includes a proxy for the Long Island public policy transmission needs solicitation, assuming an increase in transfer capacity of 2000 MW between Zone K and Zone I.[31] In addition to new bulk transmission infrastructure, multiple studies have found that investments in local system upgrades will be critical to reducing congestion and ensuring that new renewable generation can be delivered to load centers.[32,33] This analysis assumes that all new large-scale renewable projects are accompanied by investments in local transmission upgrades to "unbottle" renewables and ensure that new resources are fully deliverable. Between 2030 and 2050, New York must accelerate the build-out of new renewable resources to meet the 100% zero-emissions target and as electrification loads are added to the system. Figure 29 demonstrates the transformation of the New York capacity and generation mix over the 2020–2050 period.

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[29] NYSDPS and NYSERDA, *New York's 10-Gigawatt Distributed Solar Roadmap*, December 2021, *available at*: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B4C42AAFF-0EB9-4890-AA0D-21C70B088F4B%7D.

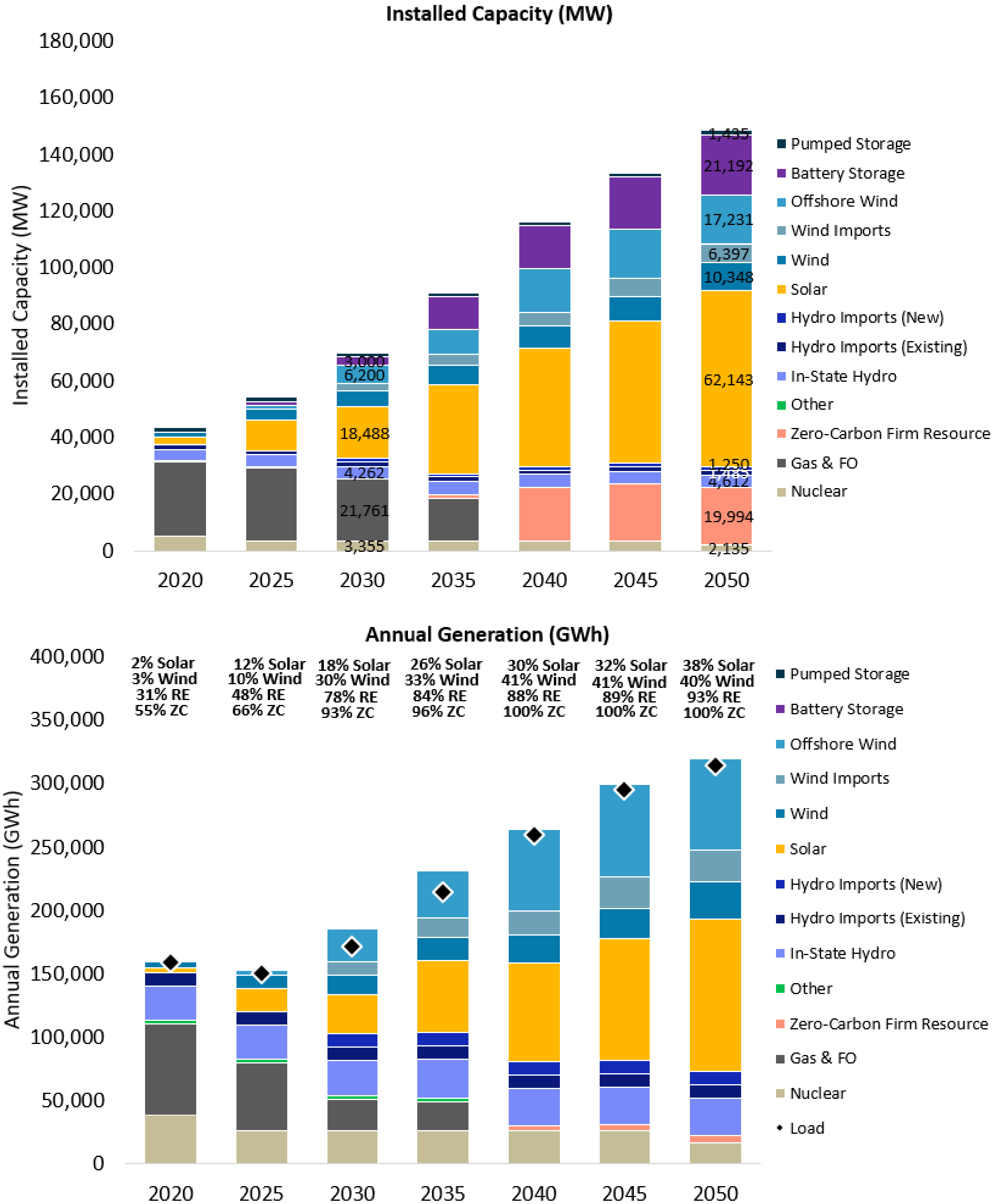
[30] New York Public Service Commission, *Order Approving Contracts for the Purchase of Tier 4 Renewable Energy Certificates*, issued and effective April 2022, *available at:* https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={4DB09036-1CEF-42CB-B9E0-F0ED88848311}.

[31] NYISO, *Long Island Offshore Wind Export Public Policy Transmission Need Project Solicitation*, August 2021, *available at*: https://www.nyiso.com/documents/20142/22968753/Long-Island-Offshore-Wind-Export-Public-Policy-Transmission-Need-Project-Solicitation.pdf.

[32] NYISO, 2019 CARIS Report, June 2020, *available at:* https://www.nyiso.com/documents/20142/13246341/2019_CARIS_Report_v20200617.pdf/fa44a341-786d-2b83-0c00-22951bb112a0, accessed December 2021

[33] New York Utilities, Utility Transmission and Distribution Investment Working Group Report, November 2020, *available at:* https://www.nyserda.ny.gov/About/Publications/New-York-Power-Grid-Study (App C), accessed December 2021

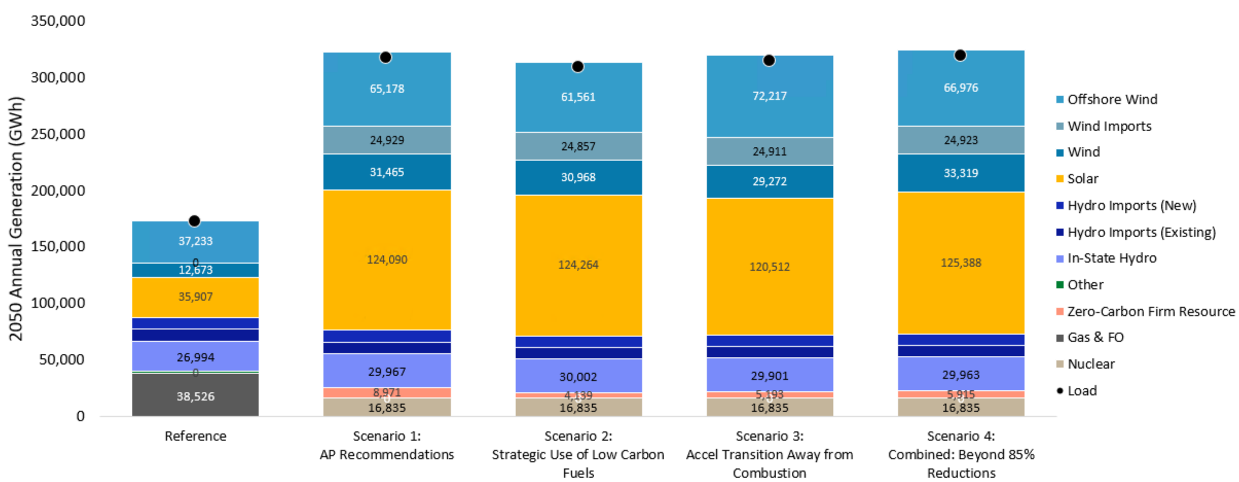
Figure 29. Installed Capacity and Annual Generation for Scenario 3: Accelerated Transition away from Combustion[34]



By 2050, across all modeled pathways, New York installs over 60 GW of solar capacity (both utility-scale and distributed resources), between 17–18 GW of new land-based wind capacity (including imported wind from neighboring ISOs), and between 15–17 GW of offshore wind resources, illustrated in Figure 30.

Figure 30. Installed Capacity in 2050, All Scenarios[35]

Figure 31. Annual Generation in 2050, All Scenarios



[35] In Scenarios 1, 2, and 4, the "zero-carbon firm resource" represents a combination of existing and new combustion-based resources (i.e., combustion turbines and combined cycle gas turbines) that convert to utilizing hydrogen as a zero-carbon fuel. In Scenario 3, firm zero-carbon capacity represents a combustion-free resource, modeled as hydrogen fuel cells.

To integrate large quantities of intermittent resources into the New York electricity system, wind and solar output must be balanced with customer demand on multiple timescales, with different resources providing integration value over each timescale.

On the intraday timescale, battery storage plays a critical role in providing flexibility and balancing renewables with customer loads on both an hourly and sub hourly basis. At the hourly level, batteries can charge during times of high renewable output and discharge during times of lower renewable output or high customer demand, and batteries can also help meet sub hourly reserve requirements. New York installs between 20–22 GW of battery storage across our modeled pathways. Dynamic end-use flexibility also has similar potential to help meet hourly balancing needs if customers are incentivized to shift their demand to times of highest renewable output. The impacts of end-use flexibility on electricity system resource needs and system costs are examined in Section 3.5.

On the inter-day timescale, firm resources are needed to serve load and maintain system reliability during multi-day periods of low renewable output – periods in which the contributions of short-duration battery storage are limited. Our analysis identified a need for firm, zero-carbon capacity – in addition to the state's existing hydro and nuclear facilities – of between 18–23 GW to maintain system reliability while achieving a 100% zero-emissions grid.[36]

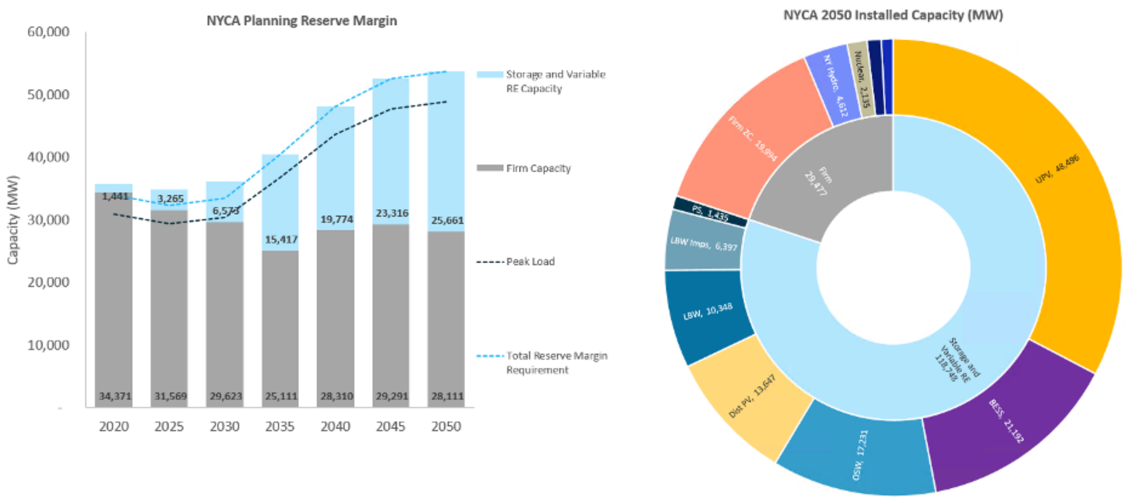
Ultimately, each resource category – renewables, battery storage, and firm zero-carbon capacity – will make important contributions to the state's achievement of a reliable carbon-free electric system. The reliability contributions of different resource types to statewide capacity requirements are detailed in Figure 32, which provides an alternative view of the 2050 resource mix in Scenario 3.[37] New renewable and storage resources provide significant reliability contributions, contributing over 25 GW towards statewide capacity requirements. However, at high penetrations of renewables and storage, the incremental reliability value of new resources is limited, because the most challenging periods for system

[36] In Scenarios 1, 2, and 4, this firm capacity need is met by a combination of existing and new combustion-based resources (i.e., combustion turbines and combined cycle gas turbines) converting to hydrogen as a zero-carbon fuel. In Scenario 3, all existing fossil fuel resources are retired by 2040 and no new combustion-based (CCGT or CT) capacity is permitted. New firm capacity is provided by a combustion-free resource (modeled as hydrogen fuel cells).

[37] In all of the modeled pathways, the analysis ensures that the resulting electric system portfolios are reliable by enforcing the current statewide and local capacity requirements on a UCAP basis. The reliability contributions of intermittent and limited-duration resources (i.e., renewables and battery storage) towards New York's UCAP requirements are measured using an effective load carrying capability (ELCC) methodology. ELCC is the quantity of "perfect capacity" or UCAP that could be replaced with renewables or storage while providing equivalent system reliability. The analysis included loss of load probability modeling using E3's reliability model, RECAP, as detailed in Chapter 5.

reliability become times in which renewable output is low and storage is quickly exhausted. Firm zero-carbon capacity, including the existing nuclear and hydro facilities as well as new resources, contribute the remaining 28 GW of capacity requirements to ensure that the system is fully reliable, including during extended periods of low renewable output. The following section details the contributions of each resource type at more granular timescales.

Figure 32. Contributions to Statewide Capacity Requirements, Scenario 3[38]



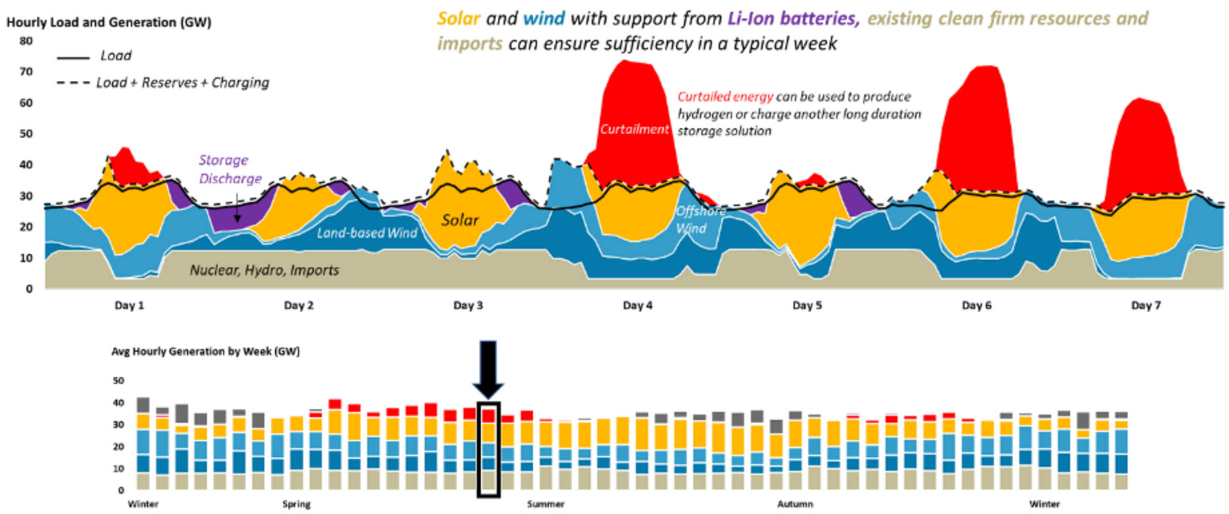
System Operations and Reliability

Wind and solar resources are foundational to New York's decarbonization goals and provide over 75 percent of annual generation. Their contributions vary over the course of the year, as indicated in the bottom of Figure 33. There are many weeks in which wind and solar, coupled with existing clean firm resources like the upstate nuclear and hydro facilities, meet the entirety of system needs over the course of the week. Figure 33 provides an illustration of system dispatch during a typical spring week, in which short-duration batteries provide intraday balancing by charging during times when renewable output exceeds demand and filling gaps of lower renewable output. Demand over the entire week is met with wind, solar, existing nuclear and hydro, small amounts of imports, and balancing from battery storage. There are also times during this week of excess renewable output – beyond what batteries are able to

[38] The CPNY line is not included in this statewide chart because it represents an internal transfer of wind and solar capacity; however, it is modeled as contributing to capacity requirements in Zone J.

absorb – which could be used to produce green hydrogen or to charge a long-duration (e.g., 100+ hours) battery storage resource.

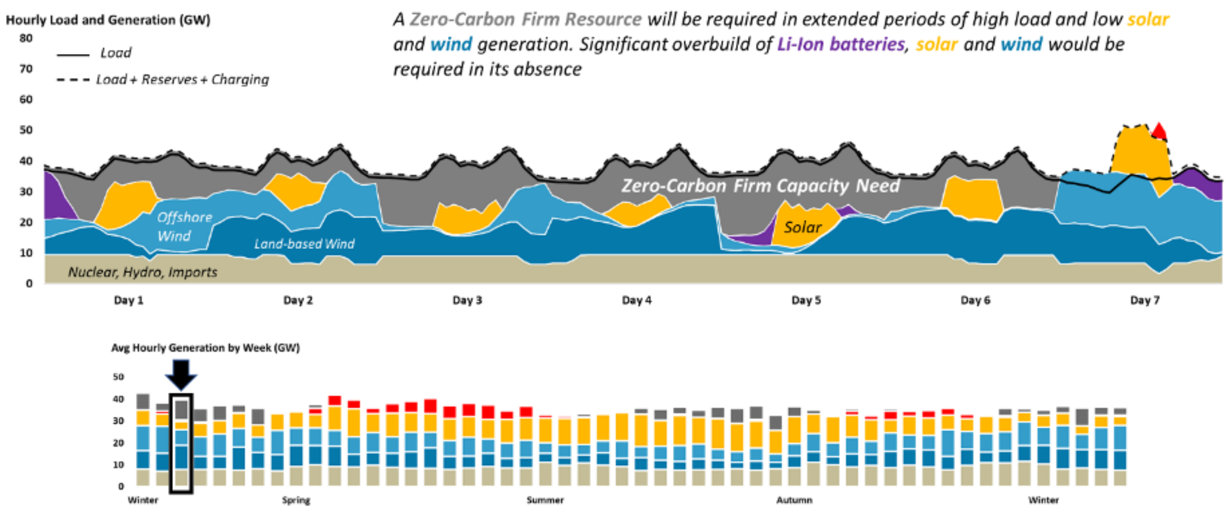
Figure 33. Hourly Dispatch Over a Typical Spring Week In 2050



There are many weeks similar to the one described above over the spring, summer, and fall. However, as indicated by the gray contributions in the weekly generation chart, there are also many weeks in the year – especially during the winter – in which the contributions from renewables and existing clean firm resources are not sufficient to meet demand. During cold weeks, as a result of the electrification of building heating needs, electric demand will be much higher in the winter than it is today. Winter months also often coincide with extended periods of low renewable output.

During a week with persistently low solar and wind generation, additional firm zero-carbon resources, beyond the contributions of existing nuclear, imports, and hydro, are needed to avoid a significant shortfall; Figure 34 demonstrates the system needs during this type of week. During the first day of this week, most of the short-duration battery storage is quickly depleted, and there are still several days in which wind and solar are not sufficient to meet demand. A zero-carbon firm resource becomes essential to maintaining system reliability during such instances. In the modeled pathways, the need for a firm zero-carbon resource is met with hydrogen-based resources; ultimately, this system need could be met by a number of different emerging technologies.[39]

Figure 34. Zero Carbon Firm Capacity Need Over a Challenging Winter Week in 2050



Hydrogen effectively provides a form of storage to the system on the order of hundreds of hours. Large quantities of fuel can be produced during the spring and summer and then utilized over the course of the winter provided that there is sufficient fuel storage. In addition to hydrogen-based resources, the analysis also examined the potential to meet reliability needs with a long-duration battery storage solution. In this assessment, the firm zero-carbon capacity, as well as renewable resources needed to produce hydrogen, were removed from the system, and the analysis identified a need for 25 GW of 100-hour battery storage to replace the contributions of 21 GW of a fully dispatchable hydrogen-based resource, along with 14 GW of incremental renewable resources to provide storage charging.[40] A 100-hour battery resource can provide firm capacity to meet system needs over several days. However, in contrast to a hydrogen-based resource, if sufficient excess energy is not available to fully recharge the batteries following a challenging

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[39] Firm zero-carbon capacity needs could be met by a number of different technologies, including but not limited to: hydrogen or renewable natural gas utilization in combustion-based resources (e.g., CTs or CCGTs); hydrogen utilization in fuel cells; long-duration battery storage; or new nuclear technologies. These solutions are at varying levels of technology readiness, though none have been deployed at commercial scale to date, and continued innovation and progress towards commercialization will be needed to ensure this system need is met.

[40] Incremental resource builds are defined relative to the resources that would be needed for electrolysis to meet 50% of New York's hydrogen demand with in-state resources. The starting point for the reliability analysis was a case without in-state electrolysis loads or associated resources, and 26 GW of new renewables were added in total.

stretch, their ability to meet a similar system need in subsequent weeks of the winter is diminished. As a result, a higher amount of 100-hour battery capacity is needed to meet the same level of reliability as hydrogen-based resources (Figure 35 and Figure 36).

Figure 35. Replacement of Hydrogen-based Resources with 100-hour Battery Storage[41]

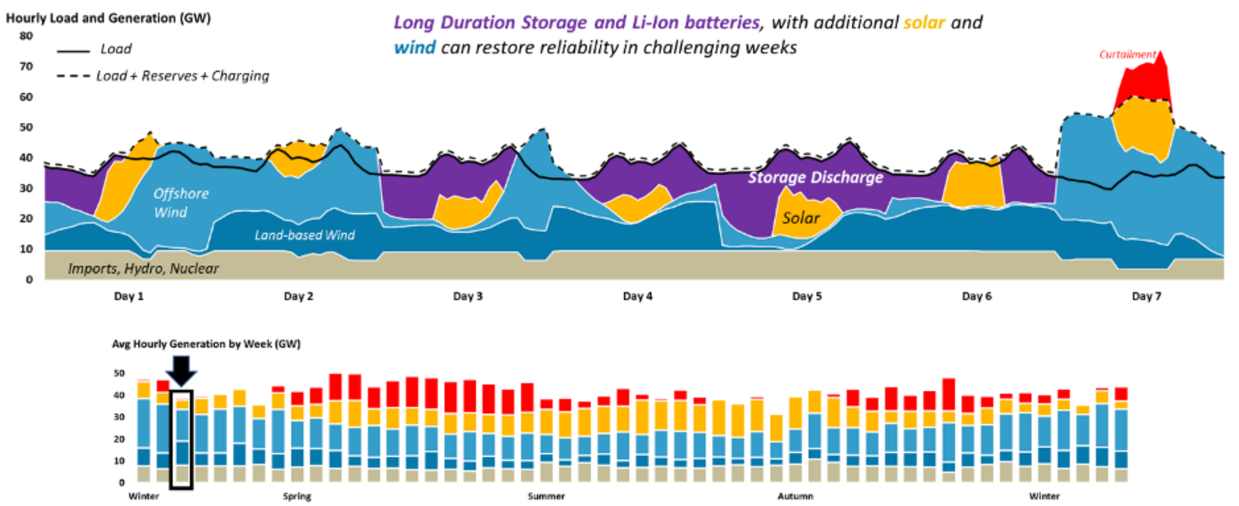
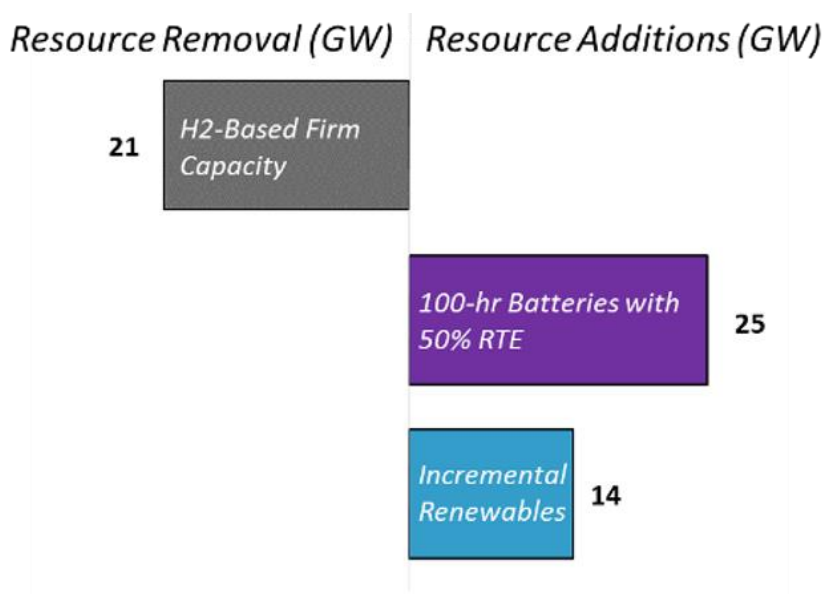


Figure 36. Utilization of Long Duration Storage to Maintain Reliability over Challenging Winter Week



[41] The starting portfolio already contains significant amounts of battery storage. As a result, the reliability value of incremental 8-hour storage was limited due to extended loss of load periods.

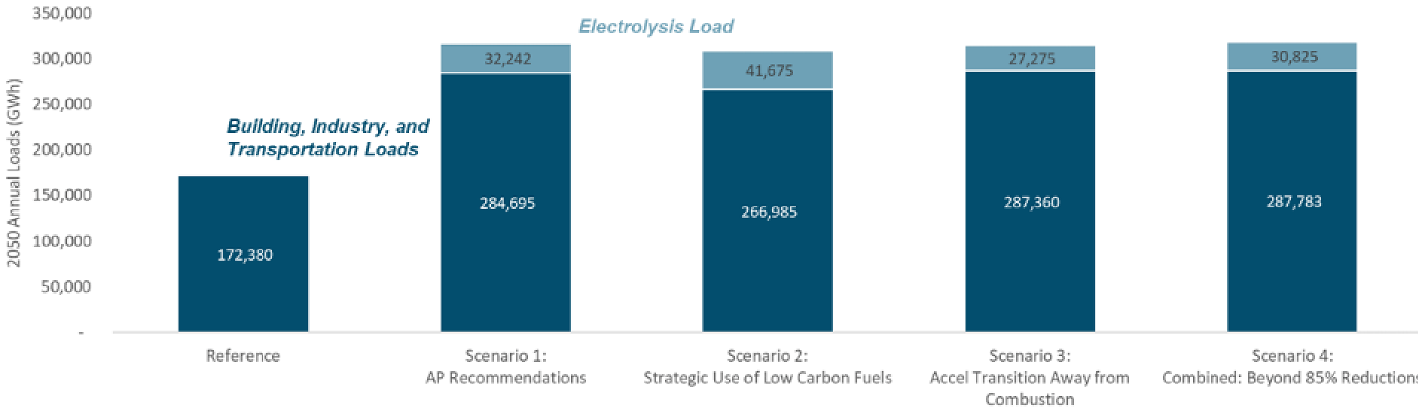
Role of Hydrogen

Hydrogen or bioenergy can play a critical role in decarbonizing sectors or applications that are difficult to electrify. By 2030, New York will likely need to spur initial market adoption of green hydrogen to help decarbonize medium and heavy-duty vehicles, as well as high-temperature industrial applications. In the longer term, low-carbon fuels may play critical roles in decarbonizing existing district heating and non-road transportation, including rail and aviation. Additionally, hydrogen-based resources can play a key role in the electric sector by providing firm capacity during extended periods of low renewable output, as discussed above.

Across all modeled pathways, New York's hydrogen demand is met with "green hydrogen," defined as hydrogen produced using electrolysis powered by renewable electricity. Hydrogen plays a strategic role across scenarios, with consumption ranging from 120–180 TBtu across modeled pathways in 2050. The production of large quantities of hydrogen can absorb excess renewable generation and prevent curtailment but will also require additional dedicated facilities to power electrolysis. In this analysis, our central assumption is that New York produces 50% of its hydrogen needs in-state and imports the remainder, with cost assumptions for that imported remainder consistent with the cost of "green hydrogen" produced in-state. Production costs for hydrogen were based on projections of electrolyzer capital costs and electricity prices, while transmission and storage costs were estimated assuming a 400-mile transmission pipeline and underground storage in salt caverns. Distribution costs for local hydrogen distribution via pipeline or freight truck were not included in this analysis, and it is important to note that there is significant uncertainty in future transmission and storage costs based on production location and underground storage availability. The hydrogen supply and infrastructure costs included in this study are a proxy for a future system that combines both in-state and imported production of hydrogen with a build out of transmission and storage infrastructure, but they are not meant to represent an optimal configuration of hydrogen production and transmission and storage infrastructure.

Producing half of New York's hydrogen demand with in-state electrolysis results in up to 42 TWh of additional electricity demand, as shown in Figure 37. An additional sensitivity examining an alternative assumption of 100% in-state hydrogen production is included in section 3.5.

Figure 37. Impacts of Electrolysis Loads on Total Electric Loads in 2050

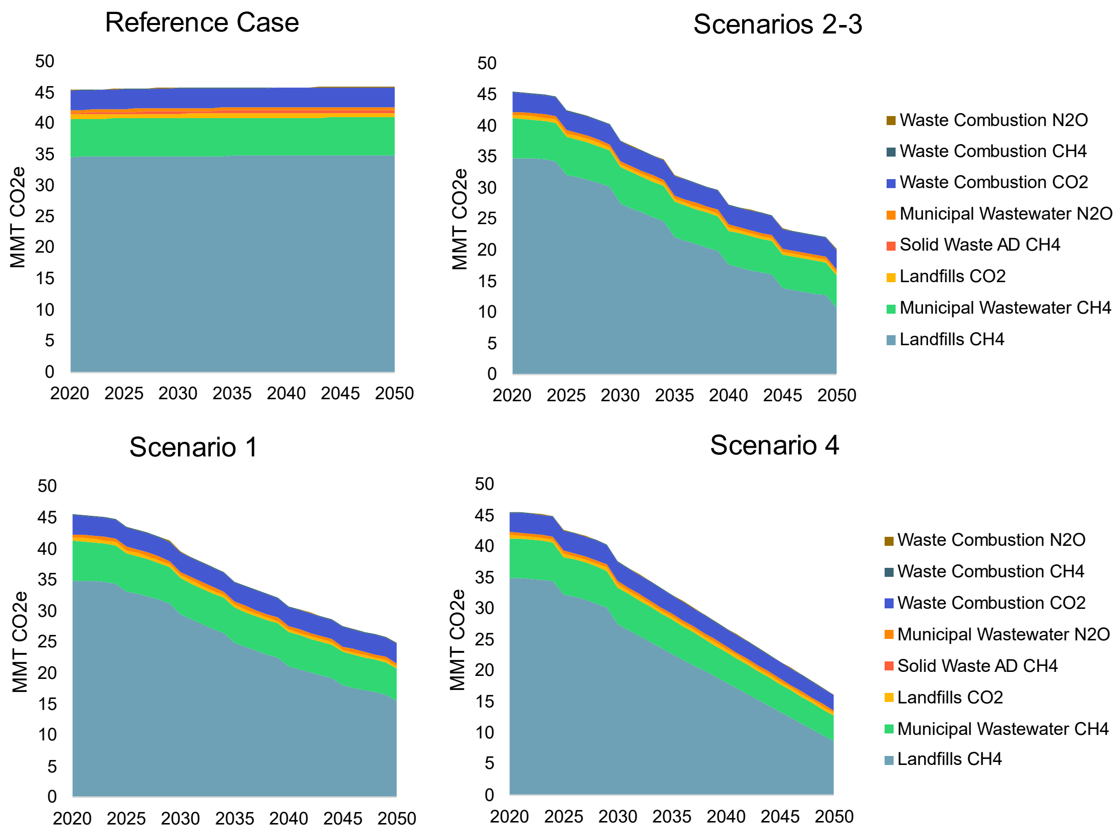


Electrolysis loads are highly flexible and can take advantage of excess renewables on a seasonal timescale, helping to balance and integrate renewables by serving as a form of long-duration storage that cannot be met with short-duration battery storage resources. However, although curtailed renewable electricity can contribute to a portion of hydrogen production needs, new renewable resources are also required to power electrolysis demand. These renewable resource needs are incorporated into the mitigation scenarios, and resource needs associated with 100% in-state hydrogen production are assessed in the sensitivity analysis included in section 3.5.

Waste

Emissions in the waste sector are dominated by methane emissions from landfills and wastewater treatment facilities. Scenarios 2 and 3 include actions to divert 100% of waste from landfills and reduce methane leakage 10% every 5 years from existing landfills, with anaerobic digesters in solid waste running at capacity in 2030 with 75% methane leakage reduction by 2050, waste combustion held constant, and methane leakage reduction from wastewater treatment facility anaerobic digesters. Scenario 4 includes the same measures as Scenarios 2 and 3, plus characterization of uncertainty in potential for additional innovation in methane management and capture, resulting in an additional 50% reduction in waste sector GHG emissions in 2050 relative to Scenarios 2 and 3.

Figure 38. Greenhouse Gas Emissions in Waste Sector

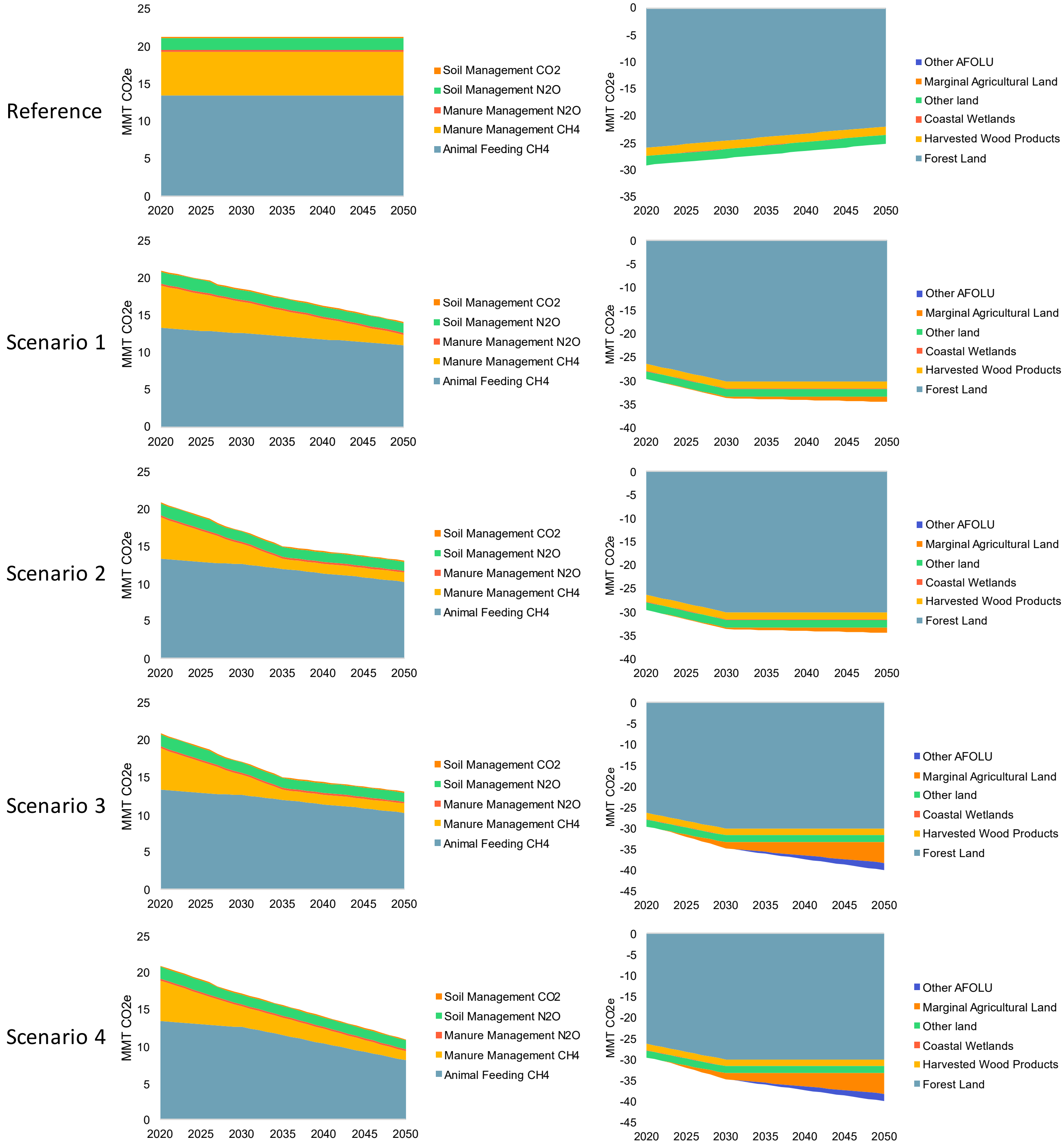


Agriculture, Forestry, and Land Use (AFOLU)

Emissions within the AFOLU sector include emissions sources from agriculture and emissions sinks from forestry and other land use. Key measures in Scenarios 2 and 3 include achievable agricultural emissions based on Cornell University estimates[42] and expansion of carbon sequestration in forests to restore the sink to 1990 levels. Scenarios 3 and 4 include additional afforestation on marginal agricultural lands, and Scenario 4 includes potential additional innovation in agricultural practices for nearly an additional 40% reduction in GHG emissions from the agriculture sector by 2050, relative to Scenario 3.

[42] Wightman and Woodbury (2020)

Figure 39. Emissions Sources in Agriculture (left) and Emissions Sinks in Forestry (right)

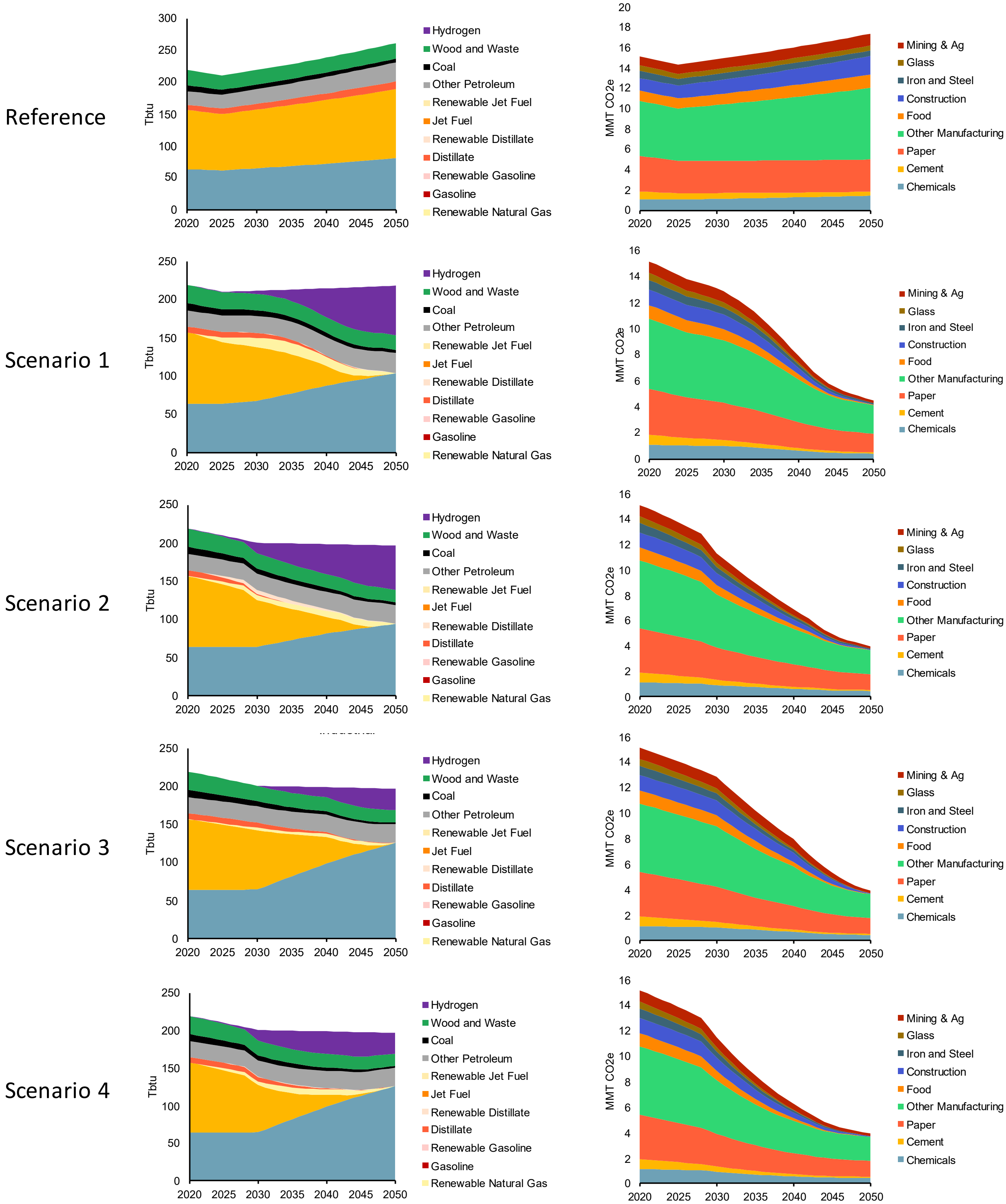


Industry

Industrial Energy Use

Industrial sector energy demand and GHG emissions are spread across a diverse range of subsectors in New York, with paper manufacturing, construction, and other manufacturing being particularly large sources. Key measures in Scenarios 2 and 3 include manufacturing energy efficiency, electrification and hydrogen fuel switching, and carbon capture and storage for cement and iron and steel facilities. Scenario 2 includes a larger role for hydrogen and Scenario 3 includes more accelerated electrification, while Scenario 4 includes some amount of both increased low-carbon fuel use and increased electrification, in addition to the aggressive levels of energy efficiency and carbon capture and storage common to all mitigation Scenarios. Figure 40 below shows the dramatic shift from natural gas to electricity and hydrogen by 2050; together these fuels account for almost 80% of industrial final energy demand in Scenarios 2-4, although the respective shares of electricity and hydrogen vary by scenario. Base year energy consumption is shown both by industrial subsector and region and by industrial subsector and fuel in Annex 1, while annual final energy demand and GHG emissions for all scenarios are reported in Annex 2.

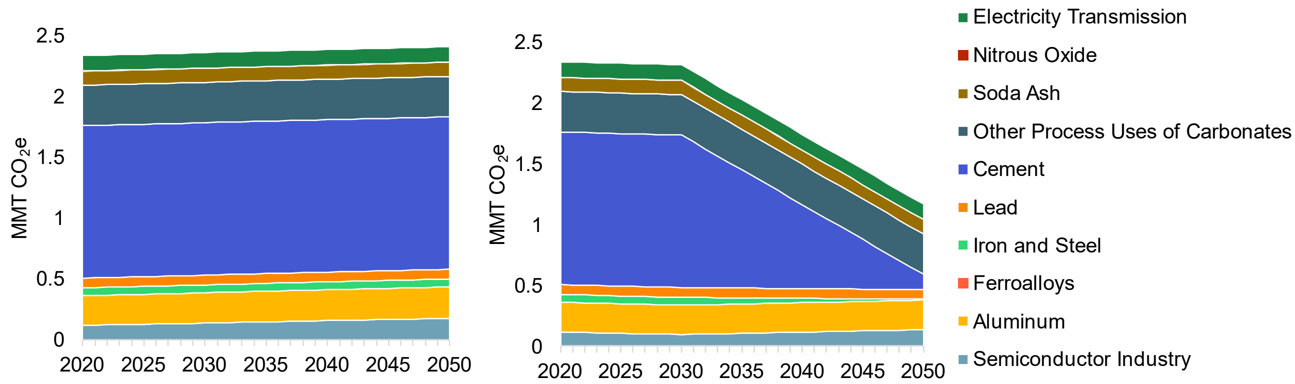
Figure 40. Industrial Final Energy Demand (left) and Greenhouse Gas Emissions (right)



Industrial Process and Product Use

The industrial process and product use (IPPU) sector includes emissions from industrial processes (e.g., cement, aluminum) and product use, which is primarily from refrigerants. Key measures in industrial process emissions are historical declines in uses of carbonates and CCS for cement process emissions.[43]

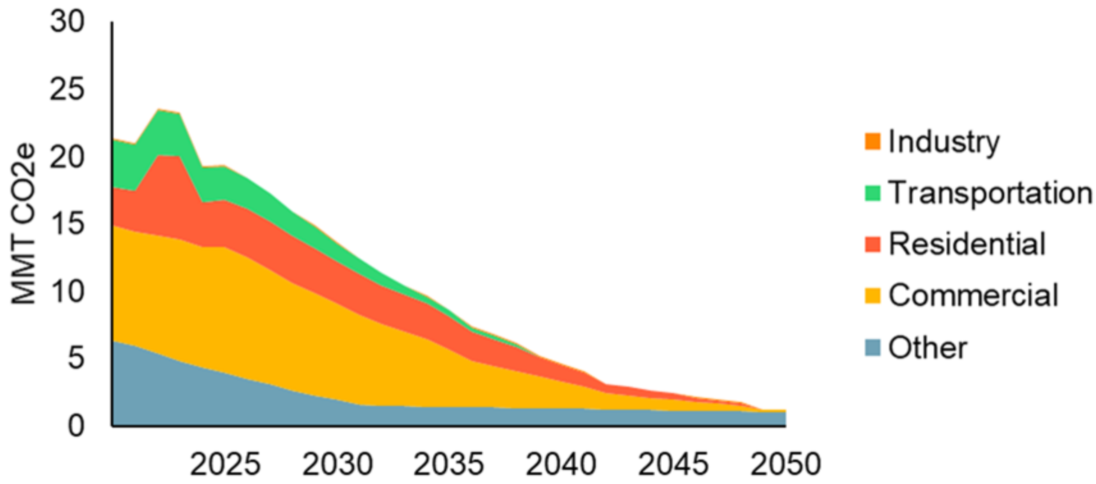
Figure 41. Greenhouse Gas Emissions from Non-HFC Industrial Processes, Reference (left) and Scenarios 1-4 (right)



Hydrofluorocarbon (HFC) use has grown from near zero in 1990 to over 20 MMT CO_2e in 2020, driven by the replacement of other refrigerants (CFCs/HCFCs) over that period. HFCs are a potent greenhouse gas but a critical part of the building electrification transition in New York. All mitigation scenarios include maximum adoption of ultra-low-GWP technologies for all building, transportation, industrial HVAC and refrigeration systems and maximum possible service reclaim at product end of life (90% recover rates).

[43] "Other Process Uses of Carbonates" includes flux stone use, flue gas desulfurization, magnesium production, acid neutralization, and sugar refining. Other non-CO_2 Industrial Process emissions are reduced based on incorporation of mitigation potential from EPA non-CO_2 report: available online: https://www.epa.gov/global-mitigation-non-CO2-greenhouse-gases/global-non-CO2-greenhouse-gas-emission-projections, accessed February 2021

Figure 42. Greenhouse Gas Emissions from HFCs, Scenarios 1-4[44]

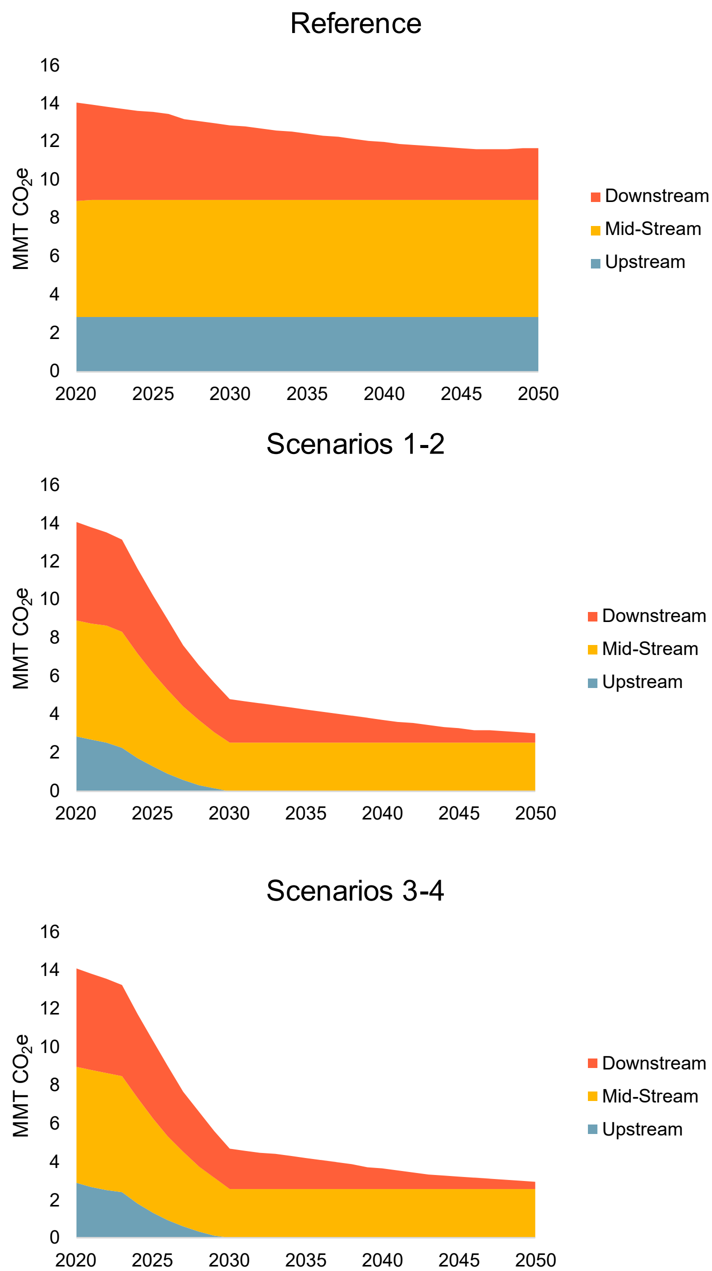


In-State Oil and Gas

Emissions from New York's oil and gas industry are dominated by fugitive methane emissions in low-producing natural gas wells, transmission and storage compressor stations, steel and cast-iron pipes in the distribution system, and buildings. Key measures in Scenarios 2 and 3 include equipment replacement and Leakage Detection and Reduction (LDAR) at compressor stations, abatement at upstream sources, distribution pipeline decommissioning, and residential building disconnection and decommissioning.

[44] "Other" includes emissions from foams, aerosol propellants, solvents, and fire suppressants.

Figure 43. Greenhouse Gas Emissions from In-State Oil and Gas[45]



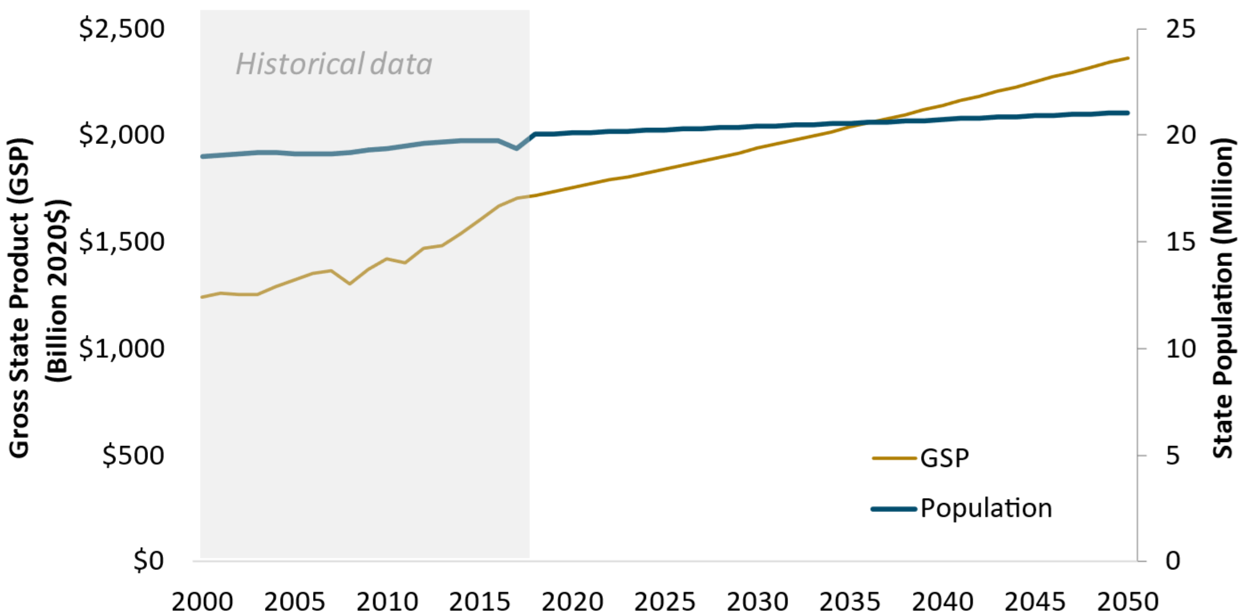
[45] Downstream includes distribution pipelines and building meters; Mid-stream includes gas transmission, compression, and storage; Upstream includes gas production and abandoned oil and gas wells

3.4 Benefits and Costs

Background

New York's economy has been steadily growing for the last two decades and state economic output per capita has been growing even more quickly (Figure 44).

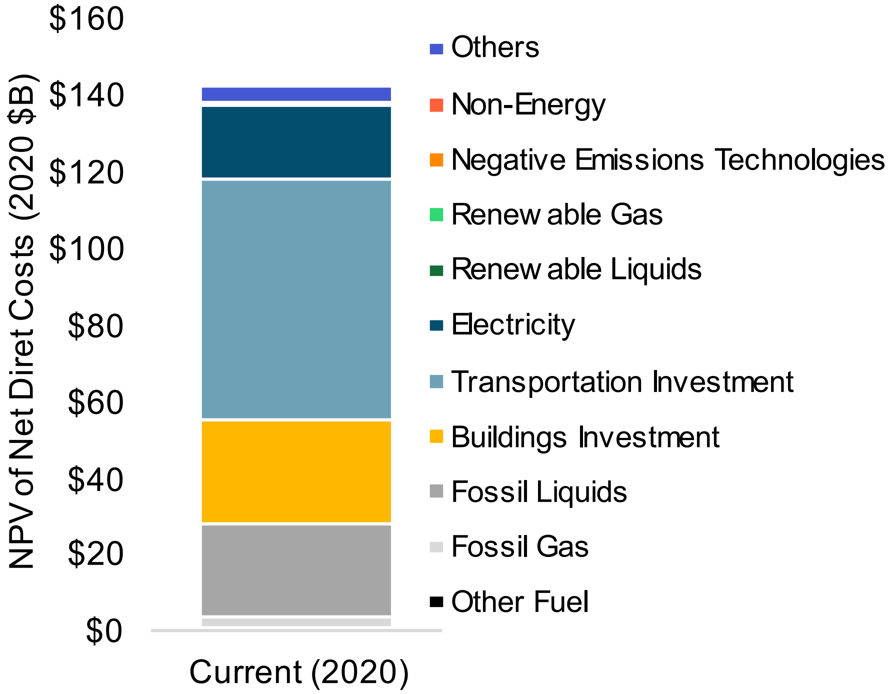
Figure 44. Historical and Projected Population and Gross State Product[46]



System expenditure is an estimate of the costs related to energy consumption in the state, which includes capital investments for energy consuming devices, liquid and gas fuel costs, and costs of in-state and imported electricity generation (Figure 45). While system expenditures are significant, these make up a small share of GSP (8.9% in 2020).

46 NYSERDA Patterns and Trends (2021), Federal Reserve Economic Data (2021), Cornell Program on Applied Demographics

Figure 45. Estimated Current System Expenditure by Category[47]



Total annual energy expenditures are approximately $50 billion, and over half of that amount (almost $30 billion) is estimated to leave New York State. Petroleum fuel expenditures are the largest single category at approximately $24 billion. The transportation sector spends the most on energy services, followed by buildings. Current energy expenditures outline the opportunity for import-substitution through electrification, where a greater share of energy services is provided by in-state resources driving economic activity and job creation.

Integration Analysis Benefit-Cost Approach

The Integration Analysis assessed benefits and costs of the decarbonization scenarios evaluated. The quantified benefits include the value of avoided GHG emissions and avoided health impacts. Cost categories include annualized capital, operations, and maintenance cost for infrastructure (such as

[47] Estimated system expenditures do not reflect direct costs in some sectors that are represented with incremental costs only. These include investments in industry, agriculture, waste, forestry, and non-road transportation

devices, equipment, generation assets, and transmission and distribution) and annual fuel expenses by sector and fuel (conventional or low-carbon fuels, depending on scenario definitions).[48]

Value of Avoided GHG Emissions

All scenarios model significant GHG emissions reductions, which avoid economic impacts of damages caused by climate change. The calculations of value of avoided GHG emissions are based on DEC Value of Carbon guidance, developed under the Climate Act.[49] The value of these avoided GHG emissions is measured in each scenario relative to the Reference Case. GHG emissions were measured using value of avoided carbon dioxide (CO_2), avoided methane (CH_4), avoided nitrous oxide (N_2O), and avoided hydrofluorocarbons (HFCs). For other GHGs, avoided emissions were converted to carbon dioxide equivalent (CO_2e) using the AR5-20year GWP values. The avoided GHG emissions time series in each year was multiplied by the annual social cost of GHG based on the DEC Value of Carbon guidance appendix, using the central case estimate for each GHG (2% discount rate for GHG emissions). When calculating NPV of avoided GHG emissions benefits, NPV calculations assume a discount rate of 3.6%.

Health Co-Benefits

The Integration Analysis also evaluated health benefits of mitigation scenarios relative to the Reference Case. For more information on these analyses, see Section II. Health Co-Benefits Analysis. Three categories of potential health benefits were modeled:

- Improvements in health outcomes due to improved air quality, including reduced incidence of premature mortality, heart attacks, hospitalizations, asthma exacerbation and emergency room visits, and lost workdays[50]
- Public health benefits from increased physical activity due to increased use of active transportation modes (e.g., walking, cycling) while accounting for changes in traffic collisions
- Estimated benefits of energy efficiency interventions in low- and moderate-income homes

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[48] This analysis does not natively produce detailed locational or customer class analysis, but those may be developed through subsequent implementation processes.

[49] The value of avoided GHG emissions calculations is based on DEC guidance: https://www.dec.ny.gov/regulations/56552.html, accessed December 2021

[50] Health benefits are calculated as "High" and "Low." The economy-wide benefits applied the High case and the Low case are included in the uncertainty analysis. For more information see Section II. Health Co-Benefits Analysis

Integration Analysis Costs

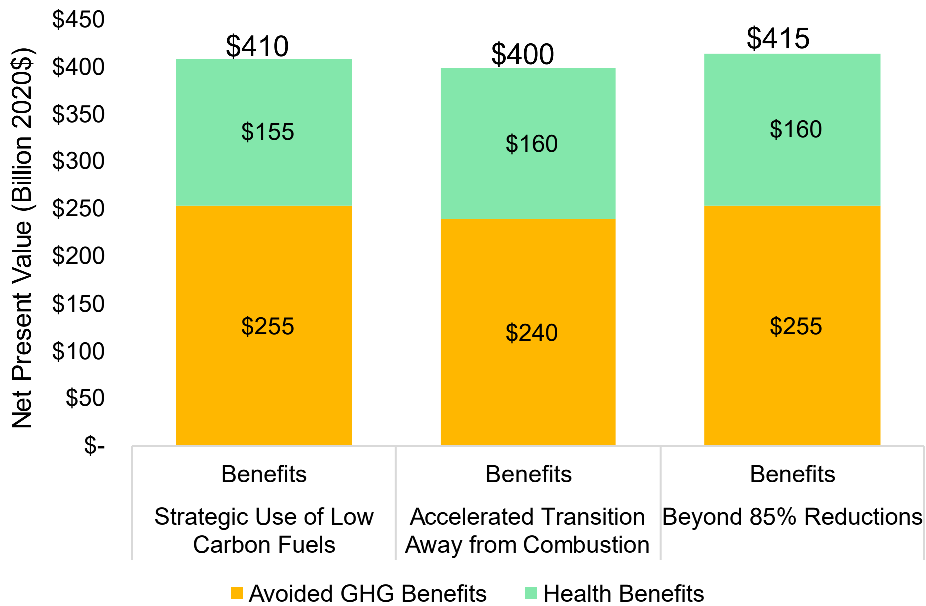
The pathways framework produces economy-wide resource costs for the various mitigation scenarios relative to a reference case. The framework is focused on annual societal costs and benefits and does not track internal transfers (e.g., incentives). Cost estimates do not include estimates of federal funding available as per the Inflation Reduction Act, which is examined as a sensitivity. Outputs are produced on an annual time scale for the state of New York, with granularity by sector. Cost categories include annualized capital, operations, and maintenance cost for infrastructure (e.g., devices, equipment, generation assets, T&D) and annual fuel expenses by sector and fuel (conventional or low-carbon fuels, depending on scenario definitions).[51]

Value of Avoided GHG Emissions and Health Co-Benefits

Reducing GHG emissions in line with Climate Act emissions limits avoids economic impacts of damages caused by climate change equaling approximately $240 to $255 billion. Improved health outcomes, including improvements in air quality, increased active transportation, and energy efficiency interventions in low- and moderate-income homes generate additional benefits ranging from $155 to 160 billion. As shown in Figure 46, collective benefits range from $400 to $415 billion over the next 30 years.

[51] This analysis does not natively produce detailed locational or customer class analysis, but those may be developed through subsequent implementation processes.

Figure 46. Net Present Value of Benefits Relative to Reference Case (2020–2050)



Integration Analysis Costs

The integration analysis includes calculations for three different cost metrics: NPV of net direct costs, annual net direct costs, and system expenditure.

- **NPV of Net Direct Costs:** NPV of levelized costs in each scenario incremental to the Reference Case from 2020-2050. All NPV calculations assume a discount rate of 3.6%. This metric includes incremental direct capital investment, operating expenses, and fuel expenditures.
- **Annual Net Direct Costs:** Net direct costs are levelized costs in a given scenario incremental to the Reference Case for a single year snapshot. This metric includes incremental direct capital investment, operating expenses, and fuel expenditures.
- **System Expenditure:** System expenditure is an estimate of absolute direct costs (not relative to Reference Case). Estimates of system expenditure do not reflect direct costs in some sectors that are represented with incremental costs only. These include investments in industry, agriculture, waste, forestry, and non-road transportation.

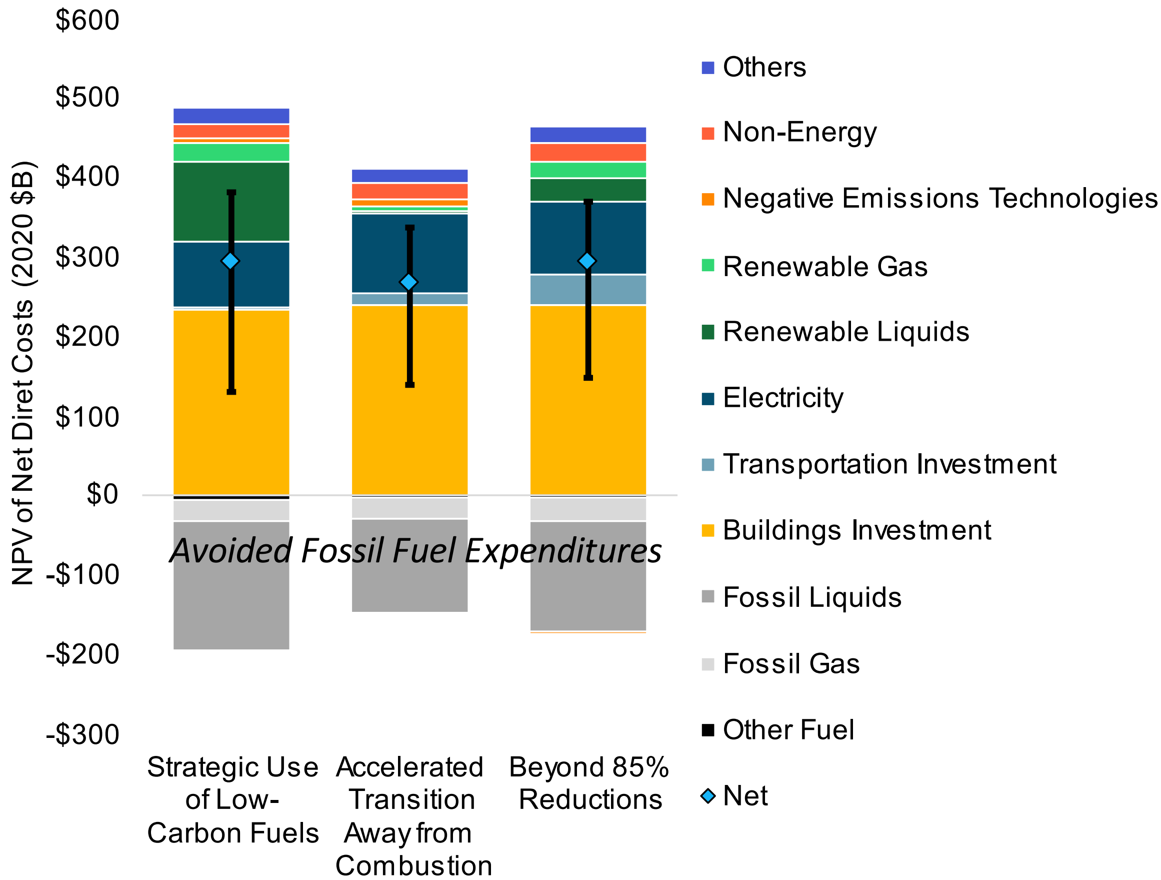
Cost categories included in the metrics listed above are shown in Table 4.

Table 4. Integration Analysis Cost Categories

Cost Category	Description
Electricity System	Includes incremental capital and operating costs for electricity generation, transmission (including embedded system costs), distribution systems, and in-state hydrogen production costs.
Transportation Investment	Includes incremental capital and operating expenses in transportation (e.g. BEVs and EV chargers)
Building Investment	Includes incremental capital and operating expenses in buildings (e.g. HPs and building upgrades)
Non-Energy	Includes incremental mitigation costs for all non-energy categories, including agriculture, waste, and forestry
Renewable Gas	Includes incremental fuel costs for renewable natural gas and imported green hydrogen
Renewable Liquids	Includes incremental fuel costs for renewable diesel and renewable jet kerosene
Negative Emission Technologies (NETs)	Includes incremental costs for direct air capture of CO2 as a proxy for NETs
Other	Includes other incremental direct costs including industry sector costs, oil & gas system costs, HFC alternatives, and hydrogen storage
Fossil Gas	Includes incremental costs spent on fossil natural gas (shown as a negative for cases when Gas expenditures are avoided compared with the Reference Case)
Fossil Liquids	Includes incremental costs spent on liquid petroleum products (shown as a negative for cases when liquids expenditures are avoided compared with the Reference Case)
Other Fuel	Includes incremental costs spent on all other fossil fuels

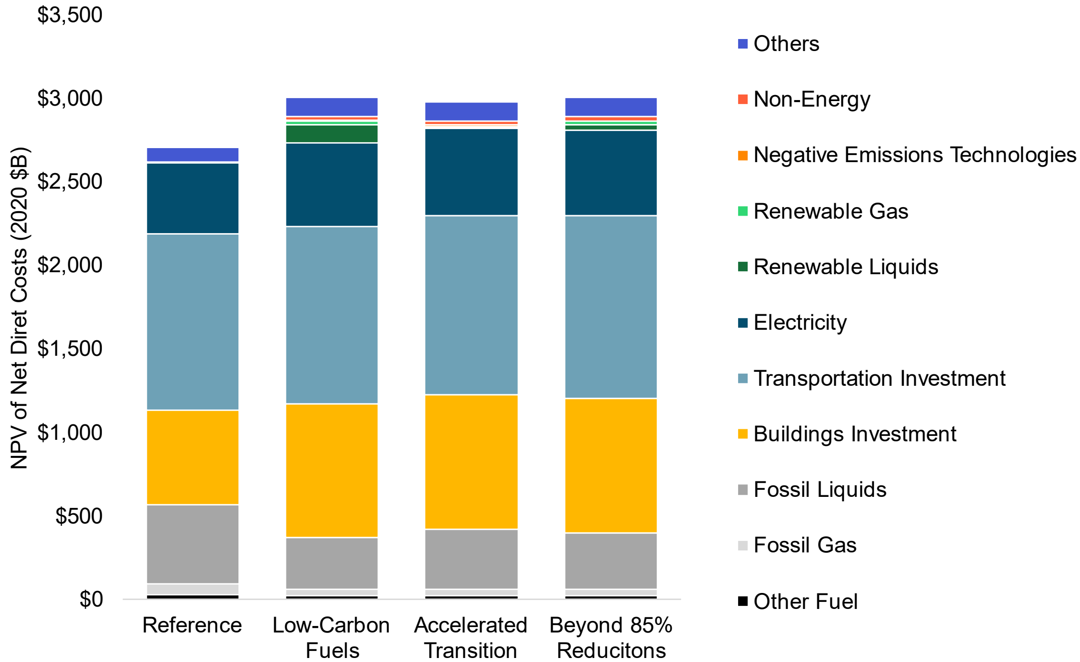
The NPV of net direct costs in Scenarios 2, 3, and 4 are in the same range given uncertainty and are primarily driven by investments in buildings and the electricity system (Figure 47). All scenarios show avoided fossil fuel expenditures due to efficiency and fuel-switching relative to the Reference Case (shown in the chart as negative costs). Scenario 2: Strategic Use of Low-Carbon Fuels includes significant investment in renewable diesel, renewable jet kerosene, and renewable natural gas. Scenario 3: Accelerated Transition Away from Combustion meets emissions limits with greater levels of electrification, which results in greater investments in building retrofits, zero-emission vehicles, and the electricity system. Scenario 4: Beyond 85% Reductions includes additional investment in transportation (rail, aviation, VMT reductions) and methane mitigation, and mitigates the need to invest in any negative emissions technologies. Scenario costs are sensitive to the price of fossil fuels and technology cost projections, as reflected in error bars (Figure 47). The Inflation Reduction Act (not included here) will further reduce net direct costs. More detail on these sensitivities is described in Section 3.5 below.

Figure 47. Net Present Value of Net Direct Costs Relative to Reference Case (2020–2050)



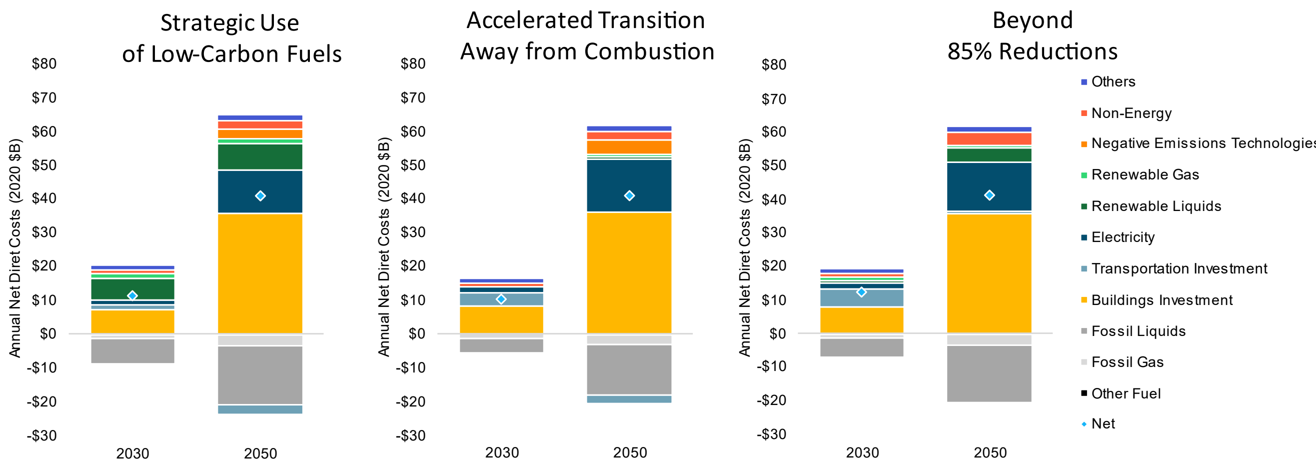
When viewed from a systems expenditure perspective (Figure 48), the NPV of net direct costs for Scenarios 2, 3, and 4 are moderate, roughly 11% as a share of the NPV of reference case system expenditures ($2.7 trillion). Because significant infrastructure investment will be needed to maintain business as usual infrastructure within the state irrespective of further climate policy, redirecting investment away from status quo energy expenditures and toward decarbonization is key to realizing the aims of the Climate Act.

Figure 48. Net Present Value of System Expenditures in Reference Case and Scenarios 2-4 (2020–2050)



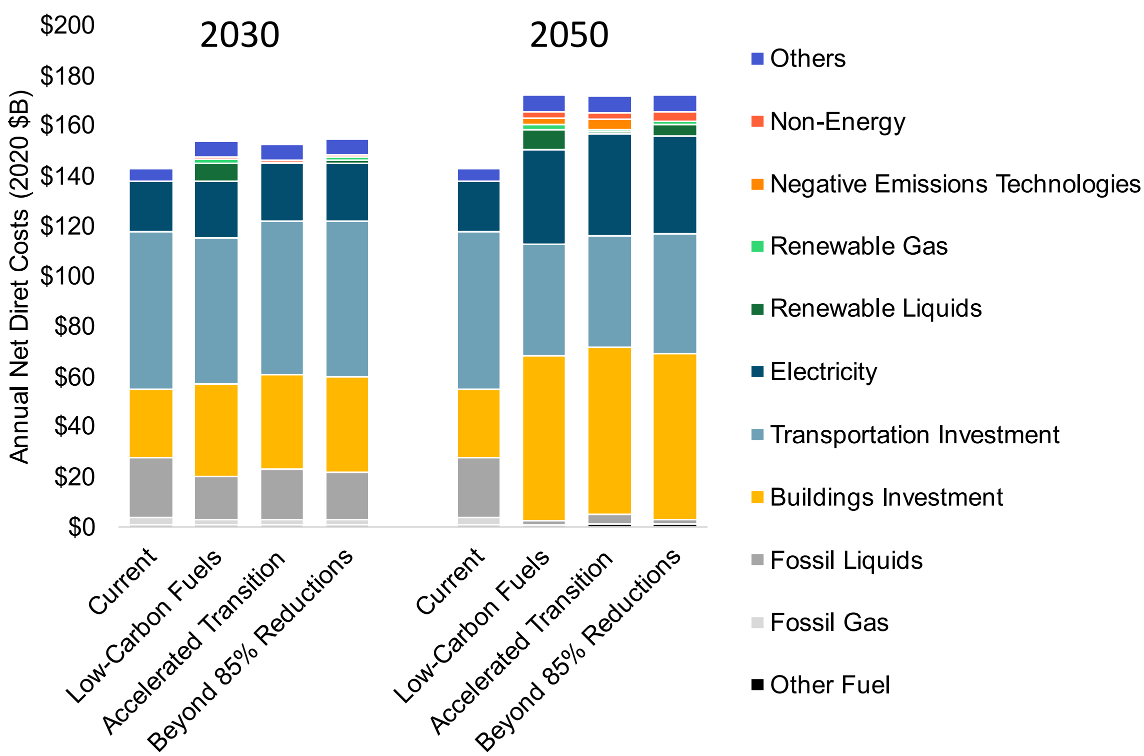
Annual net direct costs show the timing of key investments required to meet Climate Act emissions limits (Figure 49). Scenario 2 includes significant investment in renewable diesel, renewable jet kerosene, and renewable natural gas starting in the mid-2020s. Scenario 3 includes greater levels of electrification compared to Scenario 2, which results in greater investments in building retrofits, zero-emission vehicles, and the electricity system. Scenario 4 layers on even further investments in transportation and non-energy mitigation than Scenario 3 and includes a targeted investment in low-carbon renewable fuels, although not as intensive as that in Scenario 2. Both Scenarios 2 and 3 include investment in negative emissions technologies (NETs) to achieve net zero emissions by 2050, while Scenario 4 does not require any NETs to meet carbon neutrality by 2050. In 2030, annual net direct costs are on the order of $11 billion per year, approximately 0.5% of GSP; in 2050, costs increase to $41 billion per year, or roughly 1.3% of GSP.

Figure 49. Annual Net Direct Costs Relative to Reference Case in Scenarios 2-4



Net direct costs are measured relative to the Reference Case, but system expenditures are evaluated on an absolute basis. System expenditures increase over time as New York invests in infrastructure and clean fuels to meet Climate Act emissions limits. Compared to current estimated system expenditures, cost increases are moderate: 7–8% in 2030 and 20–21% in 2050 (Figure 50).

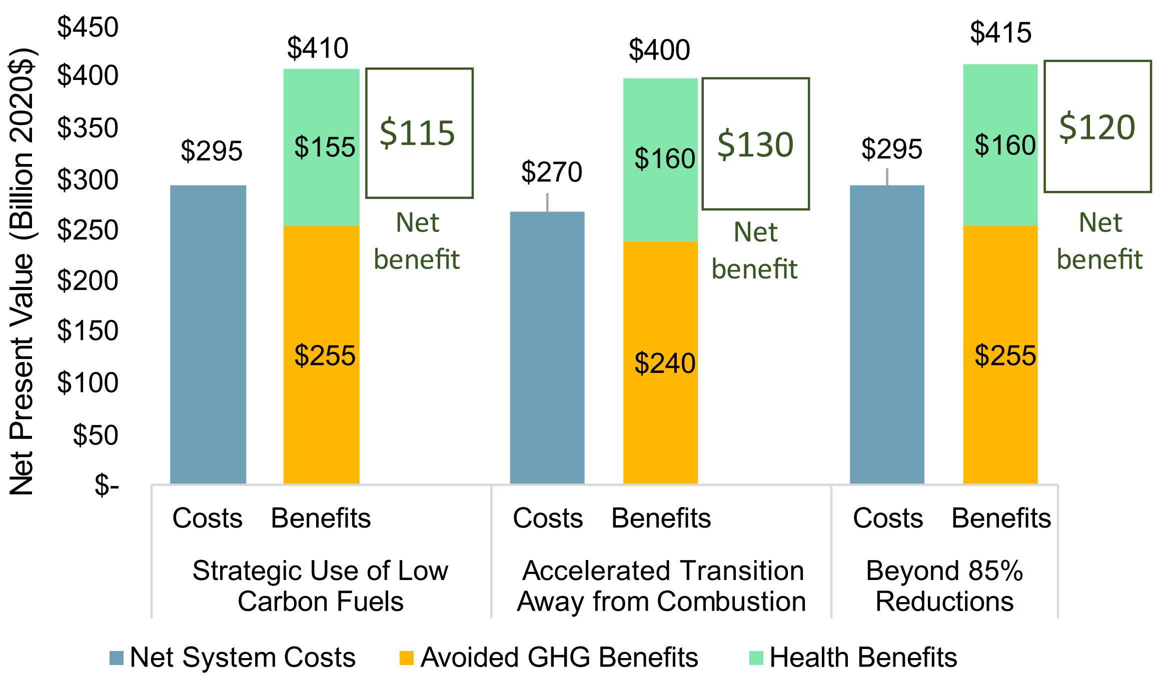
Figure 50. Annual System Expenditures in Scenarios 2-4 (Compared to Current Expenditures)



Benefit-Cost Findings

Aggregating the impacts of benefits and cost analyses, mitigation cases show positive net benefits ($115–$130 billion) when considering the value of avoided greenhouse gas emissions and health co-benefits, in addition to cost savings from reduced fuel use.

Figure 51. Net Present Value of Benefits and Costs relative to Reference Case, Including GHG benefits, Health Benefits, and Net Direct Costs (2020 – 2050)



Key findings from the benefit cost analysis include:

- **Cost of Inaction Exceeds the Cost of Action by more than $115 billion**. There are significant required investments to achieve Climate Act GHG Emissions Limits, accompanied by even greater external benefits and the opportunity to create hundreds of thousands of jobs.
- **Net benefits range from $115–$130 billion**. Improvements in air quality, increased active transportation, and energy efficiency interventions in low- and moderate-income homes generates health benefits ranging from $155 – 160 billion. Reduced GHG emissions avoids economic impacts of damages caused by climate change equaling approximately $240 – 255 billion.

- **Net direct costs are small relative to the size of New York's economy**. Net direct costs are estimated to be 0.5–0.6% of GSP in 2030, and 1.3% in 2050.
- **Realizing the GHG reduction goals of the Climate Act will require New Yorkers to redirect energy system investments and increase them by 10%.** This includes redirecting the over $140 billion New Yorkers spend each year on products and services related to energy consumption, of which over half of the $50 billion spent on fuels and electricity leaves New York.
- **The Inflation Reduction Act will meaningfully reduce net direct costs.** New York could realize up to $70 billion of federal resources in support of the Scoping Plan initiatives through 2050, which would reduce incremental costs to New Yorkers by up to 19%.

3.5 Uncertainty and Sensitivity Analysis

Because there is significant uncertainty in modeling changes to future energy demand and emissions and the benefits and costs associated with these changes, the Integration Analysis team performed a set of uncertainty and sensitivity analyses. This included estimating benefits and costs under a range of different fuel and technology costs and health benefits, evaluating the impact of demand-side measures like load flexibility and ground source heat pump deployment on the electric sector, and estimating the changes electric sector costs from flexibility of electrolysis load and availability of nuclear generating resources.

Inflation Reduction Act (IRA) Analysis

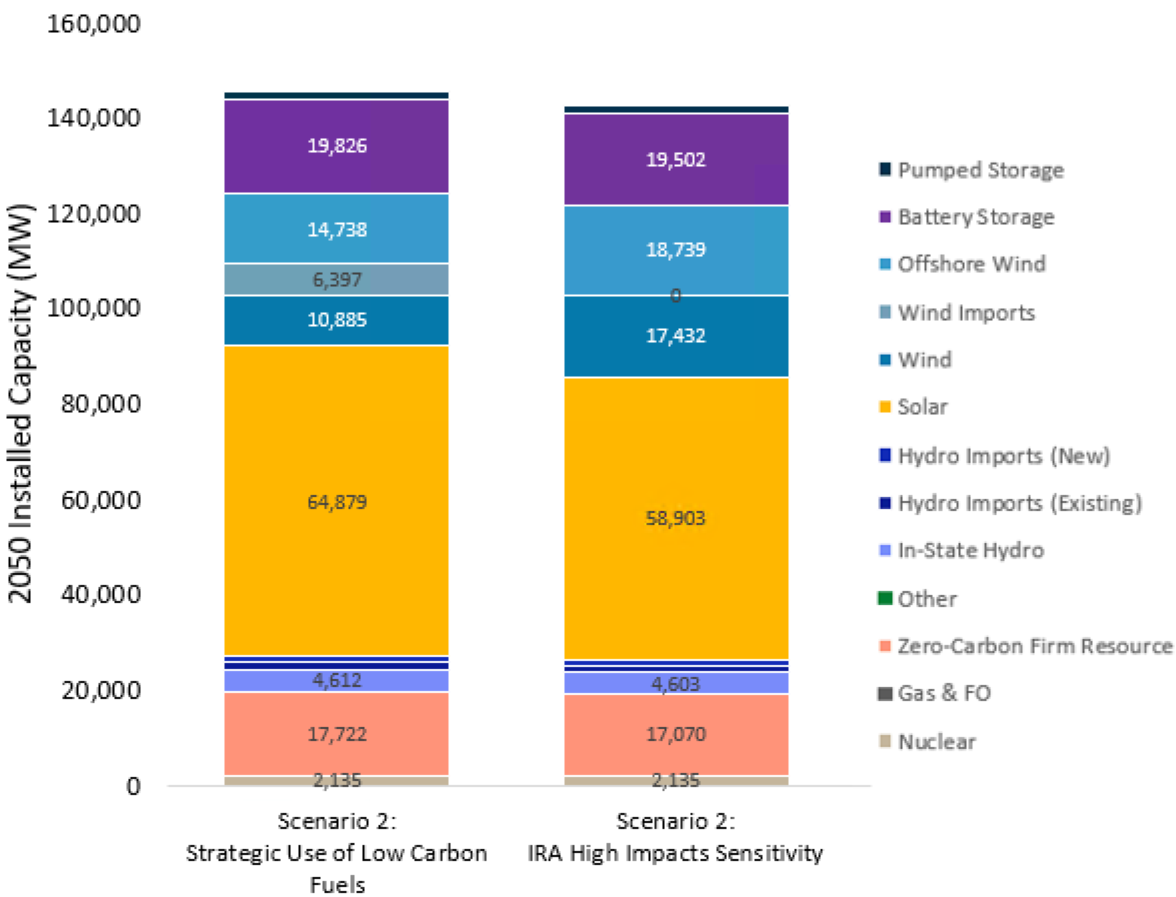
The Passage of the Inflation Reduction Act is a major policy development that will provide important funding that can offset the costs of decarbonization economywide. The full impacts of the Inflation Reduction Act will take additional time to understand in more detail. To provide an initial estimate of the impact of the Inflation Reduction Act to New York, a sensitivity was performed to estimate the federal funding that could be available to offset the cost to achieve CLCPA and the impact of this federal funding on scenario benefit-cost analysis.

The modeling focuses on the largest climate and energy provisions with the clearest implications and considers a range of outcomes to reflect uncertainty in the impact of key parameters (e.g., domestic content provisions, income caps, tax liability). An overview view of the low and high range of benefits modeled is included in Table 5. The Inflation Reduction Act analysis is inherently conservative for several reasons. First, it does not model impacts of funding provisions that were too uncertain to model, e.g., manufacturing grants, early-stage innovation, and block grants which could play an important role in keeping New York on track and driving equitable outcomes. Second, it does not measure the impact of

Inflation Reduction Act on consumer adoption behavior, as it takes as unchanged the level of adoption for demand-side technologies as in the core Integration Analysis scenarios (e.g., sales rate for EVs and HPs) but applies provisions of the Inflation Reduction Act to reduce the cost of these demand-side technologies. Lastly, it is focused only on in-state benefits for a subset of the provisions and certain out of state benefits could accrue to New Yorkers through lower prices. Ongoing analysis will be required as more federal guidance is available and more of the provisions will be feasible to model.

In the power sector, the Inflation Reduction Act's Investment Tax Credit and Production Tax Credit are modeled as a reduction in generating resource cost. High and low sensitivities explore the impact of the duration of the incentive availability and the effect of bonus adders. Electricity system model runs, which incorporate the IRA tax credit provisions, show increased demand for in state wind and offshore wind (Figure 52).

Figure 52 - IRA High Impacts Case Build Results



In the transportation sector, IRA incentives are modeled as offsetting the cost for new light duty, medium duty, and heavy-duty electric vehicle and charger costs. The high and low range reflect different shares of purchases qualifying for incentives which are dependent on a variety of factors including income level for the buyer, vehicle price, domestic content and manufacturing for the vehicle, as well as location (e.g., within rural or DAC census tracts) of the chargers. Reduced vehicle and charger costs provide a benefit of $3–$19 billion, though uncertainty remains around supply chain ability to meet domestic content and production requirements, especially in the near term.

Building sector incentives offset the costs for energy efficient building shells and air source and ground source heat pumps. These credits are highly variable, dependent on the purchase price of technologies, the marginal tax rates for building owners, renter versus ownership status, the type of building, the level of energy efficiency which the devices achieve, change in energy use intensity achieved by the updated technologies, and prevailing wage requirements. The low and high range reflect different impacts of these parameters. In addition to these technology-specific credits, grant programs, such as HUD grants, are estimated according to New York's population-weighted share of the US population. Buildings sector incentives reduce the cost of transition to an efficient, electrified building stock by $7–$11 billion, with additional grants for low-income participants helping to ensure broader adoption and further increase benefits.

Other estimated benefits include incentives for carbon capture and sequestration (CCS) and the expanded hydrogen and advanced clean fuel production tax credits. For the CCS credit, there is a range of credits available depending on size of project, prevailing wage requirements, and construction date. The clean fuel tax credits, applied to both renewable diesel and renewable natural gas, vary depending on the carbon intensity of the produced fuel and prevailing wage providing an additional bonus credit. Clean fuel credits were applied to the estimated share of in-state fuel production in the 2025–2027-time frame per the Inflation Reduction Act eligibility requirements, with a low and high range with varying assumptions on share of fuels which receive the bonus prevailing wage credit. There is considerable uncertainty regarding the impact of the production tax credit available for hydrogen production, given that it phases down in 2032 while hydrogen demand in New York State is modeled to increase significantly between 2030 and 2050. This analysis assumes that there is sufficient PTC-eligible hydrogen supply to meet 2040 demand quantities, and that the remainder of hydrogen demand in 2040 onwards is met with hydrogen supply that is not eligible for the PTC. The total costs of hydrogen consumption in New York State in each year are costed using a weighted average of PTC-eligible costs and post-PTC costs. These incentives for hydrogen and advanced renewable fuels can provide $4–16 billion.

Table 5. Key Modeling Assumptions in Inflation Reduction Act Sensitivity

Sector	Lower Benefit	Higher Benefit
Electric Generation	Credits Investment and Production Tax Credit available through 2032 plus safe harbor Projects only qualify for prevailing wage bonus	Credits Investment and Production Tax Credit available through 2042 plus safe harbor In addition to prevailing wage bonus, some additional benefit from low-income and domestic content bonuses
Buildings	Credits and grants available through 2032 for EE and heat pumps Lower program uptake reflecting lower share of buildings eligible for energy efficiency and/or electrification credits	Credits and grants available through 2032 for EE and heat pumps Higher program uptake reflecting higher share of buildings eligible for energy efficiency and/or electrification credits
Transportation	Credit for vehicles and chargers Lower uptake, less compliance with sourcing provisions, fewer chargers in low-income or non-urban tracts	Credit for vehicles and chargers Higher uptake, more compliance with sourcing provisions, more chargers in low-income or non-urban tracts
Alternative Fuels	Production tax credit for H_2, in-state renewable fuel production Lower uptake of credit reflecting uncertainty in carbon intensity, prevailing wage requirements	Production tax credit for H_2, in-state renewable fuel production Higher uptake of credit reflecting uncertainty in carbon intensity, prevailing wage requirements
Other Sectors	Not modelled	Not modelled

The Inflation Reduction Act could reduce the costs to New York to meet the requirements of the CLCPA by $41–$69 billion, with a diversity of sectors accruing benefits (Figure 54). As a result, the Inflation Reduction Act increases net benefits of the Mitigation Scenarios by up to $50 billion, compared to the core 2022 net benefit results (Figure 53).

Figure 53. Inflation Reduction Act Sensitivity Higher Net Benefits

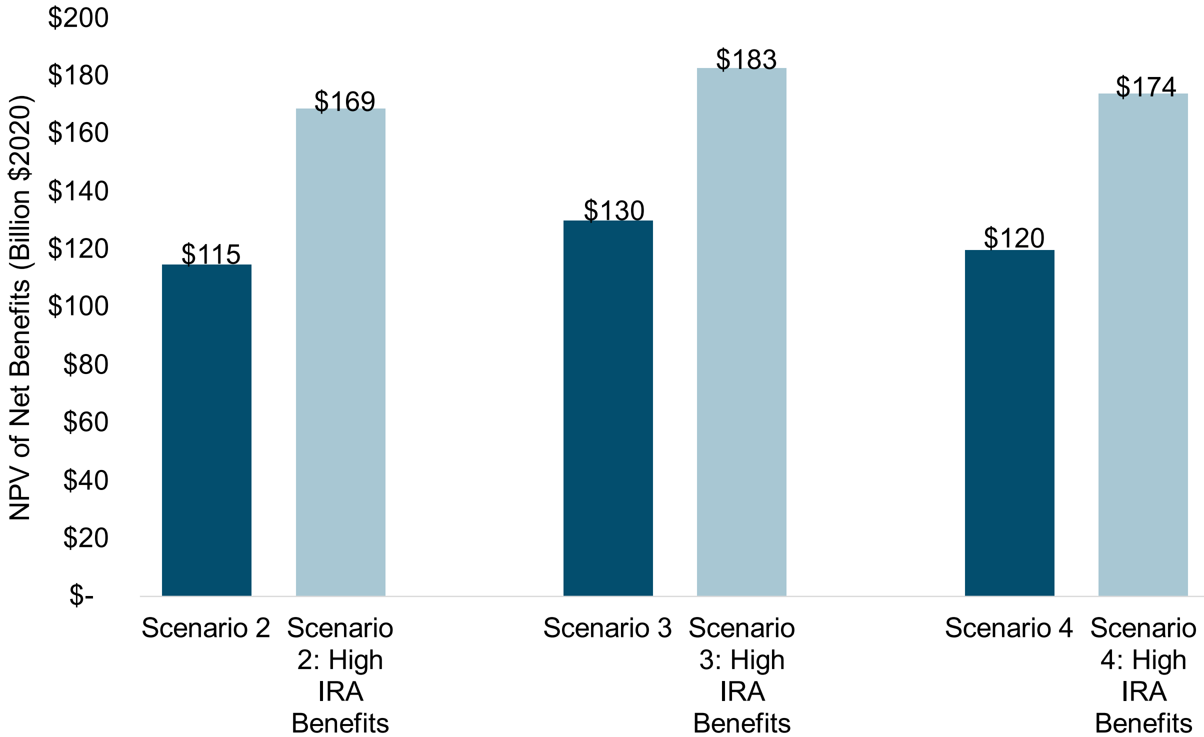
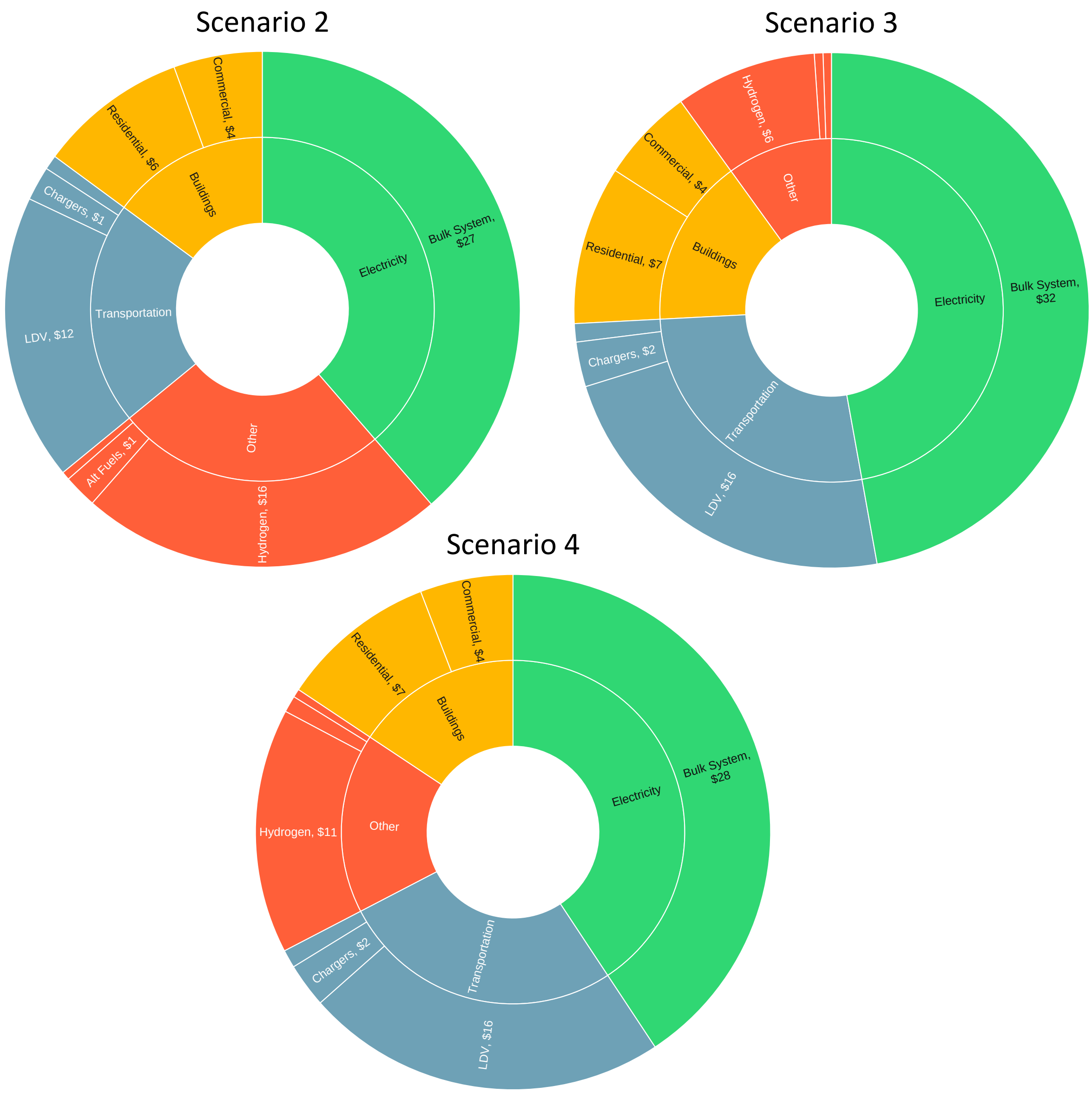


Figure 54. Inflation Reduction Act Sensitivity High Benefits



Benefits and Costs Sensitivity Analysis

There is significant uncertainty in the value of costs and benefits of the Mitigation Scenarios, so to help characterize this uncertainty, the Integration Analysis team measured a range of net costs by varying the prices of fuels and key input technologies. Uncertainty bounds for the costs of Scenarios 2 through 4 were evaluated using a range of values for fossil fuel prices, biofuels prices, technology costs, and a sensitivity layering all these together.

For fossil fuel prices, low and high ranges were taken from the Energy Information Administration's 2022 Annual Energy Outlook Report, specifically the High Oil and Gas Supply case (low fossil fuel prices) and Low Oil and Gas Supply case (high fossil fuel prices); see Figure 55 for natural gas and diesel price range. When varying fossil prices within this range and holding other fuel and technology costs constant, the NPV of the net direct costs for Scenarios 2 through 4 changes between 7–8% increase to 12% decrease depending on the scenario (Figure 56).

Figure 55. Fuel Price Sensitivity: Natural Gas and Diesel Price Range

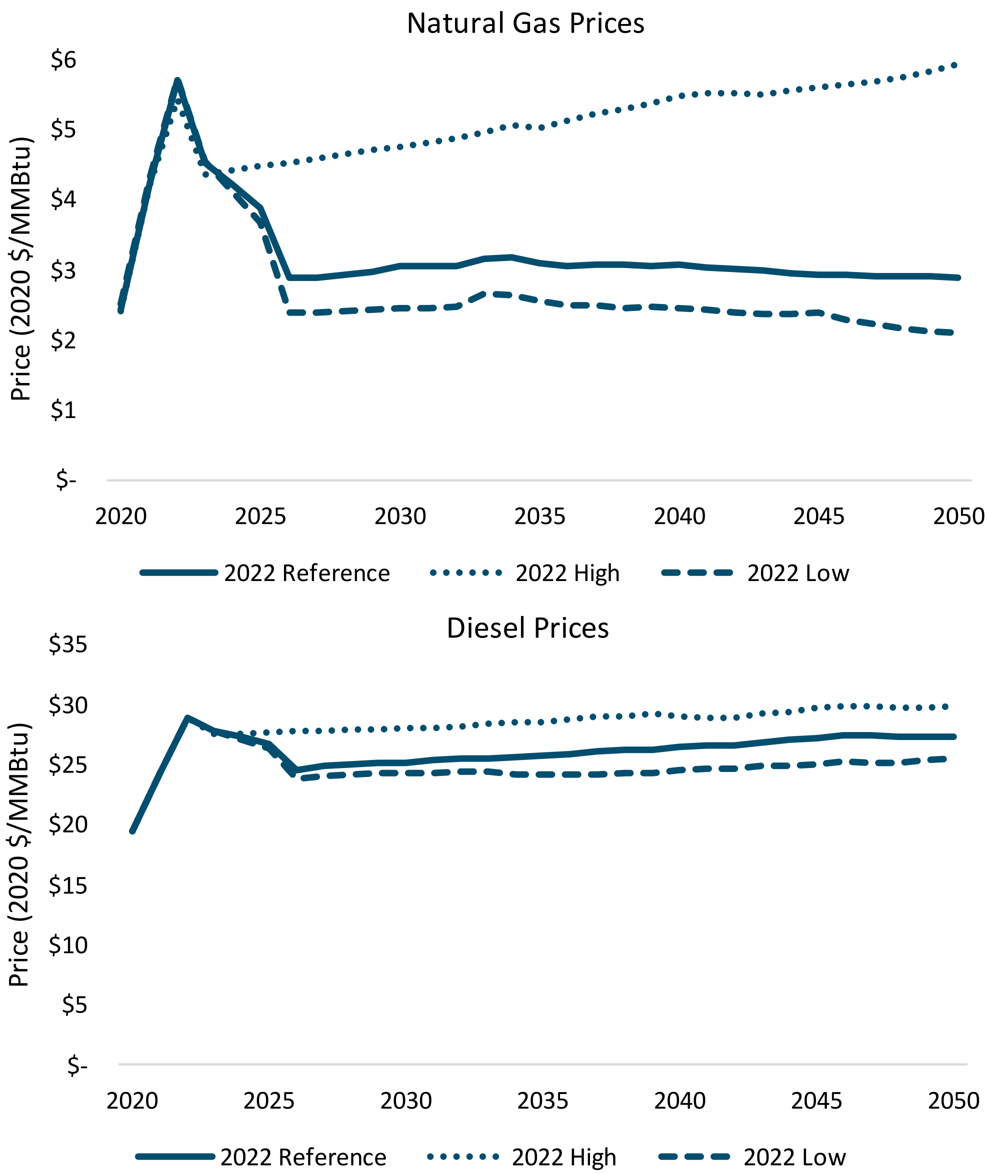
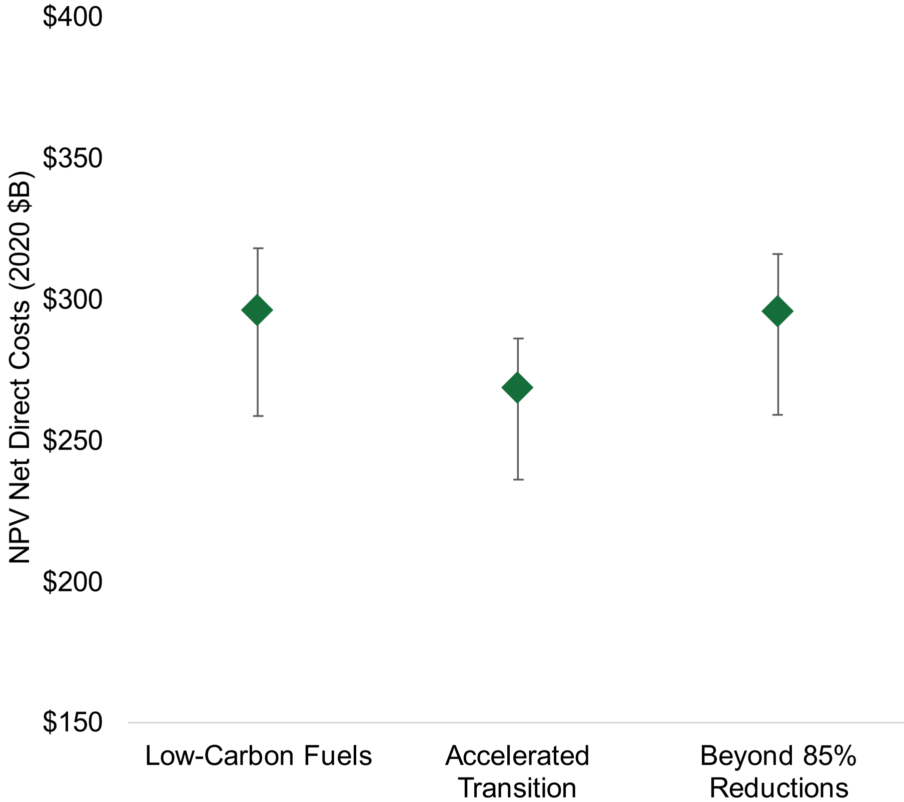
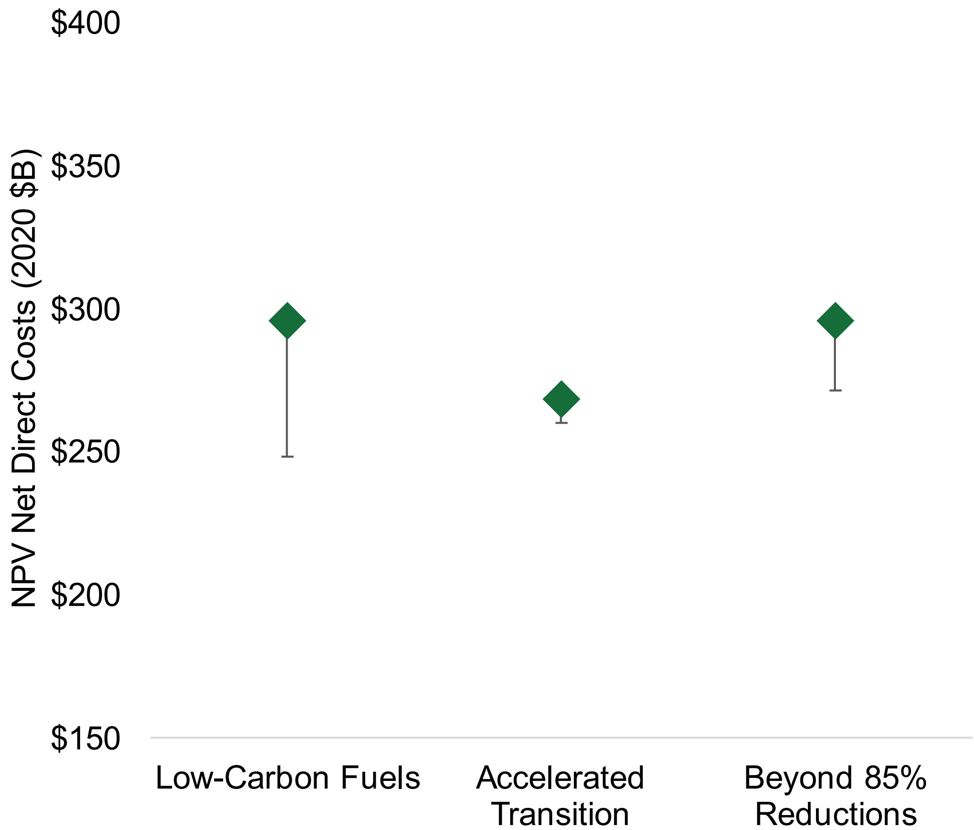


Figure 56. NPV of Scenario Net Direct Costs: Fuel cost sensitivity for Scenarios 2 through 4



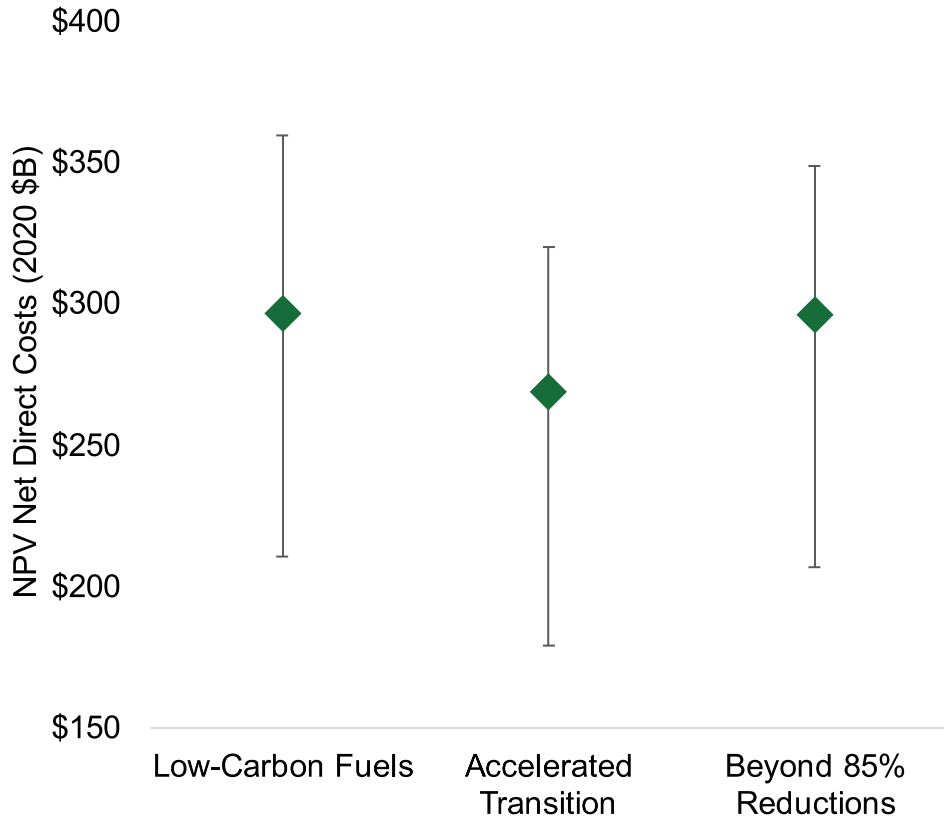
For biofuels prices, a lower price range was estimated assuming high innovation in biofuels production drives down costs. This is represented in the cost calculation as biofuels being sold at average production cost, rather than all biofuels being sold at marginal clearing prices. As shown in Figure 57, this change in biofuels prices only significantly affects Scenarios 2 and 4, where the NPV of net direct costs decline by 8 to 16%.

Figure 57. NPV of Scenario Net Direct Costs: Biofuel cost sensitivity for Scenarios 2 through 4



For technology costs, a higher and lower cost range was estimated for key demand-side technologies and a lower cost range was estimated for supply-side technologies. The demand-side technologies affected include electric heat pumps, efficient building shells and retrofits, battery electric vehicles, electrolyzers for hydrogen production, and direct air capture (DAC) equipment. Specific technology prices can be found in Annex 1. On the supply-side, lower cost trajectories for wind, solar, and storage technologies were used from NREL's Annual Technology Baseline (ATB). The result is a range, with up to 18 to 21% increase and 32 to 38% decrease in the NPV of net direct cost depending on scenario, as shown in Figure 58.

Figure 58. NPV of Scenario Net Direct Costs: Technology cost sensitivity



Finally, a single sensitivity was run using a range of fossil costs, biofuel costs, and technology costs, combining the sensitivities described above. The NPV of the net benefits of this sensitivity is shown in Figure 59. The analysis includes uncertainty in fuel prices and technology costs. Note that this graphic does not include the net benefits which would be accrued due to the Inflation Reduction Act; incorporating this could raise the bounds of the net benefits shown below on the order of $50 billion.

Within this range, two priority sensitivities were run in 2022 that were relevant to global supply chain disruption and fuel market volatility: a high fuel price sensitivity (which is a subset of the fuel price sensitivity discussed above), and a targeted high technology cost sensitivity (which is a subset of the technology cost sensitivities discussed above).

The high fuel price sensitivity evaluated the effects of the potential for persistently higher fossil fuel prices. The high fossil fuel prices increase the costs of all cases, with the largest increase in costs occurring in the Reference Case where a higher share of consumption remains fossil. This dynamic increased the net benefit of the mitigation scenarios by $33–$38 billion compared to the original runs, which underscores the value of a transition to renewables to reduce exposure to higher fossil fuel price (Figure 60). The targeted high technology cost sensitivity was developed to explore the effects of higher prices for clean buildings and transportation technologies from near-term supply chain issues that could persist. These higher technology costs would particularly increase the costs of the mitigation scenarios, which have higher adoption of heat pumps and electric vehicles. This would reduce the net benefits of the mitigation scenarios by $34–42 billion compared to the Reference Case (Figure 61). Even under this targeted high technology cost sensitivity, all mitigation scenarios see significant net benefits relative to the Reference Case, and these net benefits would be significantly increased with inclusion of the Inflation Reduction Act .

Figure 59. NPV of Net Benefit of Mitigation Scenarios (2020-2050): Range Including Uncertainty in Fuel Cost, Technology Cost (not including IRA)

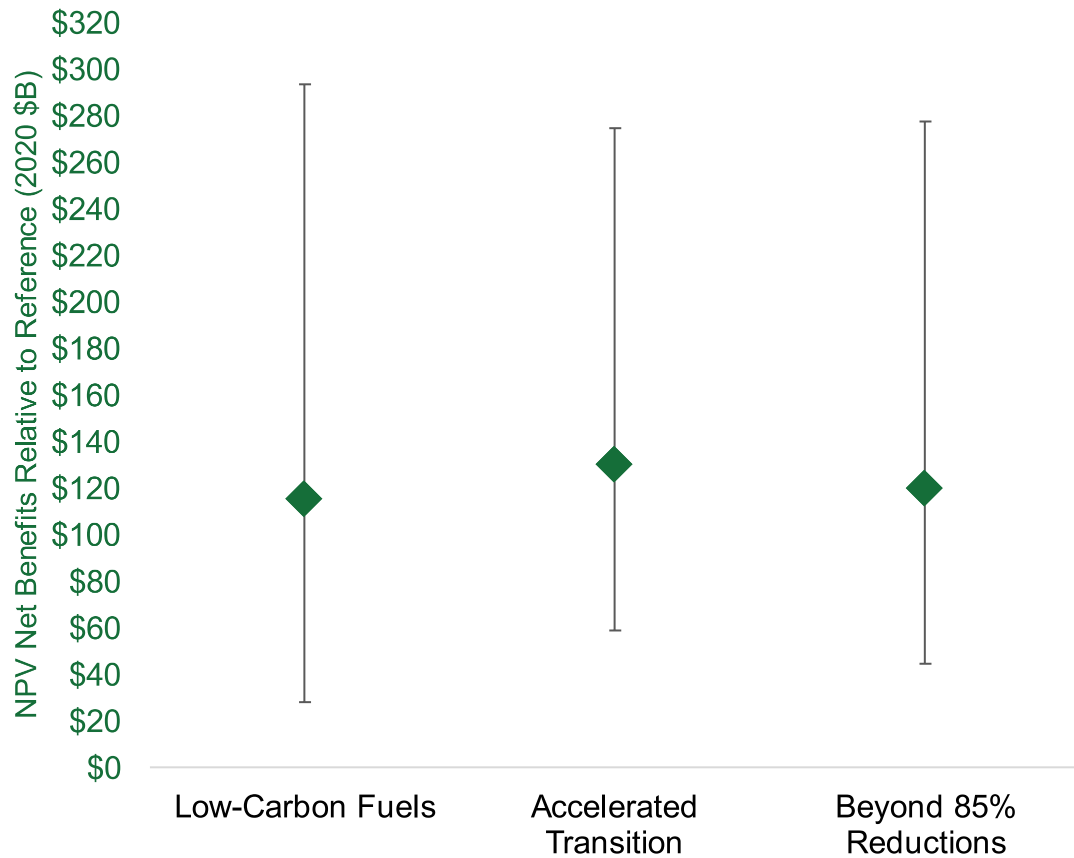


Figure 60. Net Benefits: High Fuel Price Sensitivity

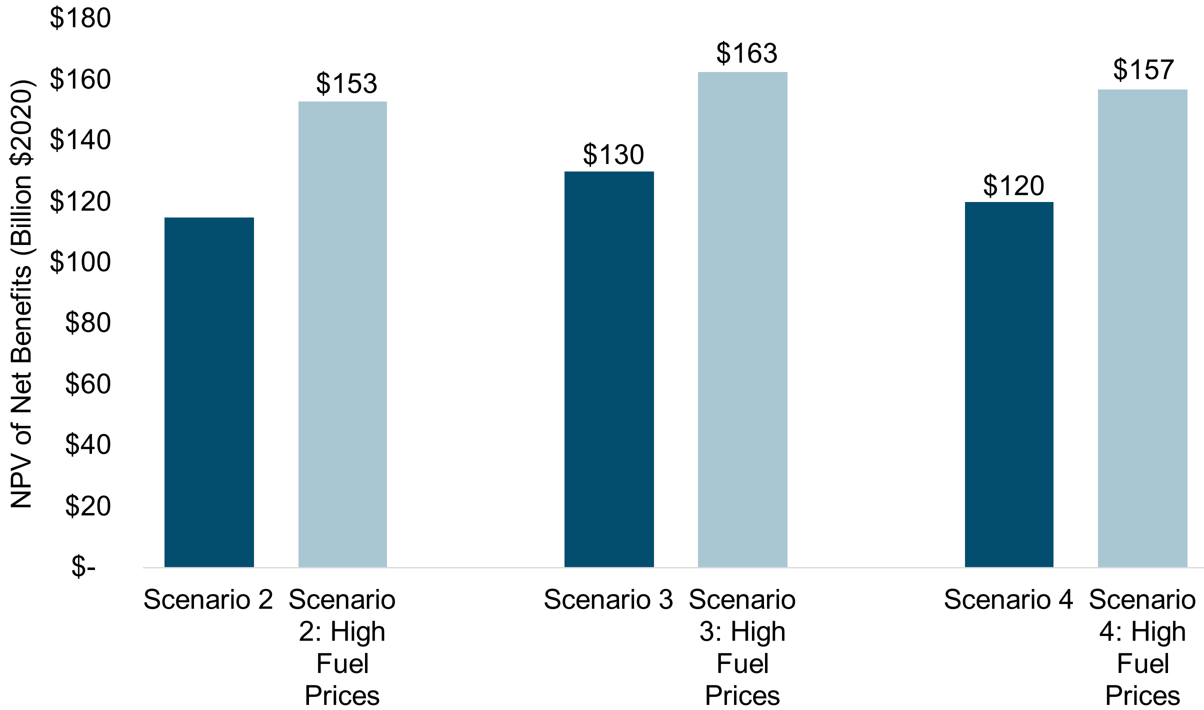
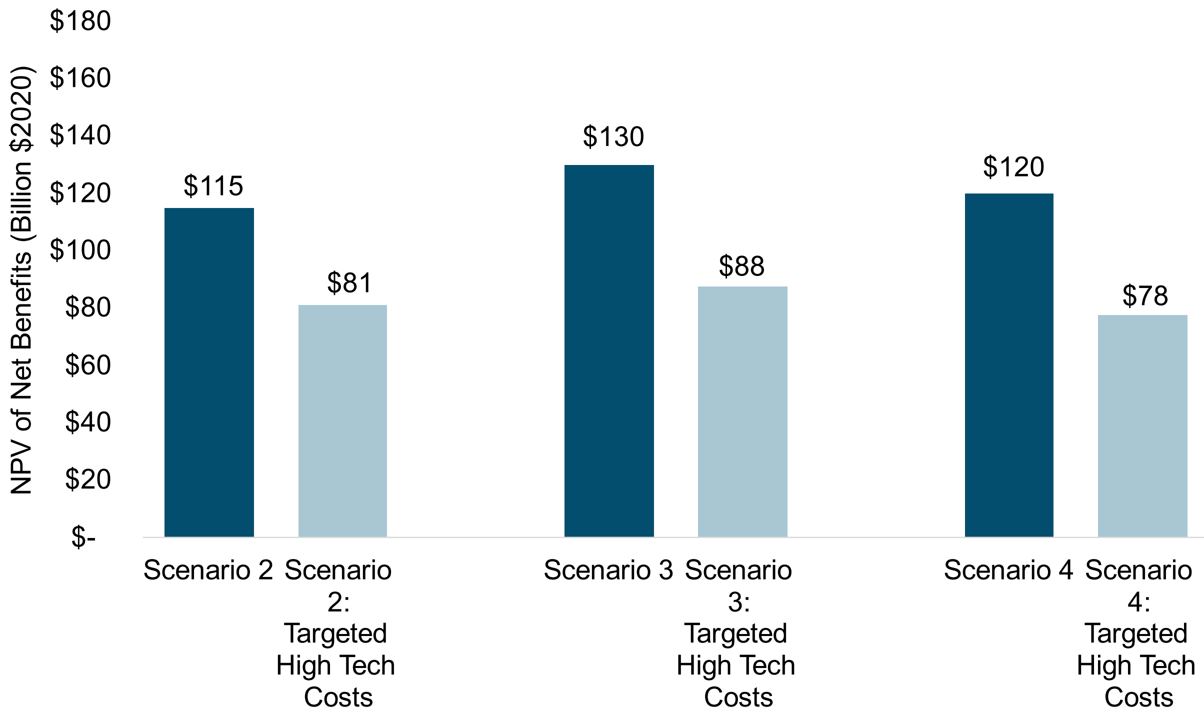


Figure 61. Net Benefits: Targeted High Technology Cost Sensitivity



Electric Sector Sensitivities

The following section details the system cost and resource mix impacts of varying assumptions in the electric sector. Additional modeling of the electricity system was performed to examine the changes on overall resource builds and system operations that would result from changes to key inputs and assumptions.

Firm Capacity Sensitivity Analysis

Across a wide range of technology cost and fuel price sensitivities, New York is projected to power more than 90 percent of its electricity demand with renewable power from wind, solar, and hydro resources. Firm zero-carbon resources will be critical to providing the remaining 5–10% of demand during times of low wind and solar output and/or high demand.

This analysis examined several sensitivities regarding the availability of both existing and new technologies to meet remaining electricity needs. The analysis detailed below (and illustrated in Figure 62) focuses on sensitivities performed on Scenario 3. The cost assessment compares the costs of each sensitivity relative to a version of the Reference Case that controls for electrification loads, to isolate the impacts of changes in the resource mix from changes in overall demand.

Under the primary assessment of Scenario 3, to facilitate a transition away from combustion in the electric sector, all existing fossil fuel resources are retired by 2040, and no new combustion-based resources are built (e.g., combustion turbines or combined cycle new firm capacity needs are met with a resource that avoids combustion and local air pollution).[52]

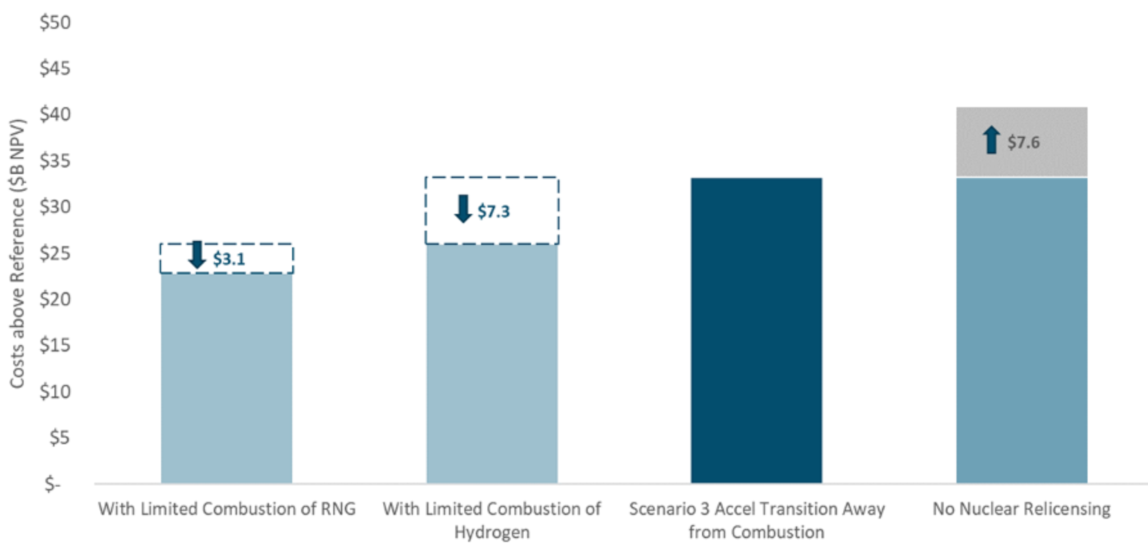
The overall electric system costs of Scenario 3 relative to a Reference Case, controlling for electrification loads, is $33 billion on an NPV basis over the 2020–2050 forecast period. The sensitivity analysis also examined a scenario in which upstate nuclear units do not receive license extensions and are retired at the end of their 60-year lifetimes; this places additional pressure on the New York system by (1) increasing the amount of zero-carbon energy needed from new renewable resources and (2) increasing the amount of new firm capacity that is needed to replace the energy and reliability contributions of nuclear generation

[52] For the purpose of the cost analysis, this resource was assumed to be a hydrogen fuel cell; however, the need could be met by a number of emerging technologies. Analysis of long-duration (100-hour) battery storage is detailed in Chapter 9.

during times of low renewable output. Retiring the upstate nuclear units at the end of their 60-year licenses would increase costs by $7.6 billion relative to Scenario 3.

The modeling also included sensitivities in which limited combustion of zero-carbon fuels such as hydrogen or renewable natural gas is used to meet firm capacity needs, similar to the assumptions in Scenarios 1, 2, and 4. Shifting from fuel cells to hydrogen combustion resources would reduce costs by about $7 billion relative to Scenario 3. Utilization of renewable natural gas (RNG), which is expected to be a cheaper fuel than hydrogen, would further reduce costs by about $3 billion, or $10 billion below Scenario 3.

Figure 62. Cost Impacts of Firm Capacity Sensitivities[53]



Load Flexibility Sensitivity Analysis

The analysis also examined the impacts of dynamic end-use flexibility on resource builds and resulting system costs. Dynamic usage can serve as a key strategy to help manage the peak load impacts of electrification, if customers are able to shift their consumption patterns in response to real-time price signals from the grid operator.

[53] The costs presented represent the costs relative to a Reference Case with equivalent levels of electrification loads, and as a result are not directly comparable to the electric sector costs presented in the economy-wide analysis, in which costs are measured relative to a Reference Case with Reference loads.

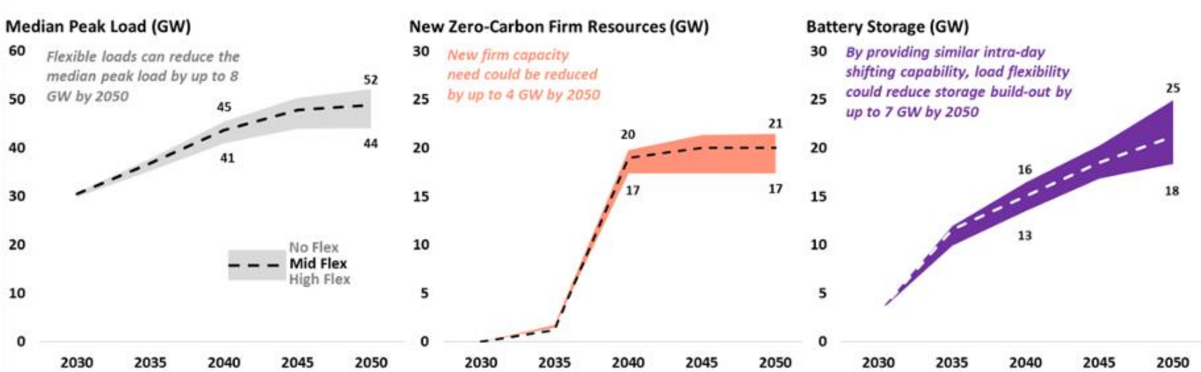
The Mitigation Scenarios each assume that light-duty electric vehicle charging is the primary focus of strategies to enable price-responsive load, and that by 2050 25% of LDV loads are shiftable within the day (while still constrained by customer driving behavior).

The analysis examined a "Low" sensitivity in which LDV loads are not dynamically managed, as well as a "High" sensitivity, in which 50% of LDV loads are flexible, and up to 60% of building end-uses are also capable of price-responsiveness, with the level of flexibility and hours of shift varying by end use. Detailed assumptions by end use for each sensitivity can be found in Annex 1.

In the Low Flexibility case, system peaks increased by over 3 GW by 2050 relative to Scenario 3, and in the High Flexibility case, dynamic end-use flexibility further reduced system peaks by nearly 5 GW by 2050 relative to Scenario 3, with system peaks ranging between 45 and 53 GW across the sensitivities.

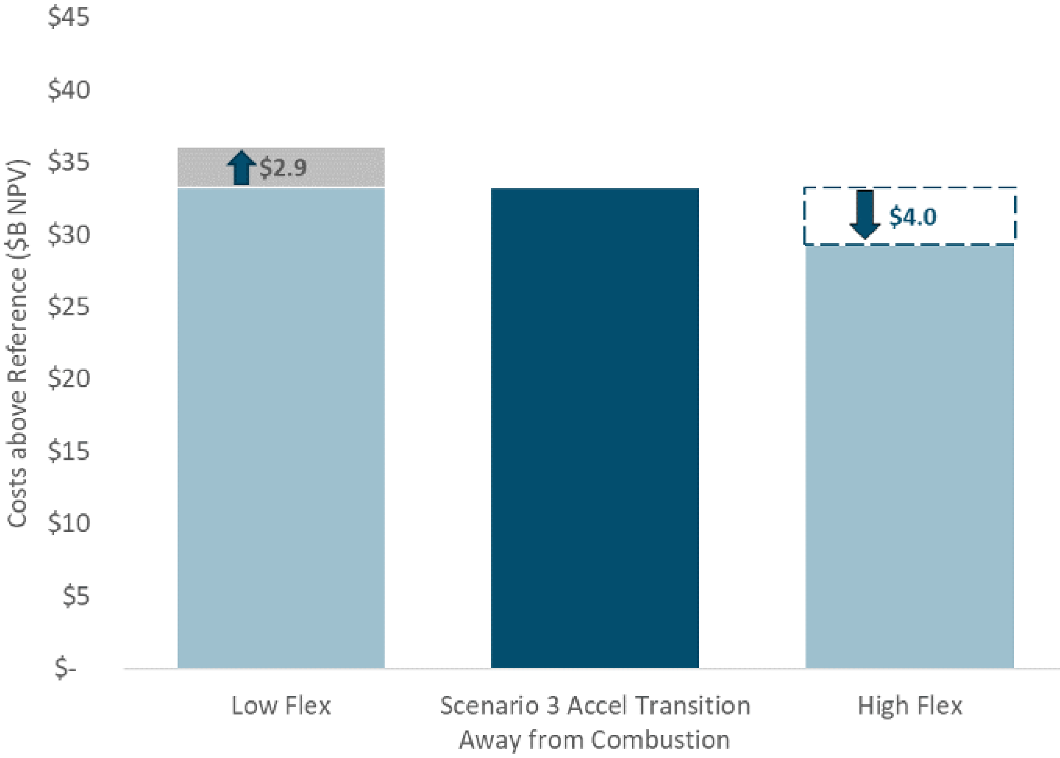
As a result of changes in end-use flexibility and resulting load impacts, the primary impacts on the electric system resource mix were the amounts of firm capacity and battery storage built by 2050. Increased amounts of end-use flexibility resulted in lower builds of new zero-carbon firm capacity, with firm zero-carbon capacity in 2050 ranging between 17 GW in the High Flexibility case to 21 GW in the Low Flexibility case. In addition to reducing peak demands, flexible loads also provide similar intra-day shifting services as battery storage, by moving customer demand to times of high renewable output. As a result, battery storage was the resource that was most impacted by flexible load assumptions, with storage capacity in 2050 ranging between 18 GW in the High Flexibility case to 25 GW in the Low Flexibility case.

Figure 63. Electric System Resource Mix Impacts of Load Flexibility



Driven by the changes in system needs and resource builds, the Low Flexibility case in turn leads to increased costs of $2.9 billion on an NPV basis, relative to Scenario 3. In the High Flexibility case, as a result of lower system needs and resulting declines in firm capacity and storage builds, system costs were reduced by $4 billion on an NPV basis relative to Scenario 3.

Figure 64. Cost Impacts of Flexible Load Sensitivities[54]



In-State Electrolysis Sensitivity Analysis

In each of the modeled pathways, New York is projected to rely on hydrogen usage as a key strategy to decarbonize sectors and applications that are difficult to electrify, in particular freight transportation, with consumption ranging between 120–180 TBtu across scenarios in 2050 (for more details, see the "Role of Hydrogen" section). All of New York's hydrogen demand is met with "green hydrogen," produced using electrolysis powered by renewable energy. For this analysis, the central assumption is that New York produces 50% of its hydrogen needs in-state and imports the remainder with cost assumptions for that imported remainder consistent with "green hydrogen" production. In addition, a sensitivity was performed

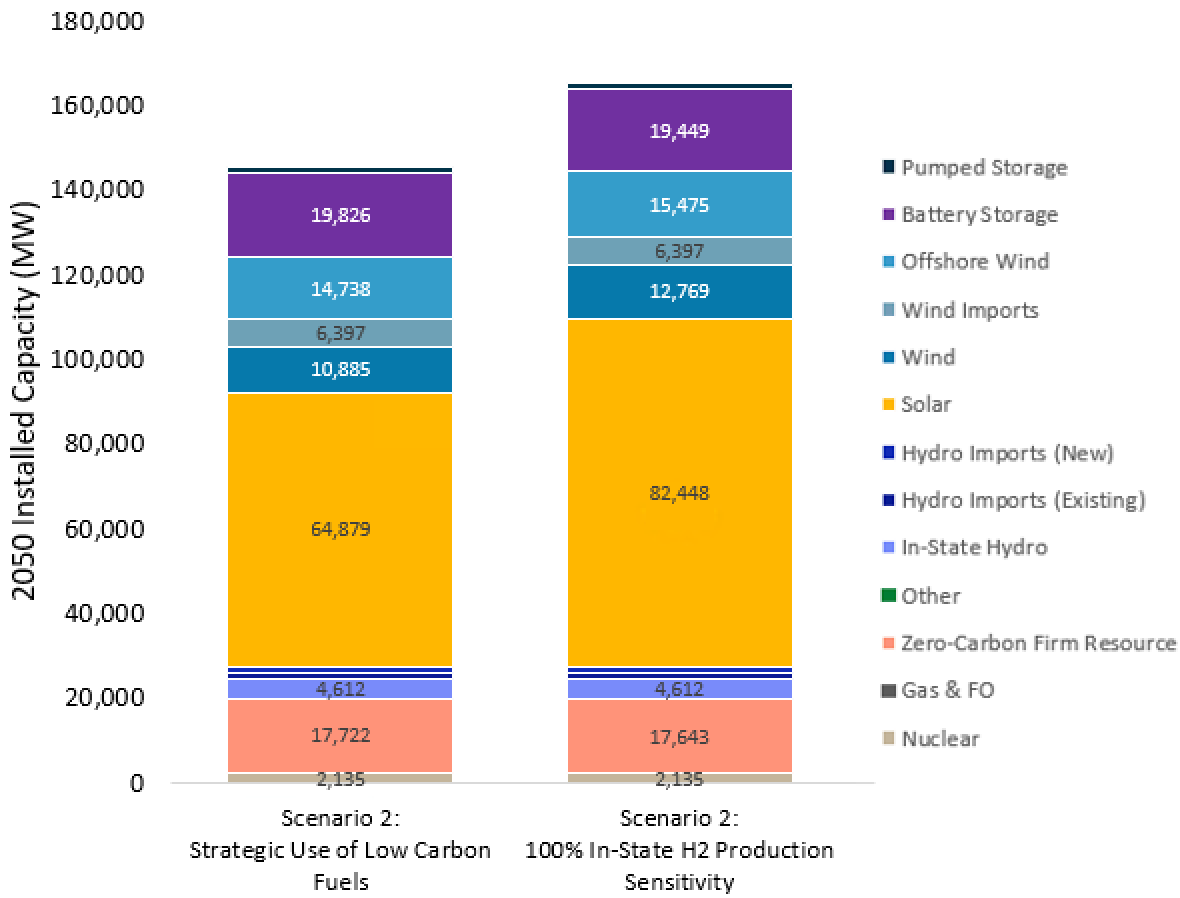
[54] The costs presented represent the costs relative to a Reference Case with equivalent levels of electrification loads, and as a result are not directly comparable to the electric sector costs presented in the economy-wide analysis, in which costs are measured relative to a Reference Case with Reference loads.

on Scenario 2 to examine the impacts on the electric system resource mix of an alternative assumption of producing all (e.g., 100%) of New York's hydrogen demand in-state.

In Scenario 2, which has the highest reliance on hydrogen of the four scenarios, increasing in-state electrolysis loads to meet all of New York's hydrogen demand results in total electricity demand of over 350,000 GWh by 2050, with over 80,000 GWh of electrolysis loads needed to produce hydrogen.

The additional electrolysis loads in turn require additional dedicated renewables, with 1,800 MW of new onshore wind resources and 17,600 MW of new utility-scale solar developed to power the electrolyzers. The total in-state wind and solar capacity in the sensitivity analysis reaches 12,800 MW and 82,400 MW, respectively. The 2050 resource mix of this sensitivity is provided in comparison to the Scenario 2 resource mix in Figure 65 below.

Figure 65. 2050 Installed Capacity, Scenario 2 and 100% In-State Hydrogen Production Sensitivity



Buildings Peak Sensitivity Analysis

A series of building sensitivities were performed to examine the implications of unmanaged load growth and the potential impacts of more widespread ground source / district loop heat pumps (GS/DHP) to help reduce electric grid system impacts from more and less managed electrified space heating, meaning more or less peak reduction from behavioral conservation, heat pump efficiency, and building shell heating demand reduction. These sensitivities were built off and compared to Scenario 2, which is labeled "Managed Electrification" in Table 6.

One sensitivity was a managed electrification sensitivity in which all measures were the same as in Scenario 2 except for the relative share of heat pump technologies, with an increase in ground source/district heat pump systems and a reduction in the share of air source heat pumps; this is the "Managed with GS/DHP" sensitivity described in Table 6. This sensitivity represents a worldview in which ground source/district heat pump systems help reduce electric grid system impacts from more managed electrified space heating. The sensitivity includes an assumption of increasing ground source and district heat pump market penetration over time, with 40% of heat pump sales being assumed to be ground source/district heat pumps by 2035, 60% by 2040, and 80% by 2045. In addition to this managed electrification sensitivity, two unmanaged electrification sensitivities were run, which included much less aggressive penetration of efficient shell measures and smart device and conservation measures combined with a lower performance of ASHP during peak conditions. One unmanaged electrification sensitivity included the same relative share of heat pump technologies as Scenario 2 (represented as "Unmanaged Electrification" in Table 6 below), and one unmanaged electrification sensitivity was modeled with the same relative share of heat pump technologies as the managed ground source/district loop sensitivity described above (represented as "Unmanaged Electrification with GS/DHP" in Table 6).

In addition to testing the peak impact and bulk electric system cost of different building peak sensitivities, a higher distribution system cost sensitivity was run on all of these sensitivities, to test the potential cost increases if distribution system upgrades were significantly more expensive than those included in the core Integration Analysis framework. This high distribution system cost sensitivity used the same analytical framework to calculate distribution system cost (multiplying the annual system peak load growth by a statewide levelized unitized distribution system cost), but instead of using a weighted-average levelized unitized distribution system cost sourced from utility filings, using a distribution system cost interpolated from the findings of the Transportation Electrification Distribution System Impact Study; the distribution system cost values are shown in Table 7.[55]

Table 6. Building Peak Sensitivity Scenario Design

Scenario	ASHP Peak COP	2050 GS/DHP Stock Share	2050 Deep Shell Stock Share	2050 Smart Device/Conservation Peak Reduction (%)
Managed Electrification (Scenario 2)	1.6	25%	26%	15%
Managed Electrification with GS/DHP	1.6	65%	26%	15%
Unmanaged Electrification	1.3	25%	5%	8%
Unmanaged Electrification with GS/DHP	1.3	65%	5%	8%

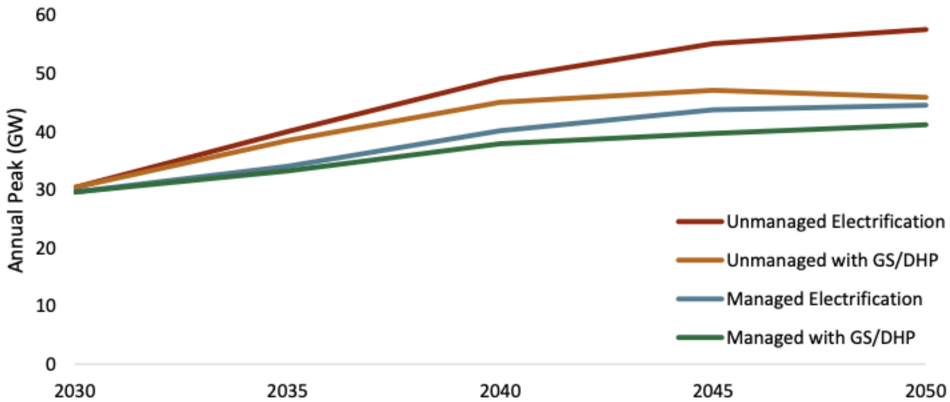
Table 7. Levelized and Unitized Statewide Distribution Cost Upgrade

Cost Scenario	Distribution Cost Upgrade (2020 $/kW-year)
Core Analysis	$112
High Distribution Cost Sensitivity	$266

Without high investment in building efficiency and higher peak heat pump performance, electric peaks could rise to up to 58 GW by 2050. The range of electric system peak reduction from higher ground source/district heat pumps is 4 -12 GW depending on the level of efficiency and heat pump performance.

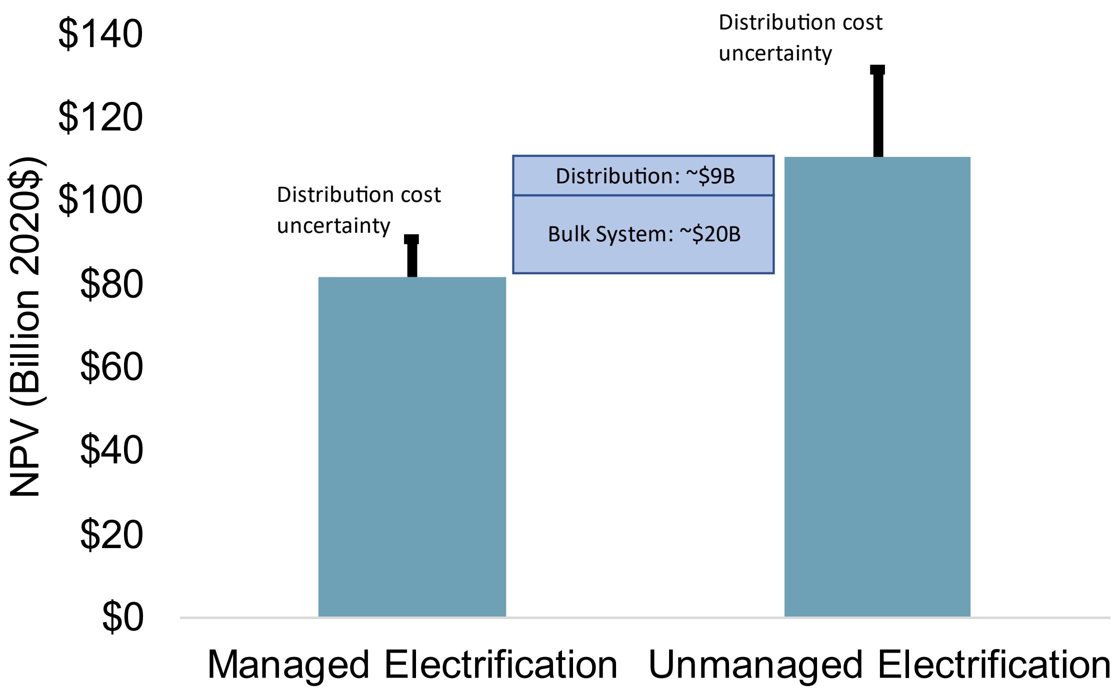
55 https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Transportation/22-13-Transportation-Electricification-Distribution-System-Impact-Study.pdf, accessed December 2022.

Figure 66. Building Sensitivities Annual Peak Load



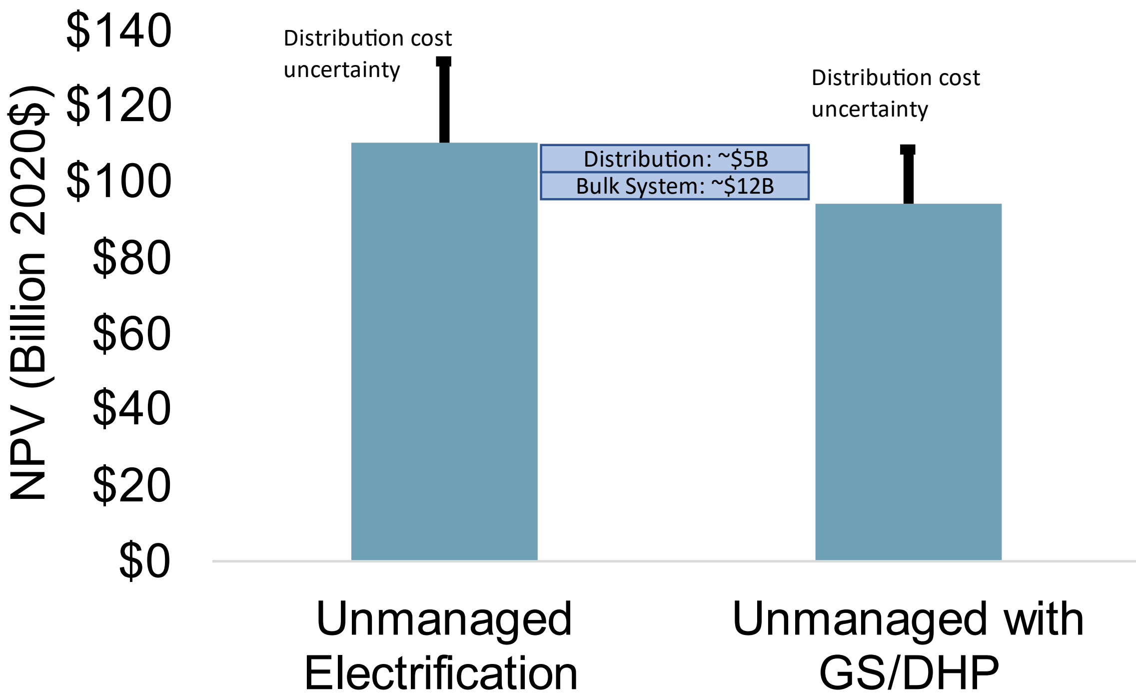
With Unmanaged Electrification, the electric system costs would rise by $29 billion, due to increased generation and transmission and distribution expenses (Figure 67). These costs include the need for up to 14 GW of additional firm capacity and battery storage resources, as well as 4 GW of incremental renewables. The higher distribution system cost sensitivity shows a further increase of the relative cost of the unmanaged case by $12 billion, increasing the growth in electric system costs to $41 billion.

Figure 67. Managed vs Unmanaged Electrification Electric System Cost



To help manage this significant expense, we consider the potential for GS/DHP to reduce electric system peak. Higher adoption of GS/DHP can reduce electric system costs by $16 billion if efficiency and ASHP performance lag (Figure 68). Higher distribution system costs would further reduce the relative cost of the GS/DHP system by $7 billion. Higher adoption of GS/DHPs leads to a reduction of firm capacity and battery storage of 13 GW relative to the unmanaged case without high GS/DHP adoption, as well as a reduction of 2.4 GW of renewables.

Figure 68. GS/DHP Impact on Electric System Costs



Although GS/DHPs can help reduce electric sector resource build and cost, GS/DHPs are more expensive than ASHPs and would cause an increase in building sector costs. These cost increases are uncertain, but as modeled we would see an increase in building sector costs of $19 billion, relative to the electric system savings of $16 billion – $23 billion. This indicates net cost differences are within modeling uncertainty. Ongoing work is warranted to monitor the relative cost trajectories of GS/DHPs versus electric peak costs. It is also important to note that substantially higher adoption of GS/DHPs will require novel financing and coordination solutions.

Key takeaways from the GS/DHP sensitivities are that energy efficiency is critical for achieving CLCPA emission limits and managing electric system peaks; GS/DHP technologies are potentially an important measure for limiting peak growth and development risks; and continued effort to monitor and evaluate the relative trajectories of GS/DHPs and electric system costs is warranted.

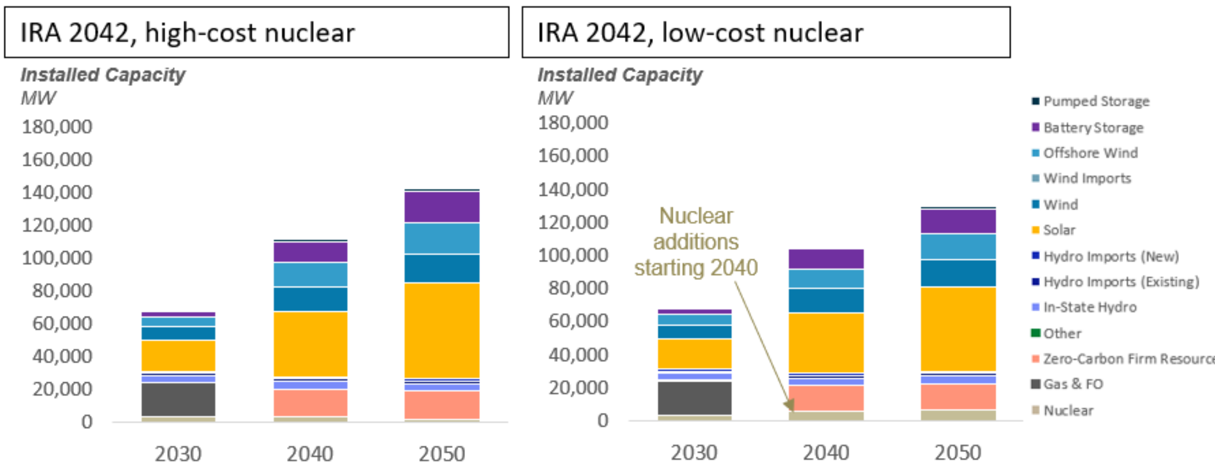
Nuclear Sensitivity

This analysis also examined how the availability of new nuclear as a candidate resource could impact capacity build and electric system costs, and the conditions under which new nuclear might play a role in New York's future energy grid. Recent market advancements along with new federal funding and incentives under both the CHIPS and Science Act and the Inflation Reduction Act made the study of new nuclear an important additional sensitivity in this analysis.

This analysis considered both high and low nuclear technology cost sensitivities to reflect substantial uncertainty around the future costs of new nuclear projects. In both sensitivities, new nuclear projects were modeled as available only in upstate NY zones (Zones A–F) and were assumed to operate at a constant 90% capacity factor. Further, this analysis was conducted based off the Inflation Reduction Act High Impacts sensitivity. This results in new nuclear resources being eligible for the technology neutral ITC/PTC for the full study period, given that the credit step-down is assumed to occur in 2042 in the High Impacts case, and the analysis assumes that nuclear will have a lengthy safe harbor period beyond that due to permitting and regulatory timelines associated with the construction of new nuclear facilities.

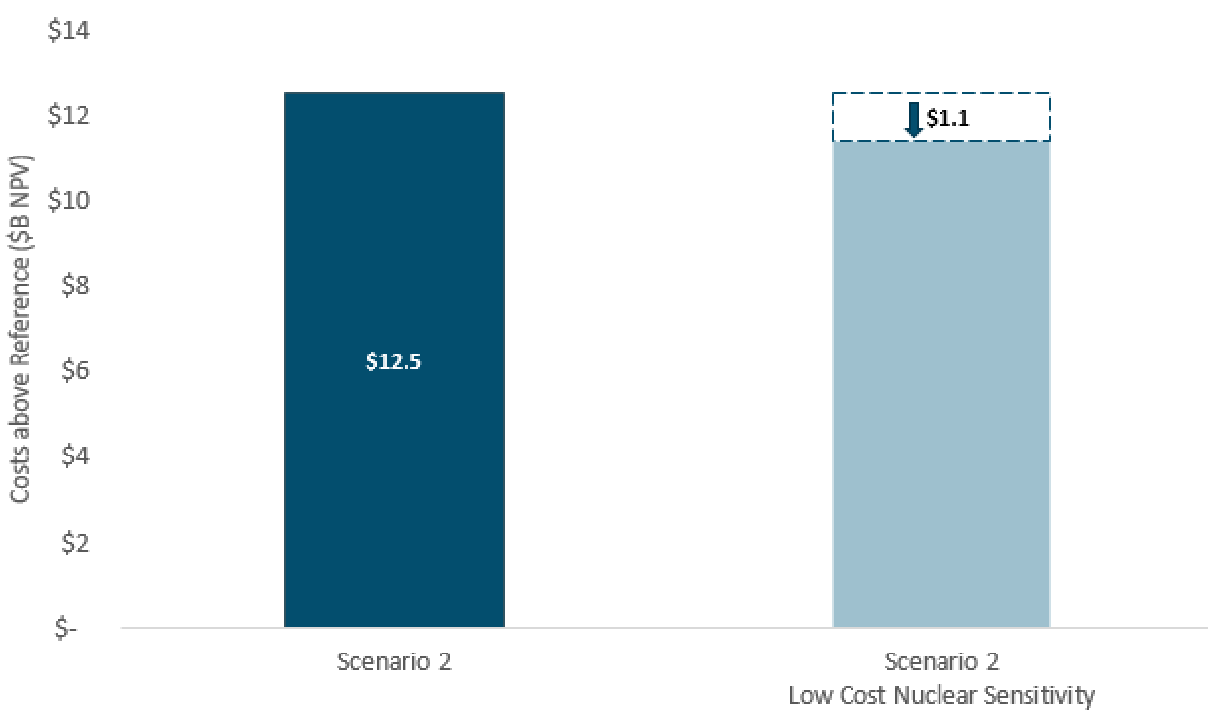
Under the high-cost nuclear sensitivity, no new nuclear capacity is economically selected. Under the low-cost sensitivity, 4 GW of nuclear capacity is added by 2050. The build-out of nuclear capacity displaces about 12 GW of intermittent renewables and 5 GW of firm resources and battery storage by 2050. However, wind, solar, and battery storage remain foundational resources in this sensitivity, with variable renewable resources representing the large majority of the capacity and generation mix by 2050.

Figure 69. Nuclear Sensitivity Build Results, Scenario 2, Inflation Reduction Act High Impacts Case



Under the Inflation Reduction Act and with low nuclear costs, adding new nuclear capacity and displacing renewables and firm generation could reduce electric system costs by $1.1B (9% of Mitigation costs) relative to the Scenario 2 Inflation Reduction Act High Impacts case without the availability of low-cost nuclear resources.

Figure 70. Cost Impacts of Low-Cost New Nuclear Sensitivity



Chapter 4. Key Findings

The integration analysis finds that there are multiple pathways to achieving New York's Climate Act GHG emissions limits. Key findings based on the integration analysis include the following.

- **Achieving deep decarbonization is feasible by mid-century**. Achieving the GHG emission limits **requires action in all sectors**, especially considering the Climate Act's emissions accounting. Every sector will see high levels of transformation over the next decade and beyond, requiring critical investments in New York's economy
- **Together, the benefits of avoiding economic impacts of damages caused by climate change and the improvements in public health total $400 – 415 billion**. Realizing these benefits will require an incremental investment over the 30-year transition of approximately 10 percent in additional spending, or $270 – $295 billion, in addition to redirecting the approximately $2.7 trillion in expected system spending under the reference case towards New York's low carbon future.
- **Energy efficiency and end-use electrification are essential parts of any pathway that achieves New York State emission limits**. Approximately 1 to 2 million efficient homes are electrified with heat pumps by 2030 across compliant scenarios. Approximately 3 million zero-emission vehicles (predominantly battery electric) are sold by 2030.
- **Consumer and community decision-making is key, and especially important for the purchase of new passenger vehicles and heating systems for homes and businesses through the next decade.** In all scenarios modeled, zero emission vehicles and heat pumps become the majority of new purchases by the late 2020s, and fossil-emitting cars and appliances are no longer sold after 2035. This represents an unprecedented rate of adoption of novel and potentially disruptive technologies and measures.
- **New York will need to substantially reduce vehicle miles traveled while increasing access to public transportation**. This should include expansion of transit service structured around community needs, smart growth inclusive of equitable transit-oriented development (E-TOD), and transportation demand management.
- **Wind, water, and sunlight power most of New York's economy in 2050 in all pathways**. Even with aggressively managed load, electric consumption doubles and peak nearly doubles by 2050, and NYS becomes a winter peaking system by 2035. Offshore wind on the order of 15 GW, solar on the order of 60 GW, and 4- and 8-hour battery storage on the order of 20 GW by 2050. Firm, zero-emission resources, such as green hydrogen or long-duration storage, will play an important role to ensure a reliable electricity system beyond 2040.

- **Low-carbon fuels such as bioenergy or hydrogen may help to decarbonize sectors that are challenging to electrify.** By 2030, scenarios include initial market adoption of green hydrogen in several applications (including medium and heavy-duty vehicles and high-temperature industrial). Additional promising end-use applications include district heating and non-road transportation such as aviation and rail.
- **Large-scale carbon sequestration opportunities include lands and forests and negative emissions technologies.** Protecting and growing New York's forests is required for carbon neutrality. Negative emissions technologies (e.g., direct air capture of CO_2) may be required if the State cannot exceed 85% direct emissions reductions. Strategic land-use planning will be essential to balance natural carbon sequestration, agriculture activities, new renewables development, and smart urban planning.
- **Necessary methane emissions mitigation in waste and agriculture will require transformative solutions.** Diversion of organic waste, capture of fugitive methane emissions are key in the waste sector. Alternative manure management and animal feeding practices will be critical in reducing methane emissions in agriculture.
- **Continued research, development, and demonstration is key to advancing a full portfolio of options.** Additional innovation will be required in areas such as carbon sequestration solutions, long-duration storage, flexible electric loads, low-GWP refrigerants, and animal feeding.
- **Although benefits and costs are in the same range across mitigation scenarios, risk levels differ by scenario**. Although all scenarios involve a high degree of transformation across strategies and sectors, very high levels of transformation increase risk of delivering GHG emission reductions. Types of risk include reliance on technologies in early stages of *development* which require substantial innovation (e.g., negative emission technologies, carbon capture and storage, advanced low-carbon fuels), reliance on widespread adoption of technologies that are in the early stages of *deployment* (e.g., zero-emission vehicles, heat pumps), and reliance on strategies that require the highest levels of transformation of social institutions and business models (e.g., land use patterns, mobility practices, waste management).
- **The Inflation Reduction Act will meaningfully reduce net direct costs**. New York could realize up to $70 billion of federal resources in support of the Scoping Plan initiatives through 2050, which would reduce incremental costs to New Yorkers by up to 19%.

Chapter 5. Methods and Data

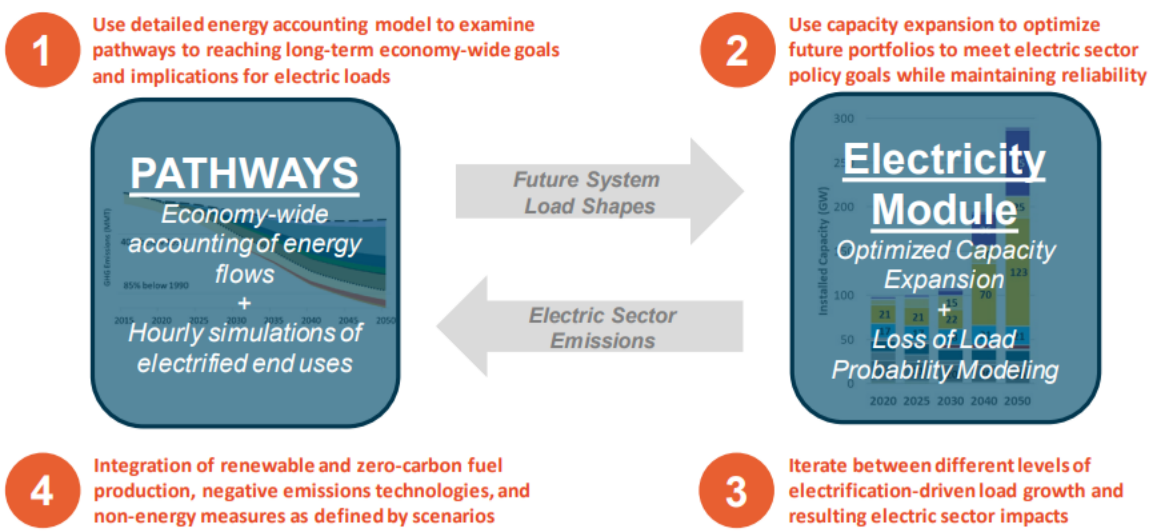
5.1 Methods

New York Pathways Model

New York State Energy Research and Development Authority (NYSERDA) commissioned Energy and Environmental Economics, Inc. (E3) to investigate the transformation of New York State's economy to one which achieves the GHG requirements of the Climate Act. The study addresses New York's greenhouse gas emissions on an annual time scale, with key outputs including annual energy demand and emissions by fuel; stocks and sales of energy-consuming devices; and electricity supply infrastructure including both generation and transmission upgrades. Inputs to the models used in this study include sale shares of new devices (e.g., vehicles, building energy and efficiency systems), cost and performance characteristics of infrastructure (both supply- and demand-side), and projections of fuel prices.

To perform this analysis, E3 analyzed the evolution of energy demand, energy supply, and non-energy GHG emissions. E3 used a variety of tools in this analysis effort. A diagram of this multi-model framework is presented in Figure 71.

Figure 71. Economy-wide energy model linked to electricity module



This analysis used a suite of tools to characterize the evolution of New York energy infrastructure and emissions. The demand-side module calculated direct[56] energy use and associated GHG emissions, as well as non-combustion related emissions and sequestration. The demand-side module interacted with the low-carbon fuels and negative emissions technologies models, as well as the electricity modules. The electricity modules took electricity demand, projected by the demand-side module, and co-optimized investment and operations of the electric power system to meet electric load reliably while complying with applicable electric sector GHG emissions and renewable energy targets. The low-carbon fuels module calculated availability of low-carbon fuels, which were used within the demand-side module as an option to reduce emissions from fossil fuel combustion by substituting fossil fuel combustion with low-carbon fuel combustion.

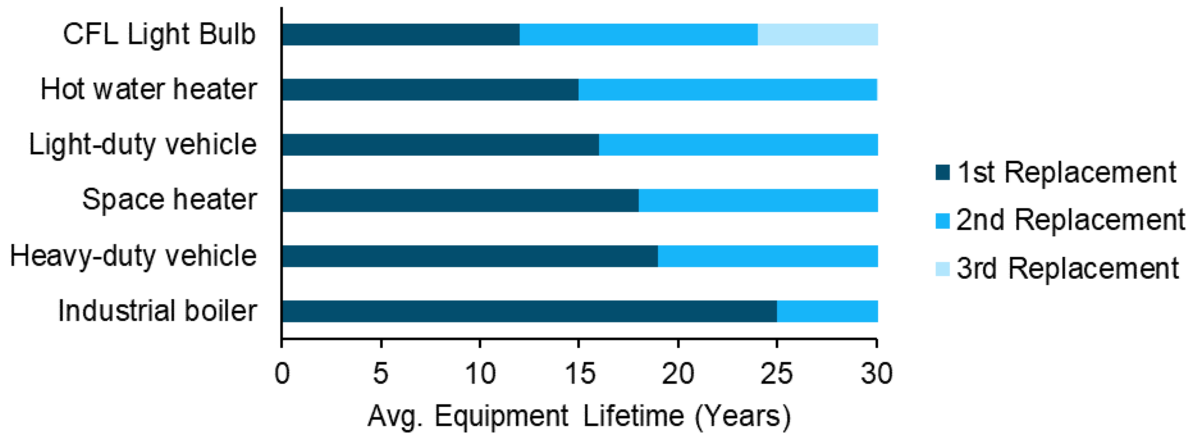
The core analytical tool in analyzing energy demand was the New York PATHWAYS model. E3 developed the New York PATHWAYS model using the Low Emissions Analysis Platform (LEAP),[57] an application that tracks energy consumption and GHG emissions sources and sinks throughout the economy in user-defined scenarios. The time horizon for all scenarios is from 2018 to 2050; 2018 was selected as the base year because it was the most recent year for which complete federal and state data on energy consumption and GHG emissions were available when the study began, and 2050 was selected as the final year to align with the final target year specified in the Climate Act. As 2019 was the most recent year for which state data were available for the GHG Inventory, that was chosen as the benchmark for sectoral energy demand and emissions outputs. The New York PATHWAYS model outputs energy use and GHG emissions in all sectors of the economy except for emissions produced by electric generating units; these were represented in the RESOLVE electricity sector model and are described in more detail in the Electricity System subsection of this chapter. A key feature of PATHWAYS is its ability to characterize stock rollover in major equipment categories (energy uses in buildings and transportation fleets). By accounting for appliance and vehicle lifetimes, the stock rollover feature of PATHWAYS assists users in analyzing the rate of change necessary to achieve decarbonization goals and captures potential path dependencies. As shown in Figure 72, many energy-consuming devices have long lifetimes,

[56] Emissions from direct fuel use are emissions associated with fossil fuel combustion when fossil fuels provide energy service. For example, combusting natural gas to provide heat or combusting gasoline in an engine are examples of fossil fuel combustion which result in direct fuel use emissions. Indirect energy related emissions are emissions produced even when the fuel used at the device is GHG free. For example, electricity emits no GHG emissions at the point of use in buildings, industry, or transportation; nevertheless, the production of electricity may create emissions, and this report considers these indirect energy related emissions.

[57] Heaps, C.G., 2021. LEAP: The Low Emissions Analysis Platform. [Software version: 2020.1.49] Stockholm Environment Institute. Somerville, MA, USA. https://leap.sei.org

meaning that timing for action is limited in terms of opportunities to replace fossil fuel-consuming devices with cleaner technologies before mid-century.

Figure 72. Average equipment lifetimes for key technologies in Pathways



To characterize demand-side energy demand and associated emissions in this study, E3 used two approaches: a stock rollover approach for subsectors where sufficient data on the number and characteristics of energy-consuming devices were available, and a total energy approach where sufficient data were not available. In the stock rollover approach, E3 characterized infrastructure, energy, and emissions associated with energy consuming devices, as new devices were added, and old devices were retired in each simulated year. In the total energy approach, E3 directly calculated energy consumption in each simulated year based on scenario-specific inputs regarding baseline energy demands, the amount of energy efficiency, potential for electrification, and potential for switching fossil fuel combustion to low-carbon fuel combustion. Non-energy sectors were represented by annual emissions by pollutant. A full representation of emissions categories is mapped out in Table 8.

Table 8. Draft GHG Inventory Categories and Representation in NY Pathways Model

Emissions Category		Emissions Sub-Category	GHGs Covered	Representation in NY Pathways Analysis
Energy	Fuel Combustion Emissions	Electricity	CO_2, CH_4, N_2O	RESOLVE modeling, least cost optimization of capacity expansion and dispatch
		Net Imports (of Electricity	CO_2, CH_4, N_2O	RESOLVE modeling of imported electricity
		Residential	CO_2, CH_4, N_2O	PATHWAYS stock rollover analysis

Emissions Category		Emissions Sub-Category	GHGs Covered	Representation in NY Pathways Analysis
		Commercial	CO_2, CH_4, N_2O	PATHWAYS stock rollover analysis
		Industry	CO_2, CH_4, N_2O	PATHWAYS total energy analysis
		Transportation	CO_2, CH_4, N_2O	PATHWAYS stock rollover analysis
	Upstream Fuel Emissions	Upstream Fuel Emissions	CO_2, CH_4, N_2O	PATHWAYS stock rollover analysis; RESOLVE modeling
	Electricity Transmission and Distribution	Electricity Transmission and Distribution	SF_6	Total emissions by pollutant
	Fugitive Emissions	Oil & Gas Systems	CH_4	Total emissions by pollutant
Industrial Processes and Product Use	Minerals	Cement Production	CO_2	Total emissions by pollutant
		Soda Ash Use	CO_2	Total emissions by pollutant
		Limestone Use	CO_2	Total emissions by pollutant
	Metals	Aluminum Production	CO_2, PFCs	Total emissions by pollutant
		Iron & Steel Production	CO_2	Total emissions by pollutant
		Lead	CO_2	Total emissions by pollutant
		Ferroalloys	CO_2, CH_4	Total emissions by pollutant
	Electronics	Semiconductor Manufacturing	PFC	Total emissions by pollutant
	Product Use	ODS Substitutes	HFC	Total emissions by pollutant
Waste	Solid Waste Disposal	Solid Waste Disposal	CH_4, CO_2	Total emissions by pollutant
	Biological Treatment of Solid Waste	Compost and Anaerobic Digestion	CH_4	Total emissions by pollutant
	Waste Combustion	Waste Combustion	CO_2, CH_4, N_2O	Total emissions by pollutant
	Wastewater Treatment	Wastewater Treatment	CH_4, N_2O	Total emissions by pollutant
AFOLU	Livestock	Enteric Fermentation	CH_4	Total emissions by pollutant
		Manure Management	CH_4, N_2O	Total emissions by pollutant
	Aggregated Sources	Agricultural Soil Management	N_2O	Total emissions by pollutant
		Agricultural Soil Liming	CO_2	Total emissions by pollutant

Emissions Category		Emissions Sub-Category	GHGs Covered	Representation in NY Pathways Analysis
		Settlement Soil Management	N_2O	Total emissions by pollutant
		Urea Fertilization	CO_2	Total emissions by pollutant
		Harvested Wood Products	CO_2	Total emissions by pollutant
	Land	Forest Land	Net CO_2e	Total emissions by pollutant
		Cropland/Grassland	Net CO_2e	Total emissions by pollutant
		Wetlands	Net CO_2e	Total emissions by pollutant
		Settlement Land	Net CO_2e	Total emissions by pollutant
		Urban Trees	Net CO_2e	Total emissions by pollutant

Buildings

The buildings sector in this study is subdivided into residential and commercial end use device types. Common energy demands for buildings include space conditioning, water heating, lighting, refrigeration, cooking, and a variety of other appliances.

E3 calculated buildings sector energy demand by breaking down energy demand into residential and commercial end use device types which provide distinct energy services and analyzing the energy demand of these end use devices. As an example, the annual energy demand for domestic hot water is the amount of fuel residential water heaters consume every year, while the energy services demand for residential water heating is the amount of hot water of a certain temperature which residences demand, regardless of water heater fuel type or efficiency of the technology delivering the hot water.

Energy demand for devices, in categories applying the stock rollover approach, was calculated by summing the energy demand for every end use device technology. In each simulated year, E3 calculated energy demand for each end use device technology by multiplying the energy service demand by the inverse of device efficiency. For example, if a residential household demanded 35 units of hot water per year and a natural gas water heater has an efficiency of 0.8 units of hot water output per unit of input natural gas, the demand for natural gas for water heating would be 35 * (1/0.8) = 43.75 units of natural gas. The stock rollover approach tracks the lifetimes and efficiencies of the fleet of devices within each end use device type and calculates the energy demand by summing the energy demand for each constituent end use device. For end uses where the total energy approach was applied, E3 characterized energy demand by fuel type directly based on scenario-specific user inputs characterizing energy efficiency, potential for electrification, and potential for switching from fossil fuel combustion to low-carbon fuel combustion.

E3 simulated building energy and emissions based on data available from the National Energy Modeling System (NEMS) and the NYSERDA *Residential Statewide Baseline Study*. See Table 9 for a list of the end-use device category and the analysis approach used. Note that residential space heating was broken into different size classes to account for the differences in space heating demand by household size, as well as differential heating demands across upstate and downstate geographies to account for different heating demands in different climate conditions within the state. This distribution was assumed to remain constant in future years – i.e., the portion of small single-family homes in the upstate region is constant as the total number of households evolves. For all other end uses, service demand was not differentiated for different household types.

The “Commercial District Heat” end use device type represents the heat demand for district heat located in New York City. A district heat system is one in which a central plant provides steam or hot water, pumped through a series of pipes to connected nearby buildings to provide space heating and/or hot water needs. The “Residential Other” and “Commercial Other” end use device types were characterized using the total energy approach to benchmark energy demand by fuel to account for all other energy demand within the residential and commercial buildings which do not appear in other end use device types. For example, residential televisions and computers demand electricity but their electricity demand was calculated within the “Residential Other” end use device type as E3 did not have detailed information on the number, efficiency, and usage patterns of televisions and computers within the state.

Table 9. Building Sector Segmentation and Modeling Approach

Sector	Subsector	Modeling Approach	Estimated Energy Use in 2019 [TBtu]	Estimated % of 2019 Energy Use [%]
Residential	Residential Air Conditioning _ Central	Stock Rollover	9.2	1%
	Residential Air Conditioning _ Room	Stock Rollover	4.7	0%
	Residential Building Shell	Stock Rollover	N/A	N/A
	Residential Clothes Drying	Stock Rollover	14.0	1%
	Residential Clothes Washing	Stock Rollover	0.7	0%
	Residential Cooking	Stock Rollover	29.4	2%
	Residential Dishwashing	Stock Rollover	5.2	0%
	Residential Exterior Lighting	Stock Rollover	1.0	0%
	Residential Freezing	Stock Rollover	4.3	0%

Sector	Subsector	Modeling Approach	Estimated Energy Use in 2019 [TBtu]	Estimated % of 2019 Energy Use [%]
	Residential General Service Lighting	Stock Rollover	5.5	0%
	Residential Linear Fluorescent Lighting	Stock Rollover	2.2	0%
	Residential Other	Total Energy by Fuel	54.3	4%
	Residential Reflector Lighting	Stock Rollover	1.7	0%
	Residential Refrigeration	Stock Rollover	27.0	2%
	Residential Space Heating _ Large Multi Family	Stock Rollover	96.1	6%
	Residential Space Heating _ Single Family	Stock Rollover	314.9	21%
	Residential Space Heating _ Small Multi Family	Stock Rollover	141.3	9%
	Residential Water Heating	Stock Rollover	129.2	9%
Commercial	Commercial Air Conditioning	Stock Rollover	19.3	1%
	Commercial Building Shell	Stock Rollover	N/A	N/A
	Commercial Cooking	Stock Rollover	34.3	2%
	Commercial District Heat	Total Energy by Fuel	14.4	1%
	Commercial General Service Lighting	Stock Rollover	5.1	0%
	Commercial High Intensity Discharge Lighting	Stock Rollover	2.0	0%
	Commercial Linear Fluorescent Lighting	Stock Rollover	35.4	2%
	Commercial Other	Total Energy by Fuel	169.7	11%
	Commercial Refrigeration	Stock Rollover	24.9	2%
	Commercial Space Heating	Stock Rollover	270.8	18%
	Commercial Ventilation	Stock Rollover	23.9	2%
	Commercial Water Heating	Stock Rollover	65.7	4%

Industrial Energy Use

The Industry: Energy sector includes all energy and emissions associated with fuel combustion within New York's industries. Non-combustion emissions related to industrial processes and product use are covered separately. E3 used a total energy approach to characterize the industrial subsectors. Base year energy use by industrial subsector and region for the most recently available benchmark year (2019) is reported in Table 10.

Table 10. Industrial Fuel Demand by Subsector and NY Pathways Region in 2019 [TBtu]

Subsector	Upstate NY A-E	Upstate NY F	Downstate NY - Lower Hudson Valley	Downstate NY – New York City	Downstate NY – Long Island	Total
Agriculture	5.17	0.79	0.33	0.01	0.13	**6.43**
Aluminum	3.17	0.73	0.13	0.00	0.08	**4.10**
Cement and Lime	0.03	5.38	1.14	0.00	0.07	**6.62**
Bulk Chemicals	13.96	2.78	0.56	0.67	0.43	**18.40**
Construction	5.37	1.29	3.48	5.43	4.94	**20.51**
Food	8.30	2.48	2.00	2.04	0.52	**15.34**
Glass	5.01	0.75	0.11	0.50	0.33	**6.71**
Iron and Steel	10.69	0.00	0.33	1.36	0.01	**12.39**
Metal Based Durables	13.85	0.98	2.50	1.30	2.35	**20.98**
Mining	6.61	0.30	0.97	1.24	0.47	**9.59**
Other Manufacturing	19.59	12.47	7.39	6.00	6.76	**52.22**
Paper	16.90	17.19	0.00	3.40	1.23	**38.72**
Plastics	4.49	0.29	0.35	0.46	0.48	**6.06**
Wood Products	2.12	1.07	0.27	0.45	0.77	**4.67**
Total	**115.26**	**46.48**	**19.56**	**22.87**	**18.57**	**222.75**

Transportation

The transportation sector includes a representation of on-road vehicles (e.g., passenger cars) and non-road transportation (e.g., aviation). For most on-road vehicle categories, E3 applied a stock rollover approach, but for non-road vehicle categories a total energy approach was used. See Table 11 for an overview of analysis approach by vehicle category.

Table 11. Transportation Sector Segmentation and Modeling Approach

Subsector	Modeling Approach	Estimated Energy Use in 2019 [Tbtu]	Estimated % of 2019 Energy Use [%]
Light Duty Vehicles _ Cars	Stock Rollover	267	24%
Light Duty Vehicles _ Trucks	Stock Rollover	454	41%
Medium Duty Vehicles	Stock Rollover	78	7%
Heavy Duty Vehicles	Stock Rollover	68	6%
Buses	Stock Rollover	19	2%
Aviation	Total Energy by Fuel	104	9%
Marine	Total Energy by Fuel	4	0%
Military	Total Energy by Fuel	0.3	0%
Railroad	Total Energy by Fuel	7	1%
Pipelines	Total Energy by Fuel	28	3%
Other Non-road: Industrial/Commercial	Total Energy by Fuel	13	1%
Other Non-road: Construction	Total Energy by Fuel	1	0%
Other Non-road: Agricultural	Total Energy by Fuel	0	0%
Other Non-road: Public Nonhighway	Total Energy by Fuel	0	0%
Other Non-road: Miscellaneous/Unclassified	Total Energy by Fuel	0	0%
Other Non-road: Lawn and Garden	Total Energy by Fuel	16	1%
Other Non-road: Marine/Boating	Total Energy by Fuel	7	1%
Other Non-road: Recreational Vehicle	Total Energy by Fuel	26	2%
Other Non-road	Total Energy by Fuel	6	1%

The unit of energy service demand for vehicle categories simulated with a stock rollover approach in transportation (Light Duty Autos, Light Duty Trucks, Medium Duty Trucks, Heavy Duty Trucks, and Buses) is VMT. The underlying future VMT growth in the Reference scenario was estimated using VisionEval-State, a disaggregate demand/aggregate supply travel demand model, combining the rich demographic and socioeconomic detail of simulated households with aggregate treatments of travel calibrated for New York State.[58] Modeled VMT reduction measures fall into three broad categories: enhanced transit & mobility, telework & transportation demand management (TDM), and smart growth & biking/walking modeshifting. In all scenarios, we assume a targeted effort to expand programs and policies in the 2020s and 2030s, with continuous investment to maintain levels of reductions beyond 2035 through mid-century. VMT reductions are high-level estimates meant to represent ambitious action in reducing VMT relative to a Reference scenario. The following is a brief description of the VMT reduction

[58] VMT modeling using VisionEval-State was conducted by RSG/Cadmus and leverages the Clean Transportation Roadmap modeling framework, which was calibrated to latest available starting year VMT data (2017)

measures attributed to each scenario, while Table 12 and Table 13 show impacts of the VMT reductions by measure achieved by 2050.

Enhanced Transit & Mobility:

- Low VMT (Scenarios 1-3): Expansion in bus transit service statewide, enhanced transit service taken from Carbon Neutral NYC report.
- Very Low VMT (Scenario 4): Incremental reductions from enhanced in-state rail aligning with 125 MPH alternative detailed in Empire Corridor Tier 1 Draft EIS

Telework & TDM:

- Low VMT (Scenarios 1-3): Additional promotion and informational TDM programs and modest increase in teleworking reduces a small amount of VMT, while in NYC additional programs like congestion pricing and other measures modeled in Carbon Neutral NYC further reduce VMT, although we do not include full Carbon Neutral NYC impacts in this case
- Very Low VMT (Scenario 4): Further ambition statewide reduce LDV VMT and full adoption of congestion pricing and other policies in Carbon Neutral NYC reduce NYC VMT. Similarly, to the Low VMT case, maximum reductions are achieved in the mid-2030s and maintained through 2050

Smart Growth & Biking/Walking Modeshifting:

- Low VMT (Scenarios 1-3): Focus on transportation-oriented development for new construction leads to reduced LDV VMT, with VMT impacts estimated using methodology from Growing Cooler report
- Very Low VMT (Scenario 4): Assume incremental ambition in smart growth development in co-locating residential and commercial development, and incremental ambition in biking/walking infrastructure investments, all which lead to greater reductions.

Table 12. 2050 VMT Reduction Measures in Scenarios 1-3

Measure	State Total (million VMT)	Reduction vs Reference (%)	Sources[59]
2050 Reference	140,400	N/A	N/A
VMT Reductions:			
Enhanced Transit and Mobility	3,700	3%	Carbon Neutral NYC, E3 Internal Analysis
Telework and TDM	2,300	2%	Carbon Neutral NYC, UCR COVID Impacts Study, FHWA Integrating TDM into the Transportation Planning Process
Smart Growth and Biking/Walking/Modeshifting	2,900	2%	Carbon Neutral NYC, Growing Cooler: The Evidence on Urban Development and Climate Change
Total Reductions	**8,800**	**6%**	

[59] Carbon Neutral NYC: https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/Carbon-Neutral-NYC.pdf, accessed November 2021

UCR Covid Impacts Study: https://ucreconomicforecast.org/wp-content/uploads/2020/08/Mobility_Emissions_COVID19_CEFD_White_Paper_August_2020.pdf, accessed November 2021

FHWA Integrating TDM Into the Transportation Planning Process: https://ops.fhwa.dot.gov/publications/fhwahop12035/chap10.htm, accessed November 2021

Growing Cooler: The Evidence on Urban Development and Climate Change: https://www.nrdc.org/sites/default/files/cit_07092401a.pdf, accessed November 2021

Table 13. 2050 VMT Reduction Measures in Scenario 4

Measure	State Total (million VMT)	Reduction vs Reference (%)	Sources[60]
2050 Reference	140,400	N/A	N/A
VMT Reductions:			
Enhanced Transit and Mobility	3,700	3%	Carbon Neutral NYC, E3 Internal Analysis
Telework and TDM	7,200	5%	Carbon Neutral NYC, UCR COVID Impacts Study, FHWA Integrating TDM into the Transportation Planning Process
Smart Growth and Biking/Walking/Modeshifting	10,800	8%	Carbon Neutral NYC, Growing Cooler: The Evidence on Urban Development and Climate Change
Total Reductions	**21,700**	**16%**	

As E3 used a total energy approach for calculating energy demand and associated GHG emissions in the non-stock vehicle categories (e.g., aviation, marine), there is no fundamental energy service demand driver which is separate from energy demand for these non-stock vehicle categories.

Scenario 4 includes greater ambition in on-road transportation reductions (from greater VMT reductions and aggressive electrification levels) as well as greater levels of non-road ambition (such as increased rail, electric and hydrogen aviation); we include estimates for costs associated with this greater ambition, as summarized in Table 14.

[60] See footnote 59

Table 14. Transportation-related Incremental Costs Associated with Scenario 4

Measure	Per-Unit Cost	Units	Sources[61]
VMT Reductions[62]	$.0309/mile	14 billion LDV miles reduced relative to Scenarios 2/3 in 2050	$/mile reduction costs based on Moving Cooler estimates
Rail Improvements	$6/mile	200 million LDV miles reduced relative to Scenarios 2/3 in 2050	Empire Corridor Draft 1 Tier EIS
Electric and Hydrogen Aviation Infrastructure	$30/MMBtu	60 Tbtu in 2050 [47% of all aviation energy consumption in 2050]	E3 analysis of white paper on hydrogen fueling infrastructure in EU

Advanced Biofuels

All mitigation scenarios utilize some amount of advanced biofuels (biogenic fuels which are drop-in replacements for fossil alternatives, such as renewable natural gas, renewable diesel, renewable jet fuel), but the total amount consumed varies widely across scenarios. Feedstock supply for advanced biofuels was sourced from the 2016 US Department of Energy (US DOE) Billion Ton Report[63] and the NYSERDA Potential of Renewable Natural Gas report[64] with additional input from Advisory Panel discussions with academic partners. The biofuel feedstocks examined in this study can be grouped into three general categories:

1. Wastes: These include animal-related wastes (manure), municipal solid waste (MSW) destined for landfill or incineration disposal, and byproducts of wastewater treatment facilities. These

[61] Moving Cooler: http://www.reconnectingamerica.org/assets/Uploads/2009movingcoolerexecsumandappend.pdf, accessed November 2021

Empire Corridor Draft 1 Tier EIS: https://railroads.dot.gov/environment/environmental-reviews/empire-corridor, accessed November 2021

EU Hydrogen Aviation Study: https://www.fch.europa.eu/sites/default/files/FCH%20Docs/20200720_Hydrogen%20Powered%20Aviation%20report_FINAL%20web.pdf, accessed November 2021

[62] Scenario 2 and Scenario 3 include 9 billion LDV miles reduced in 2050 relative to Reference scenario, from enhanced transit and mobility; telework and travel demand management; smart growth and mode shifting to biking/walking; No $/mile cost was assessed for tranche of VMT reduction achieved in Scenarios 2-3. Table above shows incremental investment relative to Scenarios 2-3

[63] https://www.energy.gov/eere/bioenergy/2016-billion-ton-report, accessed February 2021

[64] https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Greenhouse-Gas-Emissions, accessed December 2021

feedstocks require no additional agronomic inputs such as land or fertilizer to produce as they are byproducts of existing economic activities.

2. Forest and Agriculture Residues: Forest residue feedstocks include logging residues, wood wastes from mills, and harvest from forest thinning, fuel reduction, and regeneration cuts. Agriculture residue feedstocks include crop residues from corn stover, cereal straws (wheat, oats, and barley), and sugarcane. Both forest and agriculture residues require no additional cultivation of land as they are natural byproducts of existing forestry and agriculture practices.

3. Dedicated Energy Crops: These include both cellulosic crops like miscanthus, switchgrass, and sorghum and woody crops like willow, poplar, eucalyptus and other purpose-grown trees. Unlike wastes and residues, these feedstocks do require additional cultivation of land, which can be achieved using marginal agricultural lands, converting existing agricultural or forestry land to energy crop production, or re-purposing land used for other uses. The feedstocks grown as dedicated energy crops for advanced renewable biofuels in this analysis are distinct from existing energy crops used to produce conventional biofuels like corn grown for ethanol and soybeans grown for biodiesel.

Table 15 below shows the feedstock screenings used for each of the mitigation scenarios that achieve the Climate Act emission limits.

Table 15: Biofuel feedstock screening by category for mitigation scenarios

Feedstock Category	Scenario 2	Scenario 3	Scenario 4
Wastes (NYSERDA RNG Potential Report)	RNG potential available from Landfill Gas and Water Resource Recovery Facilities identified in Achievable Deployment Scenario	RNG potential available from Landfill Gas and Water Resource Recovery Facilities identified in Achievable Deployment Scenario	RNG potential available from Landfill Gas and Water Resource Recovery Facilities identified in Achievable Deployment Scenario
Wastes (DOE Billion Ton Report)	NY has access to 100% of in-state feedstocks and a percentage of regional out-of-state feedstocks[65]	None included	NY has access to 100% of in-state feedstocks
Forest & Agriculture Residues (DOE Billion Ton Report)	NY has access to 100% of in-state feedstocks and a percentage of regional out-of-state feedstocks[65]	None included	NY has access to 100% of in-state feedstocks
Cellulosic Energy Crops (DOE Billion Ton Report)	NY has access to 100% of in-state feedstocks and a percentage of regional out-of-state feedstocks[65]	None included	NY has access to 100% of in-state feedstocks
Woody Energy Crops (DOE Billion Ton Report)	NY has access to 100% of in-state feedstocks and a percentage of regional out-of-state feedstocks[65]	None included	NY has access to 100% of in-state feedstocks
Purpose-Grown Forests (DOE Billion Ton Report)	None included	None included	None included

After the available feedstocks were defined for each scenario using the above screenings, E3 used an in-house biofuel production tool to convert the biomass feedstocks from the Billion Ton Report to one of three eligible fuels: renewable natural gas, renewable diesel, or renewable jet kerosene (the feedstocks from the NYSERDA RNG Potential Report are already provided in TBtu of renewable natural gas and thus are excluded from the biofuel production tool). The tool takes biomass feedstocks and final energy demand for the three eligible fuels as inputs and converts feedstocks to final fuels based on whichever fuel production pathway provides the greatest emissions mitigation at the lowest cost. Because natural gas demand declines significantly by 2050 in all three mitigation scenarios, renewable natural gas production in 2030 was limited in the biofuel production tool to avoid a dramatic ramp up in renewable natural gas

[65] The supply curve for regional out-of-state feedstocks is confined to states east of the Mississippi River for this analysis. In 2050, the percentage of out-of-state feedstocks that New York has access to in Scenario 2 is set to 7.7% so that New York's share of total feedstocks in that year (both in-state and regional out-of-state) is equal to 10.4%, New York's share of population for the Eastern US in 2018. In 2030, this allocation is insufficient to meet all advanced biofuels demand in Scenario 2, so the percentage of out-of-state feedstocks that New York has access to was increased to 10% in that year. The assumption is that New York is an early mover and thus has access to higher than its population-weighted share of feedstocks in the near term, but in the longer term reverts to its population-weighted share of feedstocks.

production over the next seven years followed by a significant drop off over the next two decades. The 2030 renewable natural gas production limit was set to 2.5x and 2x the total natural gas demand in 2050 for Scenario 2 and Scenario 4, respectively (Scenario 3 does not include feedstocks from the Billion Ton Report and so does not require use of the biofuel production tool). Finally, the biofuel production tool generates a marginal price for each final fuel based on the most expensive feedstock to fuel conversion pathway selected. These marginal prices are used in the economy-wide costing analysis and are reported in Annex 1.

Electricity System

Electricity Load Shaping

Electrification is a central strategy to achieving New York's long-term climate goals. The scenarios in this study include significant adoption of electric vehicles and electrification of building heating systems, which will have an impact on both the magnitude and timing of electricity demands. This section describes the methods used in this study to convert annual electric load forecasts, calculated for each sector and end use device, into hourly electric load forecasts.

In this study, E3 scaled historical system load shape to future years, and this formed the basis of the hourly load forecast. E3 started with historical hourly load data, calculated by averaging 5-minute historical load data available from the NYISO. E3 used historical hourly load data from 2007-2012 to align with the calendar chronology of the renewable profiles used in this study.

E3 combined annual forecasted electricity demand by end use with normalized hourly load shapes by end use to create hourly end use load shapes in forecasted years. This methodology accounts for both load increases, such as electrifying buildings and vehicles, as well as load decreases, such as increased appliance efficiency (for example, LEDs have significantly lower loads than conventional lighting technologies). This process generated hourly load shapes based on the changing composition of end uses. For each forecasted year, hourly loads were simulated for six sequential weather years (2007-2012) to align with the calendar chronology of the renewable profile library developed for this study.

To calculate hourly load shapes for two particularly impactful set of electrified end uses (light duty transportation and electric space heating), E3 used E3's RESHAPE Tool. RESHAPE is designed to capture the diversity of space heating and transportation loads under higher levels of electrification. The tool does this by representing a diverse housing stock, including geographically explicit weather data, and using empirical estimates of hourly energy usage where possible.

E3 also used a regression analysis to extend historical system load shapes over 40 years (1979-2018) of daily temperature data. Combined with RESHAPE analysis that modeled the impacts of historical weather on electrified heating and cooling end uses, E3 developed hourly system loads for a future highly electrified system (i.e., representative of a modeled decarbonization pathway in 2050) over 40 years of historical temperature data to analyze median (1-in-2) system peaks.

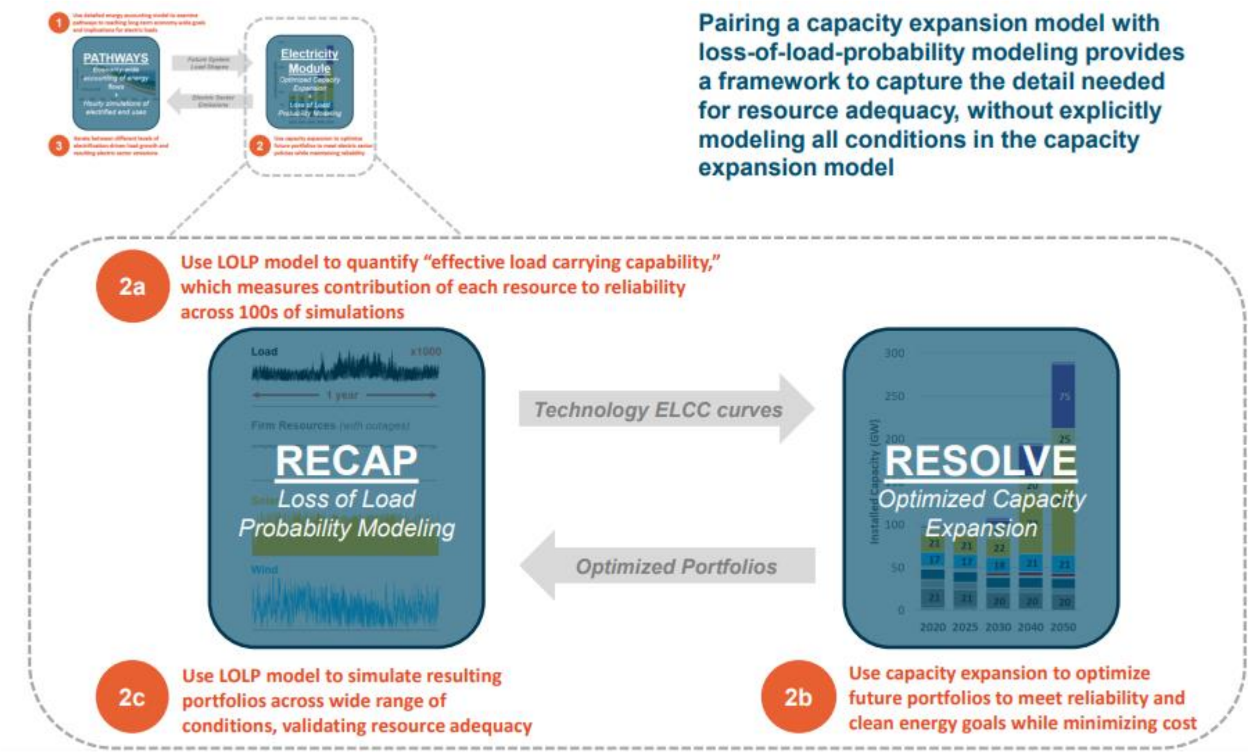
Electric Sector Framework

The electric sector analysis was performed using E3's capacity expansion and resource adequacy models, RESOLVE and RECAP. RESOLVE is an electricity-sector resource investment model that optimizes long-term generation and transmission investments subject to reliability, technical, and policy constraints. RECAP is a resource adequacy model that performs loss-of-load probability simulations to determine the reliability of resource portfolios. RECAP analysis was used in this work to determine the effective load-carrying capability (ELCC) of wind, solar, and battery storage resources. With annual and hourly load projections from PATHWAYS and ELCC curves from RECAP serving as inputs, RESOLVE was used to develop least-cost electricity generation portfolios that achieved New York's policy goals while maintaining electric system reliability.

The RESOLVE model was used in this study to determine the least-cost pathway to meeting New York's electric sector targets, including the requirement under the Climate Act to generate 70% of New York's electricity from renewable resources by 2030 and eliminate greenhouse gas emissions from the state's electricity generation by 2040. Designed specifically to address electric sector capacity expansion questions for systems seeking to integrate large quantities of variable resources, RESOLVE layers capacity expansion logic on top of a production cost model to determine the least-cost approach to achieving renewable resource targets, accounting for both the upfront capital costs of new resources and infrastructure and the variable costs to operate the grid reliably over time. As the nature of electric system loads evolves over time, RESOLVE also captures key changes in demand-side behavior, such as increased flexibility in building loads and electric vehicle charging.

This study also used RECAP, a resource adequacy model that performs loss-of-load probability (LOLP) simulations, to assess the ability of renewable power generation and limited-duration storage to contribute to electric system reliability by determining the effective load-carrying capability (ELCC) of wind, solar, and storage resources as a function of their penetration on the system. ELCC curves developed in RECAP served as inputs to RESOLVE, which ensures that the simulated New York system meets system-wide and local resource adequacy constraints. Resulting portfolios in RESOLVE were also tested again in RECAP to validate resource adequacy and ensure that the portfolios met or exceeded statewide reliability standards (i.e., with LOLE at or below 1-day-in-10-years). Iteration between RECAP and RESOLVE is shown in Figure 73 below.

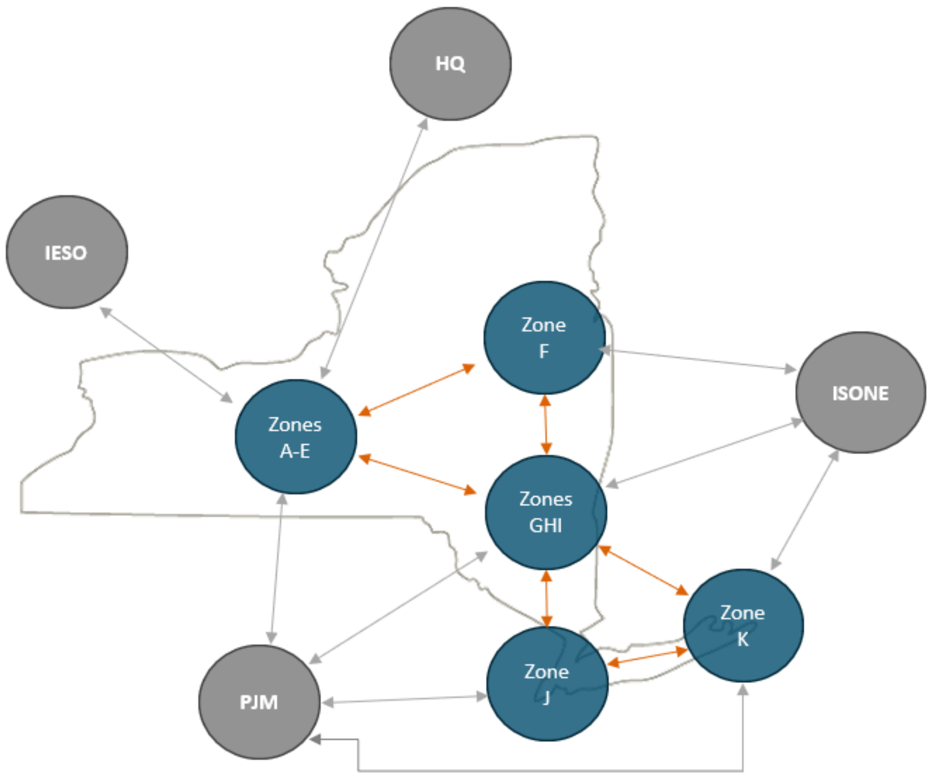
Figure 73. Interactions between RECAP and RESOLVE within Electricity Module



Representation of New York and Neighboring Systems within RESOLVE

RESOLVE has been configured to capture the operations of the New York electricity system as well as its interactions with neighboring power systems in the United States and Canada. For this study, RESOLVE was configured with nine zones: five internal zones representing zones A-E, zone F, zones G-I, zone J, and zone K within the New York electricity system; and four zones representing the external markets that interact with New York. The characterization of existing generators in New York was developed based on the NYISO Gold Book; more detail is provided in Annex 1.[66]

Figure 74. Representation of New York and Neighboring Electricity Systems in RESOLVE



Within this configuration, RESOLVE optimizes investments only on behalf of the five New York zones[67] while optimizing the integrated operations of the entire system. Conditions and assumptions for the future loads and resources of neighboring markets are specified as inputs. RESOLVE's optimization capabilities allow it to select from among a wide range of potential new resources ("candidate resources"). The full range of resource options considered by RESOLVE in this study is shown in Table 16.

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[66] New York Independent System Operator, 2020 Load & Capacity Data "Gold Book", April 2020, supplemented by updates in the 2021 edition of the Gold Book: https://www.nyiso.com/documents/20142/2226333/2020-Gold-Book-Final-Public.pdf/, accessed November 2021

[67] The optimization of investments on behalf of New York includes the ability to develop remote resources (e.g., PJM wind) that are delivered to serve New York load, but does not optimize the build-out of new generation portfolios to serve load in external areas.

Table 16: Candidate Resources in RESOLVE

Candidate Resource	Examples of Available Options	Functionality
Natural Gas Generation*	Simple cycle gas turbines Combined cycle gas turbines	Dispatches economically based on heat rate, subject to ramping limitations Contributes to meeting minimum generation and ramping constraints
Hydrogen Fuel Cells	Polymer electrolyte membrane (PEM) fuel cells	Dispatches economically based on efficiency Contributes to meeting minimum generation and ramping constraints
Hydro Generation / Imports	Upgrades of Existing In-state Hydro New Canadian Hydro Imports (coupled with Tier 4 transmission)	Imports from Hydro Quebec (HQ) are budget-limited over course of year, but are highly flexible resources and contribute to balancing renewables output
Renewable Generation	Utility-Scale Solar PV Distributed Solar PV Land-based Wind Offshore Wind	Dynamic downward dispatch (with cost penalty) of renewable resources to help balance load
Energy Storage	Li-ion Batteries (4-hour or 8-hour) Pumped Storage (12 hr.)	Stores excess energy for later dispatch Contributes to meeting minimum generation and ramping constraints
Transmission	Tier 4 Projects Transmission upgrades required to access renewable resources	Power transfer between zones is constrained by transmission limits New renewable resources will require additional transmission upgrades within the NYISO zone they are located

*Natural gas generation resources can utilize zero-carbon fuels (e.g., hydrogen) in order to continue operating while being in compliance with the Climate Act 100x40 target.

To represent the costs of building new thermal generation (i.e., CT or CCGT), E3 used the NYISO Demand Curve study to develop zone-specific cost estimates for new resources.[68] E3 also applied a 25% cost increase to new resources that are projected to utilize hydrogen in order to continue operating under the Climate Act's 100x40 target.

[68] Analysis Group, Independent Consultant Study to Establish New York ICAP Demand Curve Parameters for the 2021/2022 through 2024/2025 Capability Years – Interim Final Draft Report, August 2020, https://www.nyiso.com/documents/20142/14404876/Analysis%20Group%20Interim%20Final%20Demand%20Curve%20Reset%20Report.pdf/214567fb-b960-233f-bcda-4b919678bce4, accessed November 2021

To develop cost and potential estimates for candidate renewable energy resources, E3 relied on New York-specific and zonal-specific cost estimates developed as part of the Clean Energy Standard Cost Study as well as recent project data from the NY-Sun database for distributed solar resources.[69,70] For offshore wind, cost estimates were developed for fixed-bottom resources based on the CES Cost Study, and a multiplier for floating OSW resources was derived from NREL's Annual Technology Baseline (ATB) projections.[71] This study assumes that floating OSW resources are split between Zones J and K, and receive a higher interconnection cost than fixed bottom resources given greater expected distances for those resources to interconnect. Total floating potential was allocated between Zones J and K based on consensus estimates of 13 GW as the maximum amount of OSW that can interconnect directly into Zone J; therefore 13 GW less the fixed potential determined the Zone J floating amount, with the remainder allocated to Zone K. Future cost declines for each technology were applied to the zone-specific cost estimates based on projected cost trajectories from the CES Cost Study and NREL's ATB projections.

Hourly generation shapes for renewable resources were developed using NREL's Wind Integration National Dataset (WIND) Toolkit and NREL's System Advisor Model (SAM) simulator for wind and solar resources, respectively.[72,73] Hourly generation profiles were developed for each renewable resource in each NYISO zone to capture geographic and weather differences and associated resource diversity across New York State. Generation profiles and capacity factors for solar resources also capture differences in installation configurations, with utility-scale solar candidate resources based on a single-axis tracking system and distributed solar resources based on fixed tilt projects.

Candidate resources in RESOLVE also include both 4-hour and 8-hour Lithium-ion batteries; the cost estimates for battery storage were developed using Lazard's Levelized Cost of Storage report as well as NREL's ATB long-term projections, with adjustments made to account for near-term supply chain

[69] NYSERDA and DPS, Clean Energy Standard White Paper, Appendix A – Cost Study, prepared in collaboration with Sustainable Energy Advantage, LLC (SEA), June 2020, Case Number 15-E-0302, available at: https://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?Mattercaseno=15-E-0302., accessed November 2021

[70] NYSERDA, NY-Sun OpenNY Data, available at: https://data.ny.gov/Energy-Environment/Solar-Electric-Programs-Reported-by-NYSERDA-Beginn/3x8r-34rs, accessed November 2021

[71] National Renewable Energy Laboratory (NREL), Annual Technology Baseline 2021, available at: https://atb.nrel.gov/electricity/2021/index, accessed November 2022

[72] NREL, Wind Integration National Dataset Toolkit, https://www.nrel.gov/grid/wind-toolkit.html, accessed November 2021

[73] NREL, System Advisor Model, https://sam.nrel.gov/, accessed November 2021

disruptions.[74] Although all technologies are affected by supply chain constraints today, the imbalance between demand and available supply for materials in the battery storage industry is more acute and is expected to take longer to resolve. Based on analysis conducted in parallel as part of the Storage Roadmap process, the Integration Analysis relies on a forecast for battery storage costs that include a significant increase in prices in the 2020s, converging to a pre-disruption forecast trajectory by 2035.

In Scenario 3, fuel cell resources are available as a candidate resource to provide firm zero-carbon capacity while avoiding combustion. The costs and operating characteristics are derived from the Department of Energy's Fuel Cell Office technical targets, with cost declines that mirror projected cost declines for hydrogen electrolyzers.[75]

More detail on the characterization of candidate resources is available in Annex 1.

Operational Simulation

RESOLVE's optimization includes the annual cost to operate the electric system across RESOLVE's footprint; this cost is quantified using a linear production cost model embedded within the optimization. The following are key components of the RESOLVE model and its representation of the operations of New York's electricity system:

Zonal transmission topology: RESOLVE uses a zonal transmission topology to simulate flows among New York and its neighbors. RESOLVE includes nine zones: five zones capturing the New York system and four zones representing neighboring power systems.

Aggregated generation classes: rather than analyzing each generator within the study footprint independently, generators in each region are grouped together into categories with other plants whose operational characteristics are similar (e.g., nuclear, gas CCGT, gas and fuel oil combustion turbines (CT) and steam turbines (ST)). Grouping like plants together for the purpose of simulation reduces the

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[74] Lazard, Levelized Cost of Storage Analysis-Version 7.0, October 2021, available at: https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf, accessed November 2022

[75] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, Multi-Year Research, Development, and Demonstration Plan, https://www.energy.gov/eere/fuelcells/articles/hydrogen-and-fuel-cell-technologies-office-multi-year-research-development, accessed November 2021

computational complexity of the problem without significantly impacting the underlying economics of power system operations.

Linearized unit commitment: RESOLVE includes a linear version of a traditional production simulation model. In RESOLVE's implementation, this means that the commitment variable for each class of generators is a continuous variable rather than an integer variable, which significantly reduces the amount of time the model needs to solve. Additional constraints on each generator class (e.g., minimum and maximum power output, ramp rate limits, minimum up and down time) are included to represent their operational characteristics and limitations.

Co-optimization of energy & ancillary services: RESOLVE includes reserve requirements in its generator dispatch, which is co-optimized to meet load while simultaneously reserving flexible capacity within NYISO to meet the contingency and flexibility reserve needs across the New York zones.[76]

Smart sampling of days: whereas production cost models are commonly used to simulate an entire calendar year (or multiple years) of operations, RESOLVE simulates the operations of the NY system for 30 independent days. Load, wind, and solar profiles for these 30 days, sampled from the historical meteorological record of the period 2007–2012, were selected and assigned weights so that taken in aggregate, they produced a representation of complete distributions of potential conditions. Daily hydro conditions were sampled separately from the period 1970-2016 to provide a complete distribution of potential hydro conditions. This allows RESOLVE to approximate operating costs and dynamics over an entire year while simulating operations over a smaller subset of days.

Resource Adequacy Modeling Framework

In addition to the operational constraints and hourly simulation described above, RESOLVE includes a statewide planning reserve margin (PRM) constraint and local capacity requirements (LCRs) as a function of system and local peaks, consistent with current NYISO requirements. To ensure that the system remains reliable under changing load and resource conditions, the PRM and LCR constraints are applied on an unforced capacity[77] (UCAP) basis and capture the reliability contributions of renewables and

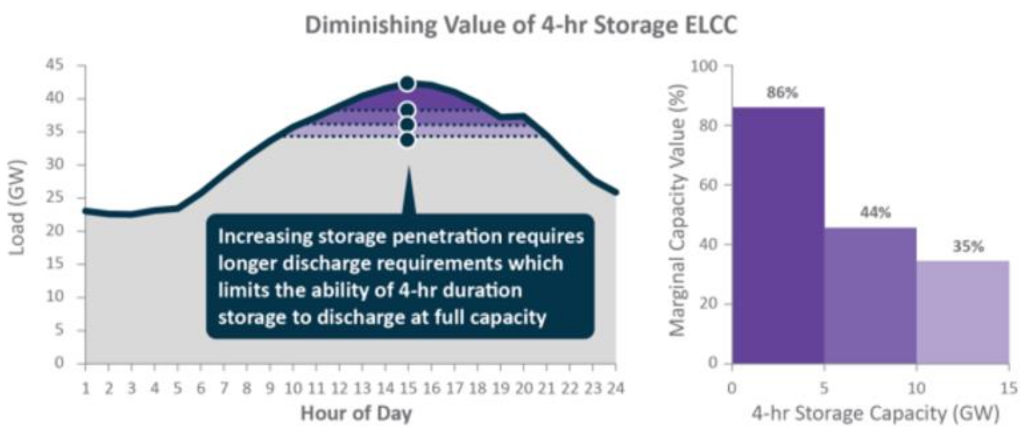
[76] Ancillary services, such as contingency and flexibility reserves, are services necessary to maintain electric system reliability that are provided outside of day-ahead and real-time energy markets.

[77] Unforced capacity is the capacity value of a generation asset after considering the asset's forced outage rate.

storage through ELCC curves developed in RECAP. RECAP performs loss-of-load probability modeling over hundreds of simulated operating years, using 40 years (1979–2018) of weather data to capture linkages between weather, loads, and renewable generation conditions.

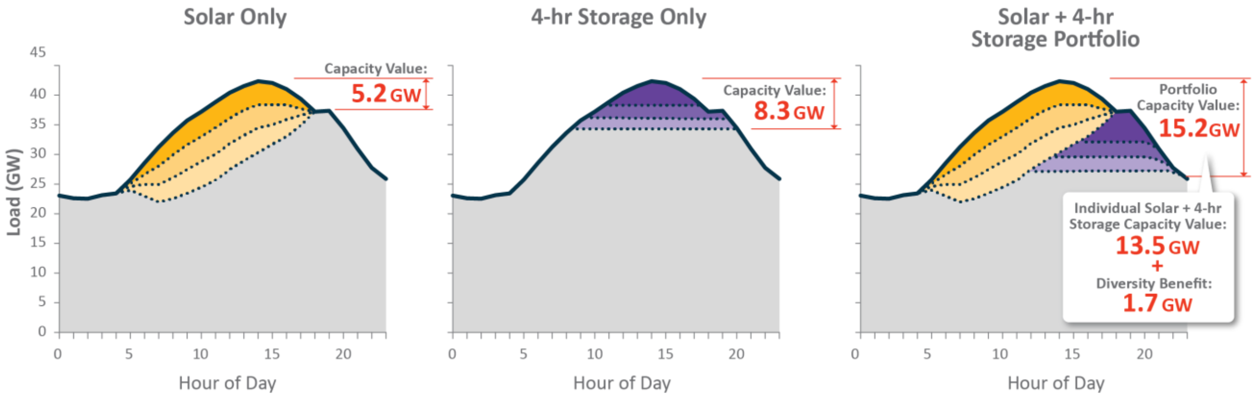
ELCC is the quantity of "perfect capacity" that could be replaced or avoided with renewables or storage while providing equivalent system reliability. For example, an ELCC value of 50% means that the addition of 100 MW of a variable resource could displace the need for 50 MW of perfect capacity without compromising reliability. For an individual intermittent or limited-duration resource, ELCC decreases with increasing penetration. As penetration of renewable resources increases, the net peak shifts to hours with less renewable production, which limits the ELCC that the next tranche of that renewable resource can provide. Storage also yields diminishing returns owing to increase in duration of the net peak; the net peak that remains after a tranche of storage is dispatched is longer in duration than it previously was, as illustrated in Figure 75. Combining resources of different types can yield a total ELCC that is less than or greater than the sum of its parts; an example of this dynamic is shown in Figure 76 for solar and storage resources.

Figure 75. Illustration of Declining ELCC Value for Storage as a Function of Penetration[78]



[78] E3, Capacity and Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy, August 2020, https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf, accessed November 2021

Figure 76. Illustrative Diversity Impacts for Solar and Storage[79]



Resource Adequacy Modeling Results and Inputs for Portfolio Development

E3 used RECAP to develop multiple sets of ELCC curves, which served as inputs to the capacity expansion modeling in RESOLVE to ensure that the resulting portfolios are reliable over a wide range of potential weather conditions (i.e., that the portfolios continue to meet or exceed statewide and local reliability criteria, based on a loss-of-load expectation (LOLE) of 1 day in 10 years).

To capture diversity benefits between specific combinations of resources, E3 implemented two "surfaces", which capture the ELCC of a resource based both on its own penetration on the system as well as the penetration of the other resource. E3 analyzed one ELCC surface for onshore and offshore wind, and a separate ELCC surface for solar and 4-hour battery storage. The solar-storage surface is analyzed with a high bookend estimate of onshore and offshore wind already on the system under each scenario in order to capture potential additional portfolio benefits.

E3 performed this ELCC analysis at both the statewide and local capacity zone level to ensure that the contributions of each resource are appropriately credited towards each requirement, because ELCCs are in part a function of the magnitude of demand. For example, the average ELCC of 1 GW of battery storage will be significantly lower when counted towards Zone J capacity requirements (~10 GW peak in 2020) than towards statewide capacity requirements (~31 GW peak in 2020). The ELCC analysis also takes into account changes in both the timing and magnitude of system loads as a result of the electrification of

[79] E3, Capacity and Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy, August 2020, https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf, accessed November 2021

buildings and vehicles in the Integration Analysis scenarios. E3 used RECAP to assess the reliability contributions of renewable and storage resources under both a Reference Case, in which the system remains summer-peaking throughout the modeled period, as well as a High Electrification case, which reflects levels of electrification consistent with the Integration Analysis scenarios and includes the impacts of New York's shift to a winter-peaking system by 2035. These ELCC surfaces are also scaled within RESOLVE to account for the differences in annual and peak load across the multiple Mitigation scenarios and across years leading up to 2050.

In today's system, the primary reliability challenge from a resource adequacy perspective occurs during summer afternoons and evenings, during peak load windows. As electrification loads are added and the system becomes winter-peaking, the reliability challenge shifts towards winter mornings and evenings, and is compounded by periods in which renewable output is also low during the winter, as shown in Figure 77. The shift in the timing of reliability challenges also has significant impacts on the contributions that renewable and storage resources can provide towards system reliability.

In the Reference Case, the system remains summer-peaking through 2050, and solar resources have a high starting point ELCC value due to strong alignment of solar output with summer afternoon peaks. The ELCC of solar declines steadily as a function of penetration, as the net peak load shifts away from high solar hours towards the evenings. Battery storage has a high starting ELCC value but declines fairly quickly once penetration exceeds roughly 10% of system peaks. Onshore wind has a low starting point ELCC value in the Reference Case due to lack of coincidence with summer afternoons and evenings, while offshore wind has more consistent output during the summer and therefore has a higher starting-point ELCC than onshore wind.

In the Mitigation scenarios, driven by the shift to a winter-peaking system, solar resources have a low ELCC value due to their lack of output during winter mornings and evenings, when system needs are greatest. Relative to the Reference Case, battery storage can provide substantially more reliability value as a function of its overall capacity in the Mitigation scenarios, because system peaks are significantly higher as a result of electrification loads. Onshore and offshore wind also both experience substantial increases in their starting point ELCC values as a result of electrification loads.

Statewide results for "slices" of each ELCC surface are provided in Figure 78 through Figure 81 below. A "slice" represents the contributions of one technology without taking into account the contributions of its complementary technology, e.g., the ELCC contributions of solar without any battery storage on the system. However, when translating ELCC results into RESOLVE, diversity benefits between solar and battery storage, as well as diversity impacts between onshore and offshore wind, are represented on a three-dimensional surface. The diversity impacts between each resource set are captured in Figure 82.

Figure 77: Impacts of Electrification on System Reliability Needs

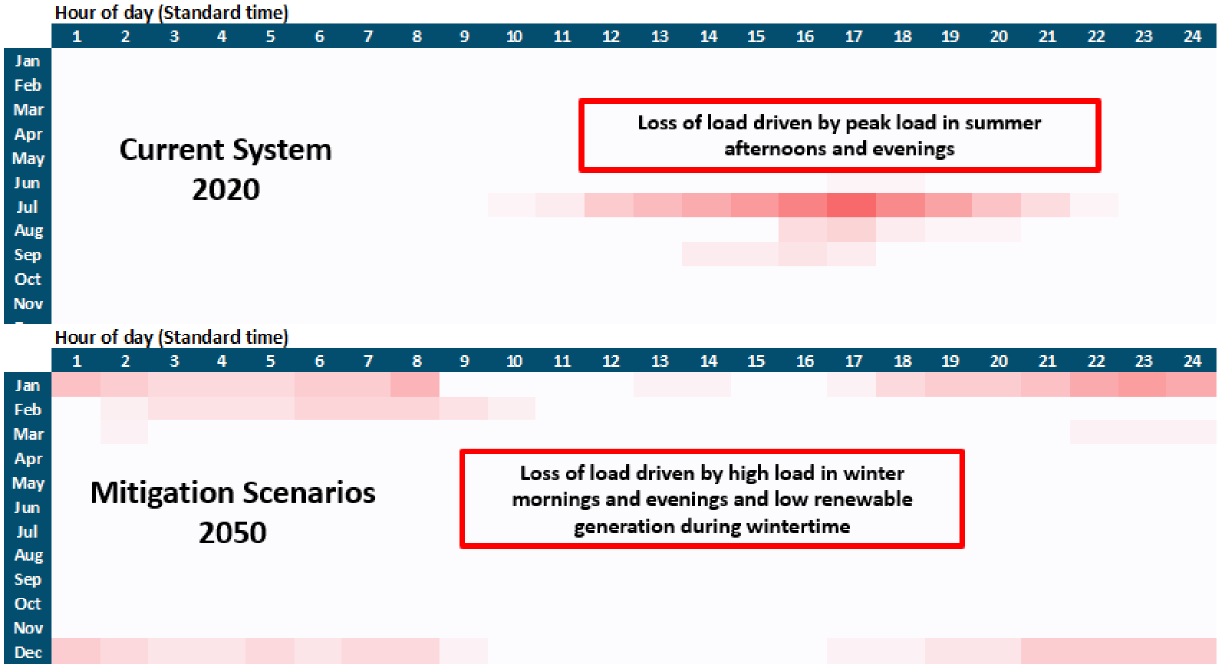


Figure 78: Slices of NYCA ELCC Surface, Onshore and Offshore Wind, 2050 Reference Case

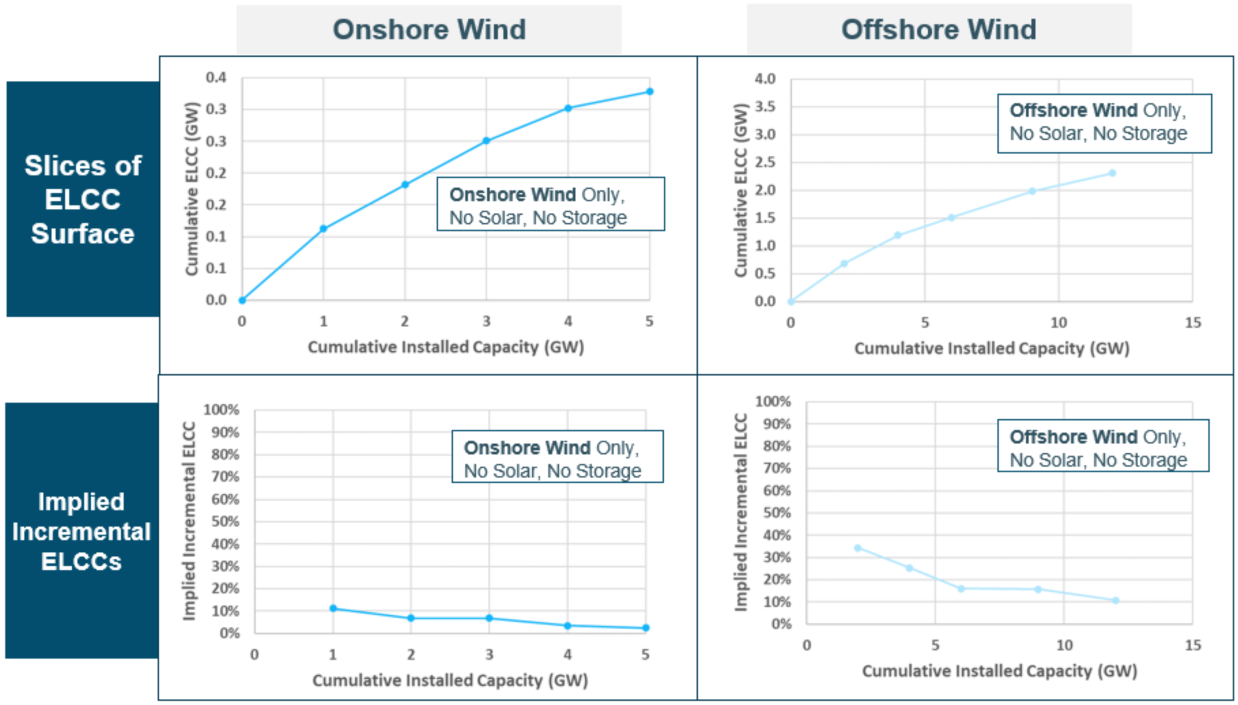


Figure 79: Slices of NYCA ELCC Surface, Solar and 4-hour Battery Storage, 2050 Reference Case

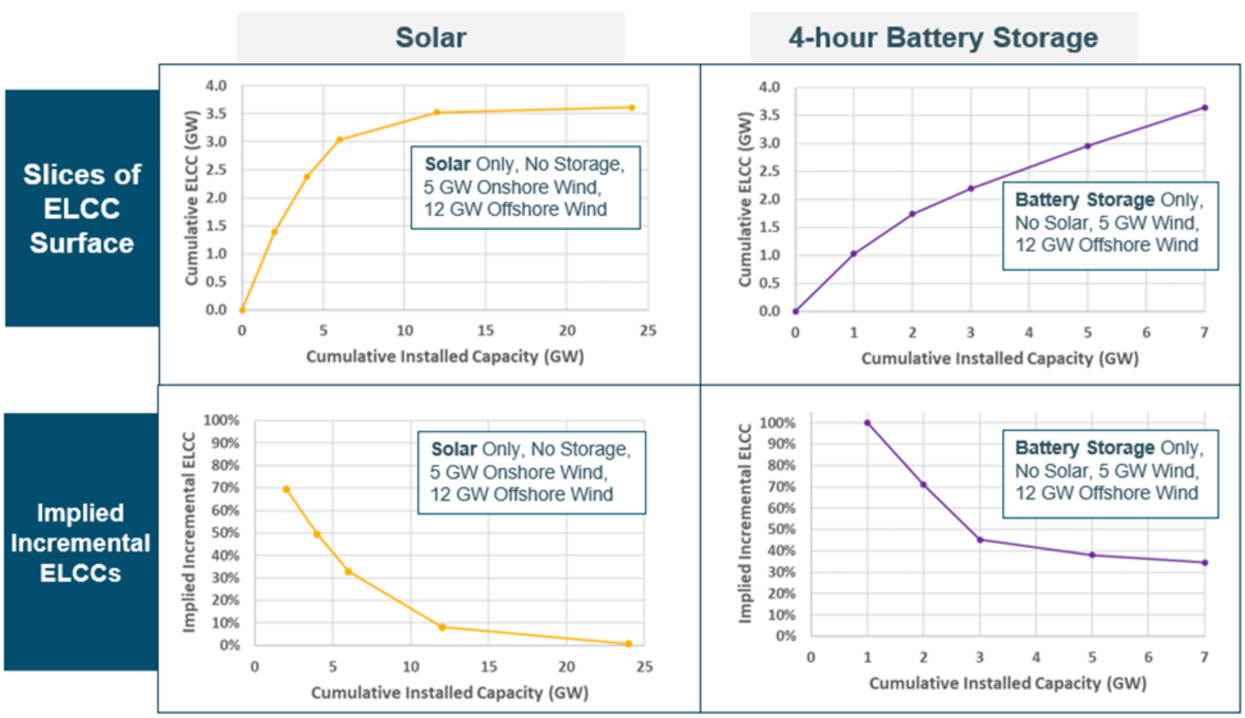


Figure 80: Slices of NYCA ELCC Surface, Onshore and Offshore Wind, 2050 Mitigation Scenarios

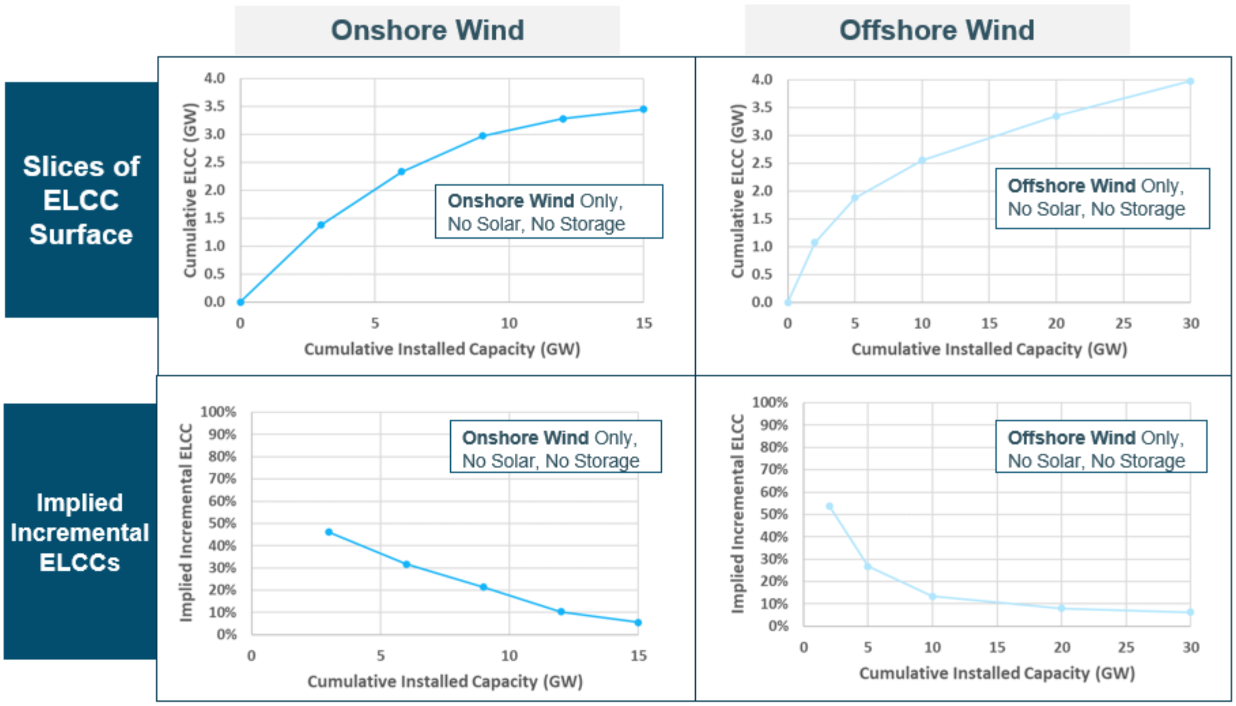


Figure 81: Slices of NYCA ELCC Surface, Solar and 4-Hour Battery Storage, 2050 Mitigation Scenarios

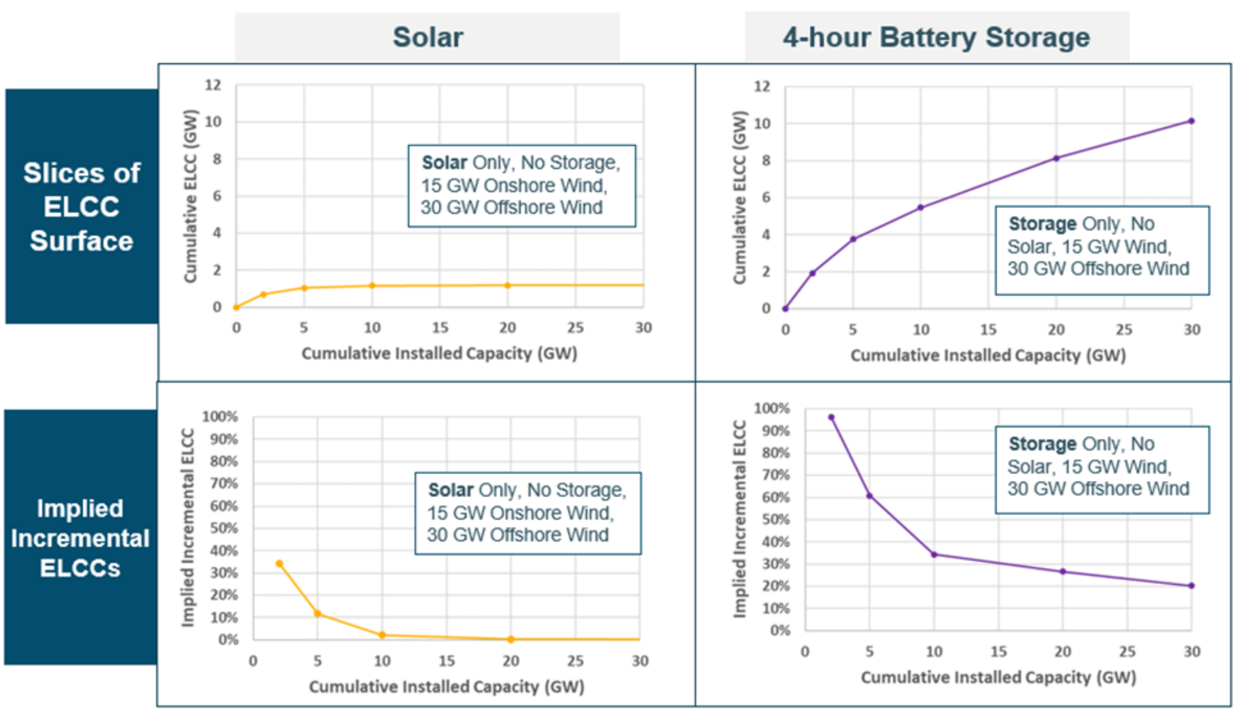
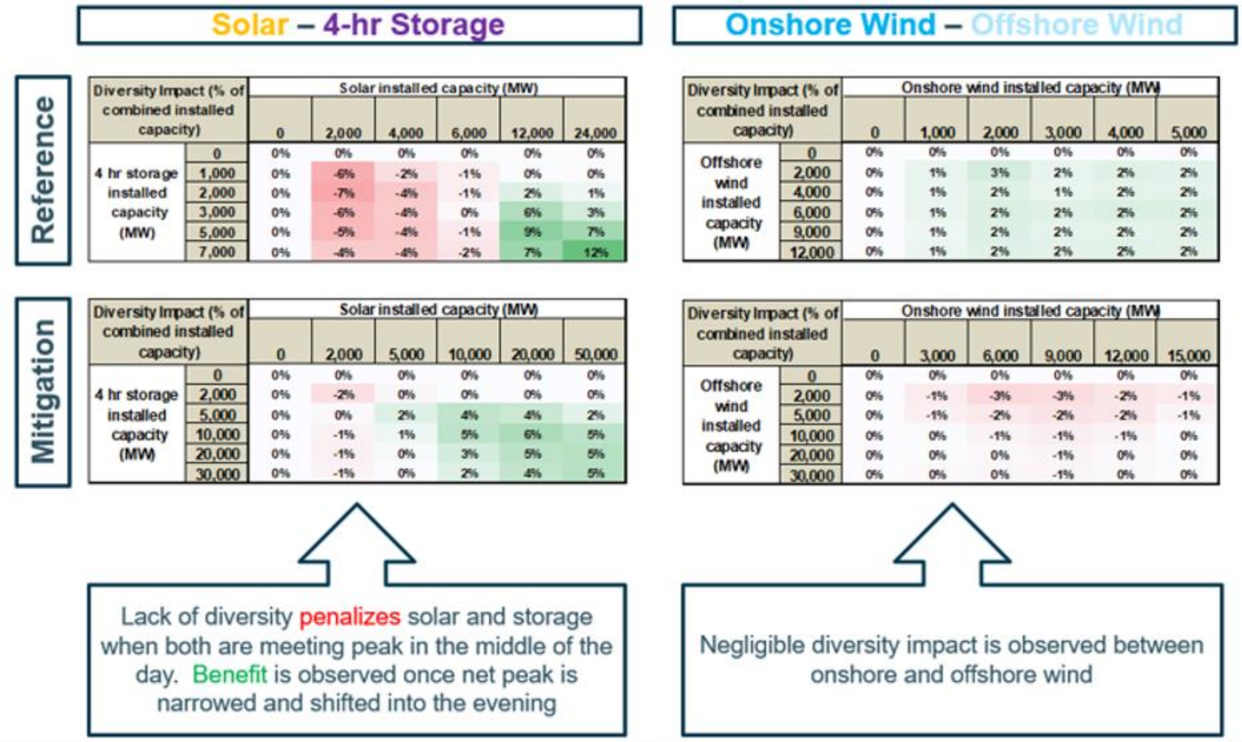


Figure 82: Diversity Impacts in 2050



Reference – Solar / 4-hr Storage

Diversity Impact (% of combined installed capacity)		Solar installed capacity (MW)					
		0	2,000	4,000	6,000	12,000	24,000
4 hr storage installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	1,000	0%	-6%	-2%	-1%	0%	0%
	2,000	0%	-7%	-4%	-1%	2%	1%
	3,000	0%	-6%	-4%	0%	6%	3%
	5,000	0%	-5%	-4%	-1%	9%	7%
	7,000	0%	-4%	-4%	-2%	7%	12%

Reference – Onshore Wind / Offshore Wind

Diversity Impact (% of combined installed capacity)		Onshore wind installed capacity (MW)					
		0	1,000	2,000	3,000	4,000	5,000
Offshore wind installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	2,000	0%	1%	3%	2%	2%	2%
	4,000	0%	1%	2%	1%	2%	2%
	6,000	0%	1%	2%	2%	2%	2%
	9,000	0%	1%	2%	2%	2%	2%
	12,000	0%	1%	2%	2%	2%	2%

Mitigation – Solar / 4-hr Storage

Diversity Impact (% of combined installed capacity)		Solar installed capacity (MW)					
		0	2,000	5,000	10,000	20,000	50,000
4 hr storage installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	2,000	0%	-2%	0%	0%	0%	0%
	5,000	0%	0%	2%	4%	4%	2%
	10,000	0%	-1%	1%	5%	6%	5%
	20,000	0%	-1%	0%	3%	5%	5%
	30,000	0%	-1%	0%	2%	4%	5%

Mitigation – Onshore Wind / Offshore Wind

Diversity Impact (% of combined installed capacity)		Onshore wind installed capacity (MW)					
		0	3,000	6,000	9,000	12,000	15,000
Offshore wind installed capacity (MW)	0	0%	0%	0%	0%	0%	0%
	2,000	0%	-1%	-3%	-3%	-2%	-1%
	5,000	0%	-1%	-2%	-2%	-2%	-1%
	10,000	0%	0%	-1%	-1%	-1%	0%
	20,000	0%	0%	0%	-1%	0%	0%
	30,000	0%	0%	0%	-1%	0%	0%

Parallel Analyses

The Pathways framework provides the final integration analysis for Scoping Plan but incorporates insights and recommendations from Advisory Panels and interacts with complementary studies.[80]

- **Power Grid Study**
- **Buildings Roadmaps**
- **Transportation Roadmap**
- **In-State oil and gas systems mitigation potential study**
- **HFC mitigation potential study**

[80] For more information, see https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Greenhouse-Gas-Emissions

2022 vs 2021 Vintage

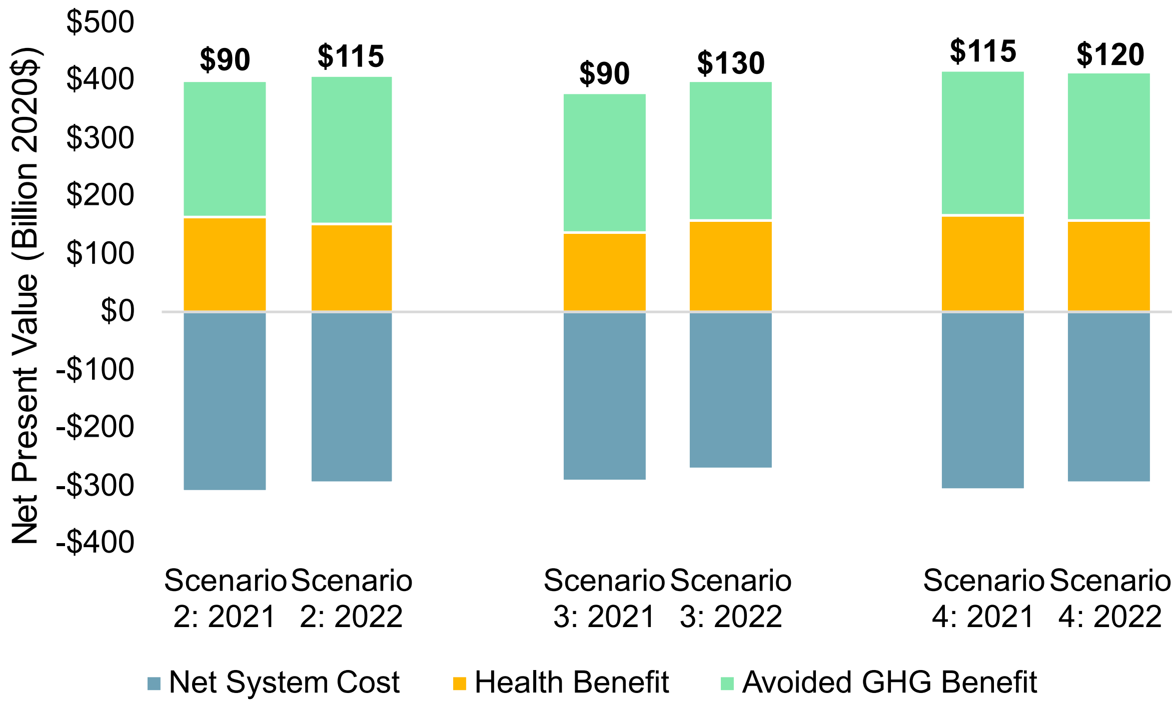
The 2022 vintage is a refresh of the Integration Analysis from the 2021 Draft Scoping Plan to align with the latest information, including a re-benchmark to the latest Statewide Inventory[81] and GHG accounting methodology; updated input data where available; and other general improvements where appropriate. The 2022 vintage does not change the modeling structure or key adoption and performance variables, such as Pathways themes; adoption rates and performance of key technologies, e.g., electric vehicles and heat pumps; electric sector 70x30 and 100x40 requirements; and emission limits.

Updated inputs where available reflect higher near-term fuel and electricity storage prices due to global supply chain disruptions but also long-term declines in electric generation costs, reflecting additional technology progress. These prices can be found in Annex 1. Re-benchmarking to the latest Statewide Inventory and updated accounting led the original Pathways studies to exceed net neutrality, driven primarily by the alignment with the Inventory's approach to treating biogenic fuels as net-zero under the net accounting convention which was performed as a sensitivity in the 2021 vintage. This reduced the need for other expensive mitigation measures like Direct Air Capture that were required to meet the 2050 net neutral target. Various improvements to storage treatment and incorporation of latest expected Tier 4 delivery quantities reduced demand for zero emission firm resources and offshore wind respectively in the Mitigation scenarios. By benchmarking to more recent Inventory data, the 2022 vintage included a refined characterization of fugitive emissions mitigation measures in NYS oil and gas systems. The 2022 vintage included a refined biofuel supply curve to reflect near-term and long-term constraints on New York's ability to obtain biomass feedstock. The health analysis refines geographic allocation of industrial wood emissions toward the areas where combustion occurs which lowered health benefits. Many of these changes reflect feedback received as part of the public comment process.

Note that overall the results reinforce last year's findings that the cost of inaction greatly exceed cost of action; system costs across all scenarios are in the same range given uncertainty (Figure 83); the range of net benefits across the scenarios are quite similar; therefore, it remains important to develop insights across multiple factors, including technology readiness and consumer acceptance.

[81] https://www.dec.ny.gov/energy/99223.html, accessed December 2022.

Figure 83. Benefit and Cost Comparison: 2021 vs 2022 Vintage



Benefit-Cost Approach

This study estimated benefits for two categories: Avoided damages from GHG pollution and avoided public health impacts. These benefits were then compared with energy system costs, which include the capital costs of energy-consuming devices and energy supply infrastructure (including electricity generation and electricity imports) in addition to fuel costs. More information on underlying cost assumptions can be found in Annex 1, and more information on the health co-benefits analysis can be found in Section II.

Calculating Benefits of Avoided GHG Emissions

The value of avoided GHG emissions calculations is based on DEC Value of Carbon guidance, developed under the Climate Act.[82] The DEC Value of Carbon guidance recommends a damages-based approach to valuing avoided GHG emissions, which means that the values are estimates of the monetary impacts on society of GHG pollution. In this study, the total value of avoided GHG emissions is measured in each scenario relative to the Reference Case. The total value of avoided GHG emissions was calculated

[82] The value of avoided GHG emissions calculations is based on DEC guidance: https://www.dec.ny.gov/regulations/56552.html, accessed December 2021

individually for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs). For other GHGs, avoided emissions were converted to carbon dioxide equivalent (CO_2e) using the AR5-20year GWP values. The avoided GHG emissions time series in each year was multiplied by the annual social cost of GHG based on the DEC Value of Carbon guidance appendix, using the central case estimate for each GHG (2% discount rate for GHG emissions). When calculating NPV of avoided GHG emissions benefits to compare with NPV of costs, NPV calculations apply a discount rate of 3.6% to all annual benefit and costs streams. Table 17 below shows the social cost of GHGs used in 2020, 2030 and 2050 for this analysis:

Table 17: Social Cost of GHG Pollutants ($2020/metric ton)

Pollutant	2020	2030	2050
CO2	$121	$137	$172
CH4	$2,700	$3,400	$4,800
N2O	$42,000	$50,000	$66,000

5.2 Data Sources

To characterize energy consumption and greenhouse gas emissions in New York, E3 relied on a variety of state and national data sources. These are summarized in Table 18 below and detailed further in Annex 1.

Table 18. Key Data Sources for Integration Analysis

Sector	Source Type	Source
Global	State Data Source	Cornell Program on Applied Demographics
	Federal Data Source	EIA National Energy Modeling System
		EIA State Energy Data System
		EIA Annual Energy Outlook
	Complementary Study[83]	NYSERDA HFC Mitigation Potential Study
		NYSERDA In-State Oil and Gas Systems Potential Study
		Staff working group analysis of AFOLU and Waste sector emissions
		Health Co-Benefits
Buildings	State Data Source	NYSERDA Residential Baseline Study
		NYSERDA Commercial Baseline Study
		NYSERDA New Efficiency New York Study: Analysis of Residential Heat Pump Potential and Economics
	Federal Data Source	EIA Residential Energy Consumption Survey
		EIA Commercial Buildings Energy Consumption Survey
		DOE LED Adoption Report
		American Community Survey
	Complementary Study	Building Electrification Roadmap
Transportation	State Data Source	NYSDEC MOVES Modeling
	Federal Data Source	US Federal Highway Administration Highway Statistics
	Complementary Study	Clean Transportation Roadmap
Industry	State Data Source	NYSERDA Energy Efficiency & Renewable Energy Potential Study
		NY Department of Labor Employment
	Federal Data Source	American Society of Manufacturers Survey
Electricity Generation	State Data Source	NYISO Gold Book
		NYISO CARIS Study
		NYISO Demand Curve Study
		NYISO Reliability Needs Assessment
		NYSERDA Storage Roadmap
		NYSDPS and NYSERDA Clean Energy Standard White Paper
	Federal Data Source	NREL Annual Technology Baseline
		EIA Annual Energy Outlook
		NREL Technical Potential Study
	National Data Source	Lazard Levelized Cost of Storage
	Complementary Study	Power Grid Study
		Utility T&D Working Group Study

[83] For more information on complementary NYSERDA studies, see https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Greenhouse-Gas-Emissions

5.3 Scenario Assumptions

The integration analysis evaluated a business-as-usual future (Reference Case) a representation of recommendations from CAC Advisory Panels (Scenario 1), and three scenarios designed to meet or exceed GHG limits and carbon neutrality (Scenarios 2 through 4). Scenarios 2, 3, and 4 all carry forward foundational themes based on findings from Advisory Panels and supporting analysis but represent distinct worldviews. A detailed compilation of scenario assumptions can be found in Annex 2.

Reference Case: Business as usual plus implemented policies.

- Growth in housing units, population, commercial square footage, and GDP
- Federal appliance standards
- Economic fuel switching
- New York State bioheat mandate
- Estimate of New Efficiency, New York Energy Efficiency achieved by funded programs: HCR+NYPA, DPS (IOUs), LIPA, NYSERDA CEF (assumes market transformation maintains level of efficiency and electrification post-2025)
- Funded building electrification (4% HP stock share by 2030)
- Corporate Average Fuel Economy (CAFE) standards
- Zero-emission vehicle mandate (8% LDV ZEV stock share by 2030)
- Clean Energy Standard (70x30), including technology carveouts: (6 GW of behind-the-meter solar by 2025, 3 GW of battery storage by 2030, 9 GW of offshore wind by 2035, 1.25 GW of Tier 4 renewables by 2030)

Scenario 1: AP Recommendations: Representation of Advisory Panel recommendations. CAC AP recommendations provide a foundation for all scenarios, but scenario modeling shows that additional effort is needed to meet Climate Act emissions limit. This scenario includes:

- Rapid adoption of electric vehicles
- Critical role for smart growth, transit, and telework
- Rapid building electrification
- Zero emission power sector by 2040, including technology carveouts**:** (6 GW of behind-the-meter solar by 2025, 10 GW by 2030; 3 GW of battery storage by 2030; 9 GW of offshore wind by 2035; 2.55 GW of Tier 4 renewables by 2030)
- Ambitious reductions in emissions from refrigerants, agriculture, waste, and fugitive emissions

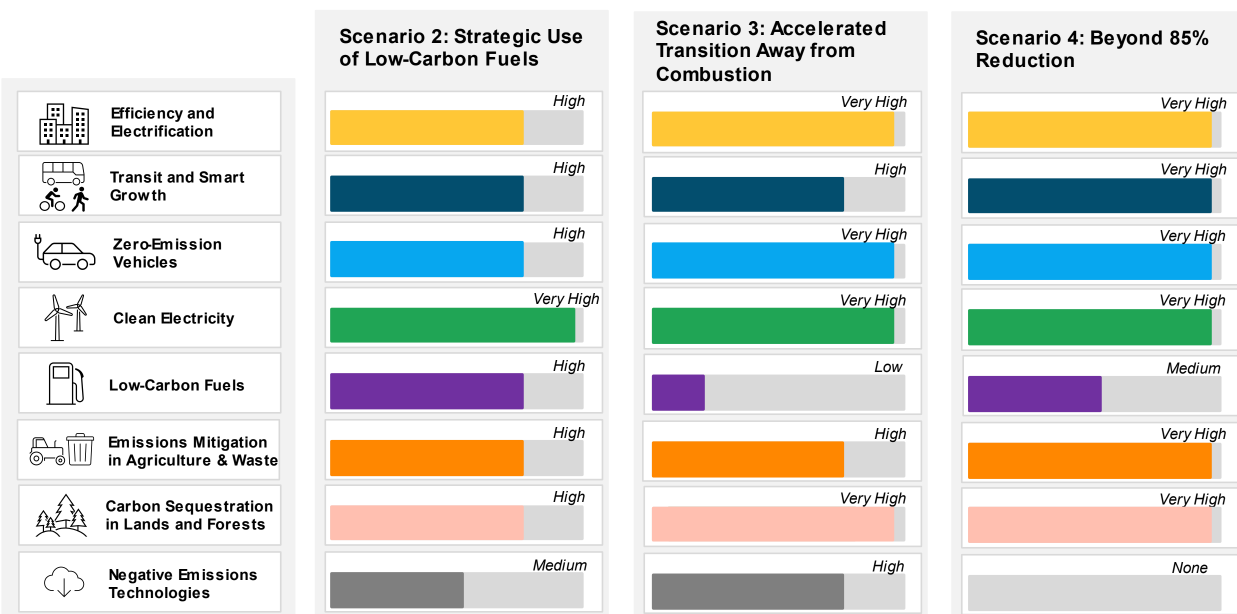
Scenario 2: Strategic Use of Low-Carbon Fuels: Includes the use of bioenergy derived from biogenic waste, agriculture & forest residues, and limited purpose grown biomass, as well as a critical role for green hydrogen for difficult to electrify applications, as well as limited use of negative emissions technologies to achieve carbon neutrality in 2050.

Scenario 3: Accelerated Transition Away from Combustion: Very limited role for bioenergy and hydrogen combustion and accelerated electrification of buildings and transportation, as well as limited use of negative emissions technologies to achieve carbon neutrality in 2050.

Scenario 4: Beyond 85% Reduction: Accelerated electrification and targeted use of low-carbon fuels. This scenario includes additional reductions from transportation emissions through additional smart growth, transit, telework, in-state rail, and hydrogen and electric aviation, as well as innovation in methane abatement. This scenario does not require the use of any negative emissions technologies to achieve net-zero by 2050.

Figure 84 highlights the key differences in assumptions across the three scenarios that meet or achieve New York's GHG emission limits and achieve carbon neutrality by midcentury. All scenarios share common foundational themes of decarbonization, including a zero-emission power sector by 2040, enhancement and expansion of transit, rapid and widespread efficiency and electrification, electric end-use load flexibility, and methane mitigation in agriculture and waste.

Figure 84. Level of Transformation by Mitigation Scenario



Scenario assumptions and level of transformation by sector and action for mitigation scenarios 2, 3, and 4 are summarized in the tables below.

Buildings

Table 19. Level of Transformation by Scenario: Buildings[84]

	Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Efficiency and Electrification	High	Very High	Very High
New Sales of Heat Pumps	77% by 2029, 100% by 2030/2035 (SF/MF+Com)	80% by 2029, 100% by 2030/2035 (SF/MF+Com), 10% early retirement by 2030	80% by 2029, 100% by 2030/2035 (SF/MF+Com), 10% early retirement by 2030
Mix of Heat Pump Technologies	70% ASHP, 10% ASHP + fuel backup, 20% GSHP	77% ASHP, 23% GSHP	77% ASHP, 23% GSHP
Share of Electrified Buildings	18% by 2030, 92% by 2050 1.5 Mil. Households by 2030, 7.8 Mil. by 2050 1.1 Bil. Com sqft by 2030, 5.3 Bil. By 2050	22% by 2030, 92% by 2050 1.8 Mil. Households by 2030, 7.8 Mil. by 2050 1.4 Bil. Com sqft by 2030, 5.6 Bil. By 2050	22% by 2030, 92% by 2050 1.8 Mil. Households by 2030, 7.8 Mil. by 2050 1.4 Bil. Com sqft by 2030, 5.6 Bil. By 2050
Share of Buildings with Efficient Shell	7% Deep Shell, 18% Basic Shell by 2030 26% Deep Shell, 66% Basic Shell by 2050	7% Deep Shell, 18% Basic Shell by 2030 26% Deep Shell, 66% Basic Shell by 2050	7% Deep Shell, 18% Basic Shell by 2030 26% Deep Shell, 66% Basic Shell by 2050
Air Conditioning Saturation	100% saturation by 2050 reflecting climate trends and HP adoption	100% saturation by 2050 reflecting climate trends and HP adoption	100% saturation by 2050 reflecting climate trends and HP adoption
NYC District Heat System	3% annual efficiency improvement, 100% hydrogen conversion by 2050	3% annual efficiency improvement, 100% hydrogen conversion by 2050	3% annual efficiency improvement, 100% hydrogen conversion by 2050
Smart Devices and Conservation (AC, Space Heating)	10% reduction by 2030, 15% by 2050	10% reduction by 2030, 15% by 2050	10% reduction by 2030, 15% by 2050
Low-Carbon Fuels	High	Low	Medium
Hydrogen (via electrolysis)	NYC district heat converted to hydrogen	NYC district heat converted to hydrogen	NYC district heat converted to hydrogen
Biomass feedstock availability	In-state + regional feedstocks incl. energy crops	None	In-state wastes and residues only
Bioenergy utilization	9% RNG, 75% renewable distillate by 2030 100% RNG and renewable distillate by 2050	4% RNG by 2030, 100% by 2050 (Limited volume from targeted methane abatement from landfills and wastewater only)	7% RNG, 7% renewable distillate by 2030 100% RNG and renewable distillate by 2050
Climate-Friendly Refrigerants	High	High	High
Transition to ultralow-GWP and natural refrigerant technologies	Max adoption for building, transportation, and industrial HVAC + refrigeration sectors	Max adoption for building, transportation, and industrial HVAC + refrigeration sectors	Max adoption for building, transportation, and industrial HVAC + refrigeration sectors
Service reclaim at end of life	90% recover rate	90% recover rate	90% recover rate

[84] Electrified buildings include all homes with a heat pump (ASHP, ASHP with fuel backup, GSHP) but do not include homes with electric resistance heat, which are appx. 470,000 in 2030).

Space heating demands are reduced by 27-44% with the basic shell package and 57-90% with the deep shell package, depending on building type. Air conditioning demands are reduced 14-27% with the basic shell package and 9-57% with the deep shell package. The total impact of building shell improvements on total HVAC service demand in buildings is a function of the market penetration of each package and distribution of building types. Building shell improvements include both retrofits and new construction, although all new construction in residential and commercial is assumed to be code -compliant and therefore has lower HVAC service demands relative to the existing building stock. E3 calculated the stock rollover of building shells with a 20-year lifetime to reflect improvements in new construction and opportunities for home retrofits.

Adoption of efficiency and electrification measures affect all existing fuels used for primary heating in buildings (e.g., natural gas, petroleum fuels, and wood).

Transportation

Table 20. Level of Transformation by Scenario: Transportation

		Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Transit and Smart Growth		High	High	Very High
	Transit Service	Enhancement and expansion of bus transit, where service more than doubles in many areas of the state	Enhancement and expansion of bus transit, where service more than doubles in many areas of the state	Enhancement and expansion of bus transit, where service more than doubles in many areas of the state
	Telework + TDM, Walking/Biking, Smart Growth, Rail	Expansion of telework + TDM programs, urban infrastructure, and smart growth	Expansion of telework + TDM programs, urban infrastructure, and smart growth	Further expansion of telework + TDM programs, urban infrastructure, and smart growth, Strategic investments in rail
Zero-Emission Vehicles		High	Very High	Very High
	New Sales of LDV ZEVs	90% by 2030, 100% by 2035, 90/10 BEV/FCEV	98% by 2030, 100% by 2035, 100% BEV 10% early retirement before 2030	98% by 2030, 100% by 2035, 100% BEV 10% early retirement before 2030
	New Sales of MDV ZEVs	40% by 2030, 100% by 2045, 50/50 BEV/FCEV	50% by 2030, 100% by 2045, 75/25 BEV/FCEV	50% by 2030, 100% by 2045, 75/25 BEV/FCEV
	New Sales of HDV ZEVs	40% by 2030, 100% by 2045, 25/75 BEV/FCEV	40% by 2030, 100% by 2045, 50/50 BEV, FCEV	40% by 2030, 100% by 2045, 50/50 BEV, FCEV
	New Sales of Bus ZEVs	100% by 2030	100% by 2030	100% by 2030
	LDV ZEVs on the Road	2.7 Million by 2030, 10 Million by 2050 26% of fleet by 2030, 95% of fleet by 2050	3.4 Million by 2030, 10.1 Million by 2050 33% of fleet by 2030, 96% of fleet by 2050	3.4 Million by 2030, 10.1 Million by 2050 33% of fleet by 2030, 96% of fleet by 2050
	LDV BEV Charging Flexibility	25% of vehicles charge flexibly in 2030, 50% in 2050	25% of vehicles charge flexibly in 2030, 50% in 2050	25% of vehicles charge flexibly in 2030, 50% in 2050
	MHDV ZEVs on the Road	19,000 by 2030, 180,000 by 2050 8% of fleet by 2030, 77% of fleet by 2050	23,000 by 2030, 200,000 by 2050 10% of fleet by 2030, 86% of fleet by 2050	23,000 by 2030, 200,000 by 2050 10% of fleet by 2030, 86% of fleet by 2050
	Bus ZEVs on the Road	10,000 by 2030, 55,000 by 2050	10,000 by 2030, 55,000 by 2050	10,000 by 2030, 55,000 by 2050
Low-Carbon Fuels		High	Low	Medium
	Hydrogen (via electrolysis)	Used for MHDVs and freight rail	Used for MHDVs and freight rail	Used for MHDVs, freight rail, and 15% of aviation by 2050
	Biomass feedstock availability	In-state + regional feedstocks incl. energy crops	None	In-state wastes and residues only
	Bioenergy utilization	75% renewable diesel by 2030, 100% by 2050 100% renewable jet kerosene by 2050	None	7% renewable diesel by 2030, 100% by 2050 48% renewable jet kerosene by 2050
Non-Road Transportation		Medium	Medium	Very High
	Aviation	Efficiency for new airplanes	Efficiency for new airplanes	Efficiency for new airplanes, 16% electrification by 2050 (short haul flights), 15% hydrogen aviation by 2050
	Marine and Ports	75% renewable diesel in 2030, 100% electrification in 2050	100% electrification in 2050	7% renewable diesel in 2030, 100% electrification in 2050
	Rail	90% electrification, 10% hydrogen use in 2050	90% electrification, 10% hydrogen use in 2050	90% electrification, 10% hydrogen use in 2050

Electricity System

Table 21. Level of Transformation by Sector: Electricity System

		Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Clean Electricity		Very High	Very High	Very High
Loads	Annual Electricity Demands: Buildings, Transportation, Industry	163 TWh in 2030, 267 TWh in 2050	171 TWh in 2030, 287 TWh in 2050	170 TWh in 2030, 288 TWh in 2050
Loads	Annual Electricity Demands: Hydrogen Electrolysis	5 TWh in 2030, 42 TWh in 2050	1 TWh in 2030, 27 TWh in 2050	3 TWh in 2030, 31 TWh in 2050
Loads	Peak Electricity Demands	30 GW in 2030, 47 GW in 2050	31 GW in 2030, 52 GW in 2050	31 GW in 2030, 51 GW in 2050
Loads	Peak Electricity Demands (with significant end-use flexibility)	30 GW in 2030, 44 GW in 2050	30 GW in 2030, 49 GW in 2050	30 GW in 2030, 48 GW in 2050
Renewables and Storage	Solar Deployment	18.8 GW in 2030, 64.9 GW in 2050	18.4 GW in 2030, 62.1 GW in 2050	18.9 GW in 2030, 64.5 GW in 2050
Renewables and Storage	Battery Storage Deployment	3 GW in 2030, 19.8 GW in 2050	3 GW in 2030, 21.2 GW in 2050	3 GW in 2030, 22.5 GW in 2050
Renewables and Storage	In-State Onshore Wind Deployment	5.5 GW in 2030, 10.9 GW in 2050	5.5 GW in 2030, 10.4 GW in 2050	5.5 GW in 2030, 11.7 GW in 2050
Renewables and Storage	Wind Imports	1.9 GW in 2030, 6.4 GW in 2050	2.7 GW in 2030, 6.4 GW in 2050	2.8 GW in 2030, 6.4 GW in 2050
Renewables and Storage	Offshore Wind Deployment	6.2 GW in 2030, 14.7 GW in 2050	6.2 GW in 2030, 17.2 GW in 2050	6.2 GW in 2030, 16.0 GW in 2050
Other	Upstate nuclear facilities	20-year license extension	20-year license extension	20-year license extension
Other	Fossil units	Significant decline in fossil utilization, hydrogen combustion starting in 2040	Moratorium on new infrastructure, and existing fossil resources are retired by 2040. Firm capacity needs must be met with technology that avoids local emissions stemming from combustion	Significant decline in fossil utilization, hydrogen combustion starting in 2040
Other	Transmission	Local upgrades required to integrate renewables to bulk system, plus new bulk transmission to deliver zero-emissions power to load centers	Local upgrades required to integrate renewables to bulk system, plus new bulk transmission to deliver zero-emissions power to load centers	Local upgrades required to integrate renewables to bulk system, plus new bulk transmission to deliver zero-emissions power to load centers

Waste

Table 22. Level of Transformation by Sector: Waste

		Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Emissions Mitigation in Waste		*High*	*High*	*Very High*
	Waste diversion	100% waste diversion	100% waste diversion	Characterization of uncertainty in potential for additional innovation in methane managemen & capture for use in “no negative emission technologies” sensitivity analysis
	Reduced methane leakage from existing landfills	10% reduction every 5 years	10% reduction every 5 years	
	Anaerobic digesters in solid waste	Digesters running at capacity in 2030 with 75% methane leak reduction by 2050	Digesters running at capacity in 2030 with 75% methane leak reduction by 2050	
Low-Carbon Fuels		*High*	*Low*	*Medium*
	Methane capture and reuse	Optimistic growth in RNG capture from landfills, wastewater treatment, and manure 32 Tbtu RNG	Targeted RNG capture from landfills, wastewater treatment, and manure 25 Tbtu RNG	Targeted RNG capture from landfills, wastewater treatment, and manure 25 Tbtu RNG

Agriculture, Forestry, Other Land Use and NETs

Table 23. Level of Transformation by Sector: AFOLU and NETs

		Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Emissions Mitigation in Agriculture		*High*	*High*	*Very High*
	Abatement in manure emissions	50% reduction in 2030, 76% reduction in 2050	50% reduction in 2030, 76% reduction in 2050	Characterization of uncertainty in potential for additional innovation in agricultural practices for use in “no negative emission technologies” sensitivity analysis
	Abatement in animal feeding emissions	6% reduction in 2030, 18% reduction in 2050	6% reduction in 2030, 18% reduction in 2050	
	Abatement in soil management	16% reduction in 2030	16% reduction in 2030	
	Additional abatement from future R&D	1 MMT CO2e	1 MMT CO2e	1 MMT CO2e
Low-Carbon Fuels		*High*	*Low*	*Medium*
	Methane capture and reuse	Optimistic growth in RNG capture from landfills, wastewater treatment, and manure 32 Tbtu RNG	Targeted RNG capture from landfills, wastewater treatment, and manure 25 Tbtu RNG	Targeted RNG capture from landfills, wastewater treatment, and manure 25 Tbtu RNG
Carbon Sequestration in Lands and Forests		*High*	*Very High*	*Very High*
	Existing forest land management	Forest sequestration returns to 1990 levels	Forest sequestration returns to 1990 levels	Forest sequestration returns to 1990 levels
	Additional afforestation on marginal agricultural lands	400,000 acres by 2050	1,700,000 acres by 2050	1,700,000 acres by 2050
	Total Natural Sequestration	-35 MMT CO2 in 2050	-40 MMT CO2 in 2050	-40 MMT CO2e in 2050
Negative Emission Technologies (NETs)		*Medium*	*High*	*None*
	Total abatement from direct air capture of CO2 (DAC) or other NETs	-11 MMT CO2 in 2050	-17 MMT CO2 in 2050	0 MMT CO2e in 2050

Industrial Processes and Product Use

Table 24. Level of Transformation by Sector: IPPU

	Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Climate-Friendly Refrigerants	*High*	*High*	*High*
Transition to ultra-low-GWP and natural refrigerant technologies	Max adoption for building, transportation, and industrial HVAC + refrigeration sectors	Max adoption for building, transportation, and industrial HVAC + refrigeration sectors	Max adoption for building, transportation, and industrial HVAC + refrigeration sectors
Service reclaim at end of life	90% recover rate	90% recover rate	90% recover rate
Industrial Processes	*High*	*High*	*High*
Process emissions from cement and iron & steel emissions	100% CCS operations (at 90% CO2 capture rates)	100% CCS operations (at 90% CO2 capture rates)	100% CCS operations (at 90% CO2 capture rates)
Other processes	Maximum abatement from EPA non-CO2 report	Maximum abatement from EPA non-CO2 report	Maximum abatement from EPA non-CO2 report

In-State Oil and Gas

Table 25. Level of Transformation by Sector: In-State Oil and Gas

	Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
In-State Oil and Gas Fugitive Emissions	*High*	*High*	*High*
Leak Detection (LDAR) at Compressor Stations	LDAR at 100% of stations phased in between 2023 and 2030	LDAR at 100% of stations phased in between 2023 and 2030	LDAR at 100% of stations phased in between 2023 and 2030
Pipeline Decommissioning and Building Disconnection	91% commercial and 84% residential decommissioning and building disconnection	99% commercial and 90% residential decommissioning and building disconnection	99% commercial and 90% residential decommissioning and building disconnection

Industry: Energy

Table 26. Level of Transformation by Sector: Industrial Energy Consumption

	Scenario 2: Strategic Use of Low-Carbon Fuels	Scenario 3: Accelerated Transition Away from Combustion	Scenario 4: Beyond 85% Reduction
Industry Electrification and Hydrogen	High	High	High
Industry Efficiency	20% increase in efficiency by 2030, 40% by 2050 for manufacturing	20% increase in efficiency by 2030, 40% by 2050 for manufacturing	20% increase in efficiency by 2030, 40% by 2050 for manufacturing
Industry Electrification	4% of natural gas use electrified by 2030, 33% by 2050	4% of natural gas use electrified by 2030, 83% by 2050	4% of natural gas use electrified by 2030, 83% by 2050
Hydrogen Fuel Switching	17% of non-electrified natural gas use converted to hydrogen by 2030, 100% by 2050	0% of non-electrified natural gas use converted to hydrogen by 2030, 100% by 2050	17% of non-electrified natural gas use converted to hydrogen by 2030, 100% by 2050
Low-Carbon Fuels	High	Low	Medium
Hydrogen (via electrolysis)	High-temperature industries that are challenging to electrify	High-temperature industries that are challenging to electrify	High-temperature industries that are challenging to electrify
Biomass feedstock availability	In-state + regional feedstocks incl. energy crops	None	In-state wastes and residues only
Bioenergy utilization	9% RNG, 75% renewable distillate by 2030 100% RNG and renewable distillate by 2050	4% RNG by 2030, 100% by 2050 (Volumes limited to targeted methane abatement from landfills and wastewater only)	7% RNG, 7% renewable distillate by 2030 100% RNG and renewable distillate by 2050

Section II. Health Co-Benefits Analysis

This section describes the methods and results of the public health benefits analyses undertaken for New York's Climate Act Scoping Plan Integration Analysis. Supplemental data can be found in Annex 3 to this document.

Contents

Acronyms and Abbreviations

AEO	Annual Energy Outlook
CEC	Commission for Environmental Cooperation
CCS	Carbon capture and storage
COBRA	CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool
eGRID	Electricity Generation Resource Integrated Database
EGU	Electricity generating unit
EIA	Energy Information Administration
GHG	Greenhouse gas
ICI	Industrial, commercial, and institutional
ISO	Independent System Operator
ITHIM	Integrated Transport and Health Impact Model
LMI	Low and moderate income
MOVES	Motor Vehicle Emissions Simulator
NEEDS	National Electric Energy Data System
NESCAUM	Northeast States for Coordinate Air Use Management
NO_x	Nitrogen oxides
NYC	New York City
NYS	New York State
PJM	Pennsylvania-Jersey-Maryland electricity grid
$PM_{2.5}$	Fine particulate matter
SO_2	Sulfur dioxide
S-R matrix	Source-receptor matrix
VMT	Vehicle miles traveled Vehicle miles traveled
VOC	Volatile organic compounds

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Chapter 1. Methodology

1.1 Health Analyses Approach Overview

The analysis of public health benefits associated with the Integration Analysis scenarios evaluated the potential for the scenarios to affect changes in public health outcomes relative to the Reference case. As discussed above in Section I of this supplement, the scenarios modeled in the Integration Analysis have been updated between the Draft and this Final Scoping Plan. The public health analysis discussed below has been updated accordingly to reflect the changes in the Integration Analysis scenarios. One exception to this is that detailed electricity sector production modeling was not undertaken again for the health analysis. Based on the projected changes in the electricity generation mix between the Draft and Final Scoping Plans, the potential change in health benefits is estimated to be relatively minor, approximately 0.4% of the total health benefits.

Three analyses were undertaken, evaluating the potential to—

- improve air quality and ensuing health outcomes through reduced combustion and associated pollutant emissions;
- improve public health through increased activity associated with active transportation modes such as walking and cycling; and
- improve health outcomes in homes, especially low and moderate income (LMI) homes, through energy efficiency interventions.

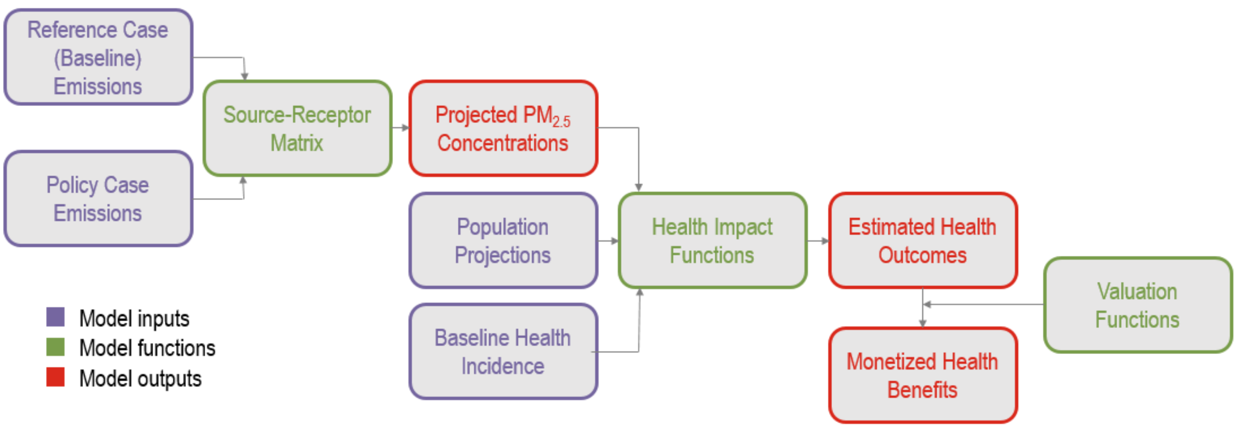
The air quality analysis applied EPA's CO Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool, customized with detailed inputs specific to New York State and the scenarios analyzed, to evaluate air quality and ensuing public health outcomes at the county level. COBRA evaluates ambient air quality based on emissions of direct fine particulate matter ($PM_{2.5}$) and its precursors (sulfur dioxide (SO_2), volatile organic compounds (VOC), and nitrogen oxides (NO_X)) and the ensuing changes in annual average total $PM_{2.5}$ concentrations. The results include 12 different health outcomes, such as premature mortality, heart attacks, hospitalizations, asthma exacerbation and emergency room visits, and lost workdays.

Results in COBRA are calculated as "High" and "Low", reflecting two alternative methods adopted by EPA for evaluating premature mortality and non-fatal heart attacks based on two epidemiological studies of the impacts of air quality on public health. For the Integration Analysis described in Section I of this

Supplement, the economy-wide benefit results applied the High case, and the Low case is included in the cost and benefits uncertainty analysis.

See Figure 1 for an overview of the framework of inputs and outputs from the COBRA analysis. Note that COBRA does not include additional potential benefits from reduced ozone concentrations; the value of those benefits is estimated to be a few percent of the benefits associated with $PM_{2.5}$. Additional benefits not included are potential benefits associated with reduced nitrogen dioxide (NO_2) concentrations; and reduced toxic pollutant emissions[85], which were not evaluated given the high uncertainty and lack of sufficient data to provide reasonable estimates.

Figure 1. Framework of Inputs and Outputs for COBRA Analysis



COBRA was applied to the Reference case and the scenarios described above for 2020 through 2050 in 5-year increments, and the value of the improved health outcomes was interpolated to estimate benefits for the entire period. The analysis includes emissions in all sectors throughout the continental U.S. and the effect of the scenarios on emissions in New York.

Potential public health benefits from increased physical activity due to increased use of active transportation modes, while accounting for potential increases in traffic collisions, were estimated using the Integrated Transport Health Impacts Model, customized to represent New York State.

[85] For a list of toxic air pollutants, see NYSDEC, DAR-1, https://www.dec.ny.gov/chemical/8568.html

Values from published literature on the health and safety benefits of energy system changes and weatherization programs in homes were used to estimate the potential benefits of energy efficiency interventions. These applied only to LMI homes expected to have upgraded systems and weatherization. While additional benefits may result from building changes in higher income homes, they would likely be lower, and no data is available to estimate those details.

1.2 Scenarios

NYSERDA analyzed the health impacts of three of the key scenarios in its Integration Analysis: the Strategic Use of Low Carbon Fuels scenario (Scenario 2), the Accelerated Transition Away from Combustion scenario (Scenario 3), and the Beyond 85% scenario (Scenario 4). Each of these scenarios includes assumptions about the rate of emission reductions due to climate change mitigation activities. The scenarios are each compared to a Reference case, which represents currently implemented policies, including:

- 70% renewable electricity,
- Energy efficiency targets under NYSERDA's New Efficiency: New York program,[86] and
- Zero-emission vehicle sales mandate[87] and related measures already implemented based on the memorandum of understanding[88] that New York signed with eight other states.[89]

The Reference case also includes business-as-usual growth in key drivers of energy activity, including population, households, and vehicle miles traveled (VMT). This scenario does not achieve the State's GHG emission reduction Limits and is used as a counterfactual to compare with the deeper emissions reductions under the scenarios.

Each scenario represents a potential pathway to reach the GHG Limits set out in the Climate Leadership and Community Protection Act that includes a diverse mix of measures such as:

- Additional building efficiency,
- Electrification of buildings and transportation,

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[86] This program includes a suite of energy efficiency measures, including state appliance standards, building codes, and building electrification, with a target of 185 trillion British thermal units (Btu) of end-use energy savings in buildings and industrial facilities below the 2025 energy-use forecast. https://www.nyserda.ny.gov/About/Publications/New-Efficiency

[87] New York Codes, Rules and Regulations, Title 6, Subpart 218-4. "Zero Emission Vehicle Sales Mandate".

[88] New York, California, Connecticut, Maryland, Massachusetts, New Jersey, Oregon, Rhode Island, Vermont. "State Zero-Emission Vehicle Programs—Memorandum of Understanding". October 24, 2013. https://www.zevstates.us/

[89] The states have agreed to a target of at least 3.3 million zero emission vehicles operating in their states collectively by 2025.

- Advanced sustainable biofuels,
- Natural and working lands, and
- Direct air capture of CO_2.

These scenarios achieve at least 40% greenhouse gas (GHG) reductions by 2030 and 85% by 2050, relative to 1990 levels. They also achieve carbon neutrality by 2050. The scenarios also reach 70% renewable electricity by 2030 and 100% zero-carbon electricity by 2040.

The scenarios were all analyzed for the years 2025, 2030, 2035, 2040, 2045 and 2050. The air quality in each of the three scenarios was compared with the Reference case to determine the change in air quality and ensuing health impacts due to the GHG emission reduction pathways.

1.3 Ambient Air Quality Analysis

Input Data

COBRA calculates annual health benefits based on the change in $PM_{2.5}$ concentrations at the county level using health impact functions from the epidemiological literature. As shown in Figure 1, above, the health impact functions in COBRA require four sets of inputs:

- Reference case (baseline) emissions of primary $PM_{2.5}$ and its precursors NO_x, SO_2, VOCs, and NH_3;
- Scenario emissions of those pollutants;
- Population; and
- Baseline health incidence.

Each of these inputs must be developed for each analysis year: 2025, 2030, 2035, 2040, 2045, and 2050. The following subsections discuss the approach for developing each of these data inputs. To the extent possible, the same datasets and assumptions used in the Integration Analysis were applied to ensure consistency. The data development also applied assumptions used by New York State (NYS) in the development of air quality state implementation plans. The areas where different datasets and assumptions are used are discussed in more detail below.

Population

Population estimates for each of the scenario years were developed for all counties in NYS based on data from Cornell University's County Projects Explorer.[90,91] This is the same dataset used to project energy demand in the Pathways Integration Analysis.

The Cornell population projections, which extend through 2040, were projected through 2050 based on linear extrapolation of the population trend in each county from 2025-2040. This is consistent with the approach used for the Pathways analyses that produced the energy and emissions scenarios.

For counties outside of NYS, population projections by age group from the Census Bureau,[92] which extend to 2060, were used.

Baseline Health Incidence

COBRA requires data on baseline health incidence for each health endpoint to determine the change in public health benefits due to a change in ambient $PM_{2.5}$ concentrations. One of the most important health endpoints included in COBRA is avoided premature mortality, which typically accounts for more than 98 percent of the monetized health benefits from emissions reduction scenarios.

Projected baseline mortality rates used in the analysis were based on national-level projections of deaths by year and age group from the Census Bureau, which extends through 2060.[93] The national-level estimate of annual deaths in each age group were distributed to each county in the U.S. based on the proportion of projected population in each age group in that year.

The analysis also uses the incidence rates for other non-mortality related health effects, such as hospitalizations, asthma exacerbations, and lost work and school days, that are included in COBRA.

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90 Cornell University. 2018. County Projections Explorer. Ithaca, New York: Cornell Program on Applied Demographics. https://pad.human.cornell.edu/counties/projections.cfm

91 Cornell University. 2018. Projections Methodology. Ithaca, New York: Cornell Program on Applied Demographics. https://pad.human.cornell.edu/counties/downloads/2018Methodology.pdf

92 U.S. Census Bureau. 2017. Projected Population by Single Year of Age, Sex, Race, and Hispanic Origin for the United States: 2016 to 2060. https://census.gov/data/datasets/2017/demo/popproj/2017-popproj.html

93 U.S. Census Bureau, 2017. Projected Deaths by Single Year of Age, Sex, Race, and Hispanic Origin for the United States: 2016 to 2060. https://census.gov/data/datasets/2017/demo/popproj/2017-popproj.html

New York City Health Impact Functions

In addition to the default health impact functions included in COBRA, the New York City (NYC) Department of Health and Mental Hygiene also regularly uses two health impact functions based on epidemiological studies of the impacts of $PM_{2.5}$ concentrations on health outcomes in NYC. Specifically, this analysis uses NYC-specific functions for respiratory-related emergency room visits[94] and hospital admissions for cardiovascular effects.[95]

The NYC health impact functions have the same functional form as those used in COBRA for these health endpoints:

$$DeltaIncidence = 1 - e^{-\beta \times AQ} \times BaselineIncidence \times Population \tag{1}$$

Where:

DeltaIncidence	=	The change in incidence of the health endpoint due to a change in $PM_{2.5}$ concentrations
β	=	The beta coefficient, representing the impact of a change in $PM_{2/5}$ concentrations on the incidence of the health impact
AQ	=	The change in $PM_{2.5}$ concentrations ($\mu g/m^3$)
BaselineIncidence	=	Baseline incidence of the health endpoint
Population	=	County-level population

The NYC functions differ from the default COBRA functions in the value of their beta coefficient, which is a unitless number that represents the impact of a change in $PM_{2.5}$ concentrations on the incidence of the health endpoint. The beta coefficient for cardiovascular-related hospital admissions is 0.000995. COBRA pools together health impact functions from five studies, with beta coefficients ranging from 0.00068 to 0.00189, with an average value of 0.0011. The NYC beta value falls within the range of default beta values used in COBRA.

Similarly, the beta coefficient used in the NYC function for respiratory-related emergency room visits is 0.004533. COBRA pools together three studies with beta coefficients ranging from 0.0029 to 0.0056,

[94] Ito K, Thurston G, Silverman R. 2007. Characterization of $PM_{2.5}$, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. *Journal of Exposure Science and Environmental Epidemiology*, 17: S45-S60.

[95] Ito K, Mathes R, Ross Z, Nadas A, Thurston G, Matte T. 2011. Fine Particulate Matter Constituents Associated with Cardiovascular Hospitalizations and Mortality in New York City. Unpublished.

with an average value of 0.0041. The NYC beta value for this health endpoint also falls within the range of default beta values used in COBRA.

Reference Case and Scenario Emissions

COBRA estimates the change in health impacts due to changes in $PM_{2.5}$ concentrations, based on emissions of primary $PM_{2.5}$ and precursors to secondary $PM_{2.5}$ formation, including NO_x, SO_2, NH_3, and VOCs. County-level emissions of these pollutants were estimated for each of the three scenarios and the Reference case, with a focus on the following sectors:

- Electric generating units
- On-road
- Non-road
- Buildings

The approaches used to estimate emissions in each sector differed for counties in NYS and counties outside of NYS and are discussed in the subsections below. Emissions for all other sectors, such as aviation, agriculture, and wildfire emissions, were taken from the existing 2025 baseline in COBRA and were held constant in all years for the Reference case and all scenarios. Note that since the COBRA analysis is entirely dependent on incremental concentrations, these unchanged emissions do not affect the results. There are some mitigation strategies in the Integration Analysis that reduce GHG emissions, particularly methane, in the agriculture and waste sectors. While there may also be some reduction in VOC emissions associated with these methane emission reductions, they are not included in this analysis. These sectors account for less than 1 percent of the VOC emissions in NYS, so the VOC emission reductions associated with mitigation strategies in the Integration Analysis are assumed to be negligible.

Emissions in Counties in NYS

The county-level emissions data for counties in NYS were estimated based largely on assumptions and results from the Integration Analysis, along with additional data provided by NYS Department of Environmental Conservation (DEC). The Integration Analysis generally estimated changes in fuel consumption and emissions at the regional level within NYS (the regions are described in Section I of this Supplement), though in some cases it estimated county-level emissions. The subsections below discuss the approach for estimating the county-level Reference case and scenario emissions for each sector, including the approach for distributing regional-level data to the county level as needed.

Electricity Generation Sector

The analysis used county-wide emissions of NO_x, SO_2, and $PM_{2.5}$ from the electricity sector for both the Reference case and scenarios. These emissions were based on electricity sector modeling conducted for NYSERDA by E3 LLC using the RESOLVE model. Analysis in RESOLVE provides the electric sector loads, peaks and the expected capacity mix by zone. These projections of loads and capacity mix were then modeled by ICF in PROMOD, an electric market simulation model, to project generation patterns that are used to calculate county-level emission projections. While RESOLVE models the electric system through a representation of generating units as aggregate blocks of capacity by zone and capacity type, PROMOD's representation of individual generators is a requirement to produce emission projections on the county-level. The electricity-sector emissions included emissions from electric generating units both within NYS and in the neighboring region, including the Independent System Operator (ISO) New England and Pennsylvania-Jersey-Maryland (PJM) electricity grids.

Note that the PROMOD results used in the health analysis are based on inputs for the Draft Scoping Plan. While there have been some updates in the projected electricity generation mix for the final Scoping Plan, PROMOD was not re-run for the final analysis. Based on the projected changes in the electricity generation mix between the Draft and Final Scoping Plans, the potential change in health benefits is estimated to be relatively minor, approximately 0.4% of the total health benefits.

ICF estimated the criteria pollutant emissions from the electricity generation sector using NO_x, SO_2, and $PM_{2.5}$ emission rates from EPA data sources, including the National Electric Energy Data System (NEEDS)[96] and the Air Markets Program Data,[97] and the Emissions and Generation Resource Integrated Database (eGRID).[98] ICF benchmarked the emissions and generation projections, comparing to historical EPA emission data and generation reported from NYISO.

The emissions data developed by ICF did not include emissions of NH_3 or VOC from the electricity generation sector. As discussed in more detail below in the *Uncertainty and Limitations* section,

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[96] U.S. Environmental Protection Agency. 2019. National Electric Energy Data System (NEEDS) v6. https://www.epa.gov/airmarkets/national-electric-energy-data-system-needs-v6. Accessed September 2019.

[97] U.S. Environmental Protection Agency. 2019. Air Markets Program Data. https://ampd.epa.gov/ampd/. Accessed September 2019.

[98] U.S. Environmental Protection Agency. 2020. Emissions and Generation Resource Integrated Database (eGRID): eGRID2018. https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid. Accessed July 2020.

emissions of these pollutants in the electricity generation sector were not estimated for the health analysis, based on the results from a sensitivity analysis conducted in COBRA.

While the electricity sector modeling included analysis of changes in emissions in PJM and ISO New England, in addition to NYS, it was felt that the results of specific emissions changes at specific locations outside of NYS were uncertain, particularly given uncertainty about decarbonization pathways for other states in the region. As a result, the core health analysis results only include benefits from emission reductions within NYS.

In Scenarios 2 and 4, from 2040 onwards, the remaining thermal electricity generating units (EGUs) are assumed to burn hydrogen. In addition, sensitivity analyses were included to evaluate the potential for the same units operating on renewable natural gas, and to evaluate the uncertainty regarding NO_x emissions from hydrogen combustion. Given the higher flame temperature of hydrogen, NO_x emissions from combustion may increase. Based on the review of technical materials focused on hydrogen combustion, it was estimated, as a conservatively high assumption, that NO_x emissions rates would double with hydrogen combustion relative to natural gas.[99] ICF and NYSERDA reviewed air permit data provided by NYSDEC and concluded that, for most EGUs assumed to be operating in 2040 and onwards, a doubling of NO_x emission rates would result in emission rates above their current air permit limits. While pathways to maintaining emission rates under hydrogen combustion are currently still uncertain, there are many options for sources to transition to hydrogen combustion while further reducing NO_x emissions. Technology solutions that would reduce NO_x emissions under hydrogen consumption could include larger and/or more efficient selective catalytic reduction (SCR) control technology, a type of NO_x controls currently in use in the power generation sector. Low NOx hydrogen combustions turbine systems are also under active development and feature advanced fuel mix systems, and while those system would require continued development to allow for 100% hydrogen combustion, active research indicates that lower than double NO_x emission rates may be feasible starting in 2040.

Therefore, a sensitivity case was modeled where NOx emissions rates were maintained at current levels, assuming continued compliance with emission rates and successful control of NO_x emissions at current

[99] https://www.ge.com/content/dam/gepower-new/global/en_US/downloads/gas-new-site/future-of-energy/hydrogen-for-power-gen-gea34805.pdf, Figure 10 and accompanying text

rates under hydrogen combustion. These two NO_x rate cases provide the best estimate for the range of outcomes associated with the potential combustion of hydrogen for electricity generation.

Overall, the sensitivity analyses included the following cases for evaluating the effect of fuel choice for the remaining thermal generation, all undertaken with Scenario 2:

- No combustion (hydrogen fuel cell or similar long-term storage technology)
- Renewable natural gas combustion (NO_x and PM similar to natural gas)
- Hydrogen combustion – low-NO_x (NO_x emissions similar to natural gas, no PM emissions)
- Hydrogen combustion – high-NO_x (NO_x emissions double relative to natural gas, no PM emissions)

Due to time constraints, Scenario 4 was not run through the PROMOD analysis and county-level emissions were therefore estimated. Scenario 4 county-level emissions were projected using the relationship between Scenario 2 and Scenario 4 results in RESOLVE and the PROMOD projections for Scenarios 2. For each model region, year, and generation unit type, the ratio between thermal generation in RESOLVE for Scenario 2 and 4 was multiplied by the PROMOD generation and emissions from the Scenario 2 results for the respective regions, categories and years.

The ratios applied to the PROMOD Scenario 2 thermal generation mix and emissions to estimate Scenario 4 thermal generation and emissions were derived from zonal thermal generation in RESOLVE in Scenarios 2 and 4. In PROMOD, individual zones contribute different amounts to the statewide generation totals than in Scenario 2 in RESOLVE. When the RESOLVE-based ratios were applied to the PROMOD zonal generation in Scenario 2, this difference in zonal generation for Scenario 2 carries over into Scenario 4 estimates. To ensure that the estimated Scenario 4 thermal generation and emissions align with the state-wide trends identified in RESOLVE between Scenario 2 and 4, all zonal thermal generation and emissions by zone were scaled with a secondary factor. The secondary factor for all types of thermal generation and emissions was calculated as the ratio between the state-wide generation increase in RESOLVE between Scenarios 2 and 4 and the state-wide thermal generation increase between Scenario 2 and the estimated Scenario 4 thermal generation. With the zonal thermal generation ratios and the secondary factor, regional thermal generation trends as well as state-wide trends are maintained for the scenario 4 estimates of county-level emissions.

On-road Sector

Emissions estimates from the on-road sector were developed using emission factors from EPA's MOtor Vehicle Emissions Simulator (MOVES)[100] and projections of VMT developed for the Integration Analysis. The process for developing the MOVES emissions factors and VMT are discussed in the following subsections.

MOVES Emissions Factors

MOVES can be run in either "inventory mode" or "emissions factor mode." DEC typically runs MOVES in inventory mode, which results in estimates of hourly emissions by vehicle type, road type, and fuel type for each county. In emission factor mode, MOVES does not result in emissions, but rather emission factors, i.e., emission rates per VMT by vehicle type, road type, fuel type, and speed bin for each hour of the day and month of the year for each county. The Integration Analysis includes multiple scenarios with different assumptions about changes in projected VMT. As a result, running MOVES to generate emission factors, rather than emissions, provides more flexibility to analyze different scenarios.

Because MOVES can be a computationally intensive model to run, with run times taking hours or days, and because this analysis required multiple runs covering scenarios for several years, DEC and NYSERDA developed an approach to provide the necessary emission factors while minimizing the amount of modeling time required. This approach followed guidelines from EPA's Transportation Conformity Guidance for Quantitative Hot-spot Analyses from $PM_{2.5}$.[101] In particular, DEC developed emission factors for two representative counties in New York: Suffolk County to represent downstate counties, and Erie County to represent upstate counties. In addition, the emission factors were developed for the months of January and August, to cover the extremes of temperatures, rather than all months of the year. The emission factors were calculated for each hour of the day by speed bin for each analysis year.

DEC provided hourly data for each county on the proportion of VMT in each speed bin by vehicle type and road type. These data were used with the emission factors by speed bin to develop a weighted average emission factor for each vehicle type, road type, and fuel type in each county. The hourly emission factors

[100] U.S. Environmental Protection Agency. 2018. MOtor Vehicle Emissions Simulator. https://www.epa.gov/moves

[101] U.S. Environmental Protection Agency. 2015. Transportation Conformity Guidance for Quantitative Hot-spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas. Washington, DC. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NMXM.pdf

by speed bin were weighted based on the proportion of VMT in each speed bin in each hour from the DEC data.

VMT Data

The Integration Analysis used county-level projections of VMT by vehicle type and road type to develop scenarios with different levels of VMT reductions. The VMT used in each scenario and the Reference case of the Integration Analysis were aggregated to five regions (described in Section I of this Supplement) and were reported by vehicle type and fuel type, but not road type. However, because the weighted average MOVES emission factors differ by county and road type, the projected VMT from the Integration Analysis were disaggregated to the county and road type level.

Ratios from the VMT projections were used to disaggregate the regional VMT from the Integration Analysis scenarios into VMT by county, road type, vehicle type, and fuel type. For example, Albany County had approximately 30 percent of the passenger car VMT of the Region F counties in the disaggregated VMT data in 2030. Therefore, 30 percent of the projected VMT in Region F from the Integration Analysis scenarios was attributed to Albany County. Similarly, within Albany County, 50 percent of the VMT from passenger cars was on the Urban Unrestricted-Access road type in the disaggregated data. Therefore, 50 percent of the VMT estimated for Albany County was distributed to that road type.

Emissions Calculations

The county level emissions were calculated by multiplying the weighted average VMT in each county for each road type, vehicle type, and fuel type, by the corresponding emissions factor, and then summing across road types and vehicle types.

$$E_{p,c,f} = \sum_{r,v} EF_{p,c,r,v,f} \times VMT_{c,r,v,f} \qquad (2)$$

Where:

$E_{p,c,f,}$ = On-road sector emissions of pollutant *p* in county *c* from fuel type *f*

$EF_{p,c,r,v,f}$ = Weighted average emission factor for pollutant *p* from road type *r*, vehicle type *v*, and fuel type *f* mapped to county *c*

$VMT_{c,r,v,f}$ = Vehicle miles traveled on road type *r* by vehicle type *v* and fuel type *f* in county *c*

Non-road Sector

The Reference case and scenario emissions from the non-road sector were developed for NYS counties using county-level non-road sector emissions projections provided by NYS DEC, which were developed using EPA's MOVES model. These estimates include emissions from combustion from non-road equipment in various sectors, such as construction, agriculture, lawn and garden, and support vehicles for ports, airports, and railroads.

MOVES does not include emissions from commercial marine vessels, locomotives, or aircraft. Emissions from commercial marine vessels and locomotives were estimated based on growing 2017 emissions in these sectors by the change in fuel consumption projected in these sectors as estimated in the Integration Analysis in the Reference case and scenarios. The regional-level data on fuel consumption in these sectors was distributed to the counties based on the proportion of $PM_{2.5}$ emissions in these sectors in 2017. This distribution assumes no major change in the geographic distribution in commercial marine or rail activity over time. The health impacts analysis excluded changes in emissions from aircraft; while some changes may occur in that sector in the scenarios, given the uncertainty in the location of those reductions, including both elevation and distance from populations, it was conservatively assumed that those changes would not substantially impact public health. Furthermore, it is assumed that renewable jet fuel would not have a substantial impact on emissions relative to fossil jet fuel.

Buildings Sector

The Reference case and scenario emissions from the buildings sector were developed for NYS counties based on the estimated fuel consumption in the industrial, commercial/institutional, and residential sectors from the Integration Analysis. Emissions in each sector were estimated using fuel- and sector-specific emissions factors from the EPA Industrial, Commercial, and Institutional (ICI) Emissions Tool and NYS DEC's Residential Emissions Tool. These emissions factors were multiplied by the estimated consumption of each fuel type in each sector.

$$E_{p,c} = EF_{p,c,f,s} \times F_{c,f,s} \quad (3)$$

Where:

Ep,c,	=	On-road sector emissions of pollutant p in county c
EFp,c,r,v	=	Emission factor for pollutant p from fuel type f in sector s in county c
Fc,f,s	=	Consumption of fuel type f in sector s in county c

Regional-level data on fuel consumption from the Integration Analysis were distributed to the county level based on distribution factors in the ICI and Residential Emissions Tools. In the ICI Tool, the distribution factors are based on data from the Census Bureau on employment in the industrial and commercial sectors.[102] In the Residential Emissions Tool, the distribution factors are based on the number of homes in each county that use each fuel type as a primary fuel source, from the Census Bureau's American Community Survey.[103]

There are two exceptions to this method. One is for residential wood consumption. Instead of using data from the Census Bureau to distribute the residential wood consumption from the Integration Analysis to the county level, the health analysis used county-level data on residential wood consumption in NYS derived from a survey conducted by the Commission for Environmental Cooperation (CEC) and the Northeast States for Coordinated Air Use Management (NESCAUM).[104] This is the same data used by the U.S. EPA to estimate criteria pollutant emissions for the 2017 National Emissions Inventory. The Integration Analysis data on regional residential wood consumption were summed to the state level and distributed to the county level based on the proportion of wood consumption in each county from the CEC and NESCAUM data.

The other exception to the county-level distribution method is for industrial coal. Rather than using employment-based distribution factors, the analysis uses data on point source fuel consumption from DEC. In 2019 (the latest year of data available) there were four industrial facilities that used coal. The projected coal consumption from the Integration Analysis was distributed to these counties based on the proportion of their coal consumption in 2019.

Emissions in Counties Outside of NYS

In addition to the emissions estimates for counties in NYS, emissions estimates were also developed for all other counties in the contiguous United States. This step is important, because the health benefits in NYS are dependent not only on emissions in the state, but also on emissions from other states that are transported in the atmosphere. The emissions in counties outside of NYS are generally not expected to differ between the Reference case and scenarios, with the exception of the electricity generation sector, in which mitigation activities in NYS may result in changes in emissions at electric generating units in other states in the region. Emissions from the electric generation sector in counties in the ISO New England and

[102] U.S. Census Bureau. 2018. County Business Patterns. https://www.census.gov/programs-surveys/cbp.html

[103] U.S. Census Bureau. 2019. American Community Survey. https://www.census.gov/programs-surveys/acs

[104] Commission for Environmental Cooperation. 2019. Residential Wood Use Survey to Improve U.S. Black Carbon Emissions Inventory Data for Small-Scale Biomass Combustion. Montreal, Canada.

PJM Interconnection regional transmission organization areas were estimated as part of the modeling process described above for NY State counties.

Reference case and scenario emissions were developed for counties outside of NYS based on projected energy consumption from the Energy Information Administration's (EIA's) Annual Energy Outlook (AEO).[105] The AEO contains regional projections of fuel consumption by fuel type and sector by year through 2050. The 2025 emissions baseline from COBRA was adjusted to create new baselines for each scenario year based on the percent change in projected fuel consumption between 2025 and the scenario year. For example, the AEO projects that consumption of natural gas in the electricity generation sector will decrease by 15 percent between 2025 and 2030 in the New England region. Therefore, the emissions in the Fuel Comb. Elec. Util/Gas/Natural emissions tier in the 2025 baseline in COBRA was decreased by 15 percent for all counties in New England for the 2030 emissions baseline. This process was repeated for each region and for all fuel types in each sector, including the electricity generation, industrial, commercial, residential, and transportation sectors.

This approach is based on the approach used for an analysis of the health benefits of the Regional Greenhouse Gas Initiative.[106] That analysis required individual emissions baselines for the years 2009-2014, and the 2007 baseline from COBRA was adjusted based on percent changes in EIA data on fuel consumption to develop those emissions baselines.

Uncertainty and Limitations

This analysis has multiple sources of uncertainty and limitations. Some of the sources of uncertainty are based on the use of the COBRA Tool, which is a screening-level tool for the assessment of health benefits from emission reductions. Other sources of uncertainty are based on simplifying assumptions used in the analysis and underlying uncertainties in the available data. Each of these sources of uncertainty is discussed below. Because this is a screening-level analysis, the uncertainty is not fully quantified, but it is generally discussed here qualitatively. In some cases uncertainty is discussed in a semi-quantitative manner, such as the results of sensitivity analyses.

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105 U.S. Energy Information Administration. 2019. Annual Energy Outlook 2019. https://www.eia.gov/outlooks/aeo/

106 Abt Associates. 2017. Analysis of the Public Health Impacts of the Regional Greenhouse Gas Initiative. https://www.abtassociates.com/insights/publications/report/analysis-of-the-public-health-impacts-of-the-regional-greenhouse-gas

Uncertainty in Underlying Datasets

The health analysis relied on multiple underlying datasets, which have been projected through 2050, including energy consumption in each sector, VMT, and population. Each of these datasets has some degree of uncertainty; however, because the uncertainty of these underlying datasets is not quantified, it is not necessarily clear how it affects the results of the analysis. For this reason, this analysis is an estimate of health outcomes that could result from the outlined scenario and associated assumptions about energy consumption, emissions, and population growth in future years.

Uncertainty in the Use of the COBRA Tool

One of the sources of uncertainty in this analysis is related to the use of COBRA, including uncertainty around both the air quality modeling and benefits analysis.

Air Quality Modeling

COBRA includes a reduced-form air quality model to estimate the impact of changes in emissions in a given county on the air quality in other counties, accounting for the transport of pollution in the atmosphere. While COBRA is considered a screening-level tool, it has been used in many analyses by NYSERDA, U.S. EPA, and other agencies to provide an estimate of the health benefits of emissions reductions.

The reduced form air quality model included in COBRA, called the Source-Receptor (S-R) Matrix, was developed using a more sophisticated model called the Climatological Regional Dispersion Model to establish relationships between sources of emissions and receptors at the county level. The development of the S-R Matrix involved modeling of all emissions sources in each county, including point sources, nonpoint sources, and mobile sources. Point sources were modeled based on their actual location, while nonpoint and mobile sources were modeled at the center of each county. The dispersion modeling produced a set of transfer coefficients for each county that represent the relationship between emissions in a source county and air quality concentrations in all other receptor counties (including within the county itself). There are four transfer coefficients in the S-R matrix for each county, based on four levels of stack heights: ground-level sources and low, medium, and high stacks.

COBRA estimates the formation of secondary $PM_{2.5}$ through the reaction of SO_2 and NO_x with NH_3 to form ammonium sulfate and ammonium nitrate, as well as the oxidation of VOCs to form secondary organic aerosols. These reactions are based on the projected emissions of each pollutant, which were determined for each sector for this analysis as discussed above in the Input Data section. The atmospheric chemistry simulations in the model allow it to be flexible to account for changing air pollutant concentrations in NYS. For example, recent studies have shown a sharp decline in SO_2 emissions and resulting ammonium sulfate concentrations in NYS since the early 2000s.[107,108] Therefore, even while SO_2 and other pollutant emissions are projected to continue to decline in NYS, COBRA accounts for this in the resulting estimation of secondary $PM_{2.5}$ formation.

It should be noted that the S-R Matrix in COBRA is calibrated to reproduce observed $PM_{2.5}$ concentrations. In the most recent version of COBRA, the emissions from the 2011 National Emissions Inventory were run through the model and the results were compared to actual observed $PM_{2.5}$ concentrations. The differences between the modeled and observed concentrations were used to develop county-level calibration factors that were incorporated into the model. The county-level calibration factors are multiplied by the estimated $PM_{2.5}$ concentrations in each county, and the calibration factors range from 0.16 to 3.53, with an average value of 0.91 across all counties. Nevertheless, this analysis focuses on the differences in air quality between the Reference case and each scenario, and the resulting health impacts, rather than the absolute estimated ambient $PM_{2.5}$ concentrations.

In addition, the S-R matrix used in COBRA has been compared favorably to the CALPUFF model in an analysis of emissions from power plants in Georgia, where it was reported that COBRA produced results that were generally similar to those from the more sophisticated dispersion model.[109] The results of that comparison indicated that estimates of primary $PM_{2.5}$ and secondary $PM_{2.5}$ formation from SO_2 emissions predicted by the S-R matrix were within 6 percent of those predicted by CALPUFF.

Benefits Analysis

While the air quality model in COBRA is a reduced-form model, the approach used in COBRA to estimate the health impacts from changes in air quality is *not* a reduced-form approach. The health impacts included in COBRA are standard health impact functions used in EPA regulatory analyses, and are the same functions included in EPA's Benefits Mapping and Analysis Program. These health impact

[107] Blanchard, C.L. S.L. Shaw, E.S. Edgerton, and J.J. Schwab. 2019. Emission influences on air pollutant concentrations in New York state: II. $PM_{2.5}$ organic and elemental carbon constituents. Atmospheric Environment: X, 3: 100039.

[108] Masiol, M., S. Squizzato, D.Q. Rich, and P.K. Hopke. 2019. Long-term trends (2005-2016) of source apportioned $PM_{2.5}$ across New York State. Atmospheric Environment, 201:110-120.

[109] Levy, J., A. Wilson, J. Evans, and J. Spengler. 2003. Estimation of Primary and Secondary Particulate Matter Intake Fractions for Power Plants in Georgia. *Environmental Science and Technology*, 37:5528-5536.

functions were developed from the epidemiological literature, which identified changes in health outcomes associated with changes in $PM_{2.5}$ concentrations. While these functions are commonly used to estimate changes in health outcomes, they also have some uncertainty. To address this uncertainty, COBRA provides the results of multiple health impact functions. In particular, COBRA estimates premature adult mortality using two separate health impact functions (Krewski et al.[110] and Lepeule et al.)[111]. The results from the health benefits analysis, including the monetized health benefits, are presented separately using these two health impacts functions, which can be seen as a high and low range of the estimates. As discussed above, the health analysis uses two additional health impact functions also regularly used by the NYC Department of Health and Mental Hygiene to estimate changes in cardiovascular-related hospital admissions and respiratory-related emergency room visits in NYC.

It should be noted that there are additional health impact functions that could be used in this analysis. For example, one recent study on $PM_{2.5}$ exposure in NYS used data from the Global Burden of Disease study to estimate mortality impacts.[112] However, the health impact functions included in COBRA continue to be among the most widely used in benefits analyses, including in recent analyses of health impacts of $PM_{2.5}$ exposure in New York City, which used the Krewski function included in COBRA.[113,114]

Nevertheless, the health impact functions included in COBRA were developed from a specific population exposed to specific levels and compositions of $PM_{2.5}$, and conditions in NYS have changed since these functions were developed. For example, the health impact function from the Krewski study was based on examining mortality impacts from 500,000 people in 116 U.S. cities between 1980 and 2000. The levels and compositions of $PM_{.2.5}$ have decreased substantially since 2000, as discussed above, with sharp declines in ammonium sulfate, making ammonium nitrate and secondary organic aerosols relatively more important components of $PM_{2.5}$. However, the synthesis of the research into $PM_{2.5}$ impacts on public

[110] Krewski, D., Jerrett, M., Burnett, R.T., Ma, R., Hughes, E., Shi, Y., Turner, M.C., Pope III, C.A., Thurston, G., Calle, E.E. and Thun, M.J., 2009. *Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality* (No. 140). Boston, MA: Health Effects Institute.

[111] Lepeule, J., Laden, F., Dockery, D. and Schwartz, J., 2012. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. *Environmental health perspectives*, *120*(7), pp.965-970.

[112] Jin, X, A.M. Fiore, K. Civerolo, J. Bi, Y. Liu, A. van Donkelaar, R.V. Martin, M. Al-Hamadan, Y. Zhang, and T.Z. Insaf. 2019. Comparison of multiple $PM_{2.5}$ exposure products for estimating health benefits of emission controls over New York State, USA. Environmental Research Letters, 14: 084023.

[113] Kheirbek, I., J. Haney, S. Douglas, K. Ito, S. Caputo, and T. Matte. 2014. The public health benefits of reducing fine particulate matter through conversion to cleaner heating fuels in New York City. Environmental Science and Technology, 48: 13573-13582.

[114] Kheirbek, I., J. Haney, S. Douglas, K. Ito, and T. Matte. 2016. The contribution of motor vehicle emissions to ambient fine particulate matter public health impacts in New York City: a health burden assessment. Environmental Health, 15: 89.

health conducted for EPA's draft Integrated Science Assessment for Particulate Matter indicates that the literature provides evidence that the health impact functions may be linear with no threshold below which reductions in exposure to $PM_{2.5}$ provides no benefits.[115] In other words, even though $PM_{2.5}$ concentrations have been reduced in NYS in the time since the health impact functions were developed, the evidence suggests that the functions can adequately estimate changes in health impacts even at relatively low levels of $PM_{2.5}$. Similarly, EPA's draft Integrated Science Assessment finds that the literature is unclear as to whether changes in the composition of secondary $PM_{2.5}$ species results in differential changes to health impacts. For this reason, this health analysis, along with most other similar benefits analyses, uses the total change in $PM_{2.5}$ concentrations to evaluate health impacts rather than looking separately at impacts by the different $PM_{2.5}$ species.

Another limitation in this analysis is that it focuses specifically on health benefits due to $PM_{2.5}$ reductions and does not estimate changes in health impacts associated with ozone. The focus on $PM_{2.5}$ reductions is based on the fact that health benefits from $PM_{2.5}$ reductions tend to be substantially larger than the health benefits from ozone reductions. For example, EPA found that $PM_{2.5}$ accounted for approximately 85 percent of the health benefits of emission reductions associated with the Clean Air Act, with ozone accounting for the remainder.[116] Similarly, a recent analysis of air quality implications of electrification in California found that $PM_{.2.5}$ accounted for 97 percent of the benefits, with ozone accounting for 3 percent.[117] The California electrification study is somewhat similar to this analysis in that it reduces emissions of all pollutants as a result of reduced combustion (as opposed to the Clean Air Act analysis which applied various different controls for different pollutants).

COBRA also does not estimate other benefits of reduced $PM_{2.5}$ concentrations, such as improved visibility and reduced ecological impacts. Furthermore, there may be some additional benefits associated with reducing toxic pollutant emissions not already accounted for within the $PM_{2.5}$ emissions, which were not accounted for given the limited health and emissions data and high uncertainty.

[115] U.S. Environmental Protection Agency. 2018. Integrated Science Assessment for Particulate Matter: External Review Draft. Research Triangle Park, North Carolina.

[116] U.S. Environmental Protection Agency. 2011. The Benefits and Costs of the Clean Air Act from 1990 to 2020. Final Report – Rev. A. U.S. Environmental Protection Agency Office of Air and Radiation.https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2020-report-documents-and-graphics.

[117] Alexander, M., et al. 2019. *Air Quality Implications of an Energy Scenario for California Using High Levels of Electrification.* Prepared by Electric Power Research Institute and Ramboll for California Energy Commission. Palo Alto, California.

All of the above limitations indicate that while the analysis captures most of the benefits, there are some additional benefits which would accrue. Therefore, the benefits calculated in this analysis may be seen as a lower bound on the actual total benefits of the NYS GHG emission reduction pathways.

Limited Pollutants in Electricity Generation Sector

The county-level emissions data from the electricity generation sector included emissions of NO_x, SO_2, and primary $PM_{2.5}$, but it did not include emissions of NH_3 or VOCs. However, since emissions of these pollutants from this sector are relatively minor they were not included; electricity generation accounted for approximately 1 percent of the NH_3 emissions and 0.1 percent of the VOC emissions in New York in the 2017 National Emissions Inventory. Emission reduction of these pollutants from other sectors, which were included, are substantially higher.

In addition, a sensitivity analysis was conducted, involving running multiple scenarios in COBRA, changing emissions of all five pollutants in some scenarios and only of NO_x, SO_2, and $PM_{2.5}$ in other scenarios. The results of these sensitivity analyses showed less than a 1 percent difference in the total health benefits between scenarios.

As a result, NH_3 or VOC emissions from the EGU sector were not estimated for this analysis. This is a conservative assumption because including emission reductions from those pollutants would results in slightly higher total health benefits.

Simplifying Assumptions in On-Road Sector Modeling

In the MOVES modeling for the on-road sector NYS DEC did not develop emissions factors for all 62 New York counties. Rather, emissions factors were developed for two representative counties: Suffolk to represent downstate counties and Erie to represent upstate counties. These emissions factors were used with county-specific data on speeds by road type to estimate emissions in each county. This is the same approach that EPA uses to estimate the emissions from the on-road sector for the National Emissions Inventory.

In addition, NYS DEC did not model emissions factors for all months of the year, but instead modeled emission factors for January and August. These simplifications are in line with EPA's guidance for transportation conformity quantitative hot-spot analyses of $PM_{2.5}$,[118] which specifies that the modeling can use representative months rather than all months of the year.

Assumptions about Carbon Capture and Storage

The Integration Analysis is using a limited amount of CCS as a control strategy for some portion of the emissions in the industrial sector. The health analysis did not make any adjustments to the criteria pollutant emissions from any energy consumption in the industrial sector that uses CCS as a control technology. Most of the literature on criteria pollutant impacts of CCS has focused on the electricity generation sector, with relatively brief mention of the use of CCS in industrial settings. The literature suggests that this type of control has the potential to substantially reduce SO_2 emissions by more than 90 percent for coal-fired units, but the impacts on primary $PM_{2.5}$ and NO_x are less certain.[119] Some studies suggest that pre-treatment of exhaust gases to remove primary $PM_{2.5}$, NO_x and SO_2 prior to removal of CO_2 increases the efficiency of the CO_2 controls.[120,121] The Integration Analysis does not specify whether additional criteria pollution controls will be added to industrial equipment to increase the efficiency of CO_2 removal. One type of post-combustion CCS technology—amine scrubbing—has the potential to increase NH_3 emissions, because emissions of the amine solvent used in the CO_2 control can oxidize to ammonia,[122] although the Integration Analysis does not specify whether this technology will be used in the industrial sector. NH_3 reacts with SO_2 and NO_x to form ammonium sulfate and ammonium nitrate, which are key components of secondary $PM_{2.5}$. An increase in NH_3 emissions would lead to increases in secondary $PM_{2.5}$ formation only if there is excess SO_2 and NO_x for it to react with. There have been large decreases in ammonium sulfate concentrations in New York State since the early 2000s, and little change in the ammonium nitrate concentrations. The Integration Analysis projects further decreases in both SO_2

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118 U.S. Environmental Protection Agency. 2015. Transportation Conformity Guidance for Quantitative Hot-spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas. Washington, DC. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NMXM.pdf

119 Koornneef, J, A. Ramirez, T. van Harmelen, A. van Horssen, W. Turkenburg, and A. Faaij. 2010. The impact of CO_2 capture in the power and heat sector on the emission of SO_2, NO_x, particulate matter, volatile organic compounds, and NH_3 in the European Union. Atmospheric Environment, 44: 1369-1385.

120 Spigarelli, B.P. and S.K. Kawatra. 2013. Opportunities and challenges in carbon dioxide capture. Journal of CO_2 Utilization, 1: 69-87.

121 Mukherjee, A., J.A. Okolie, A. Abdelrasoul, C. Niu, and A.K. Dalai. 2019. Review of post-combustion carbon dioxide capture technologies using activated carbon. Journal of Environmental Sciences, 83: 46-63.

122 Heo, J., S.T. McCoy, and P.J. Adams. 2015. Implications of ammonia emissions from post-combustion carbon capture for airborne particulate matter. Environmental Science and Technology, 49: 5142-5150.

and NO_x emissions. Therefore, there may already be excess ammonia in NYS, suggesting that an increase in NH_3 emissions may not necessarily increase $PM_{.2.5}$ formation.

Because it is unclear which specific type of CCS technology will be used in the industrial sector or whether additional criteria pollution controls will be employed, the health analysis made no adjustments to the criteria pollutant emissions for industrial sector facilities that use CCS. This assumption is likely to be conservative, given that CCS could also reduce criteria pollutant emissions and increase health benefits.

Assumptions about Renewable Fuels

The Integration Analysis includes consumption of renewable fuels, including biodiesel and renewable diesel in both the Reference case and scenarios. Renewable diesel is a synthetic fuel that is chemically similar to petroleum diesel. Biodiesel has different characteristics and is therefore generally blended with petroleum diesel up to 20 percent. Biodiesel is currently blended into transportation fuels and heating oil in New York. For example, heating oil in NYC currently includes 5 percent biodiesel, increasing up to 20 percent by 2030.

One of the potential GHG mitigation strategies included in the scenarios involves increasing consumption of renewable fuels in the transportation and building sectors. The literature is mixed on whether renewable diesel reduces emissions compared to petroleum diesel. Studies have found both increases and decreases in NO_x emissions from renewable diesel compared to petroleum diesel, by +/-20%.[123,124,125] Studies have generally found that emissions of $PM_{2.5}$ from renewable diesel are similar to or lower than petroleum diesel by up to 40%.[123,125,126] Two analyses by the California Air Resources Board (CARB) have found no significant difference in $PM_{2.5}$ emissions from renewable diesel or biodiesel compared to

[123] Singh, D., K.A. Subramanian, and S.K. Singal. 2015. Emissions and fuel consumption characteristics of a heavy-duty diesel engine fueled with Hydroprocessed Renewable Diesel and Biodiesel. Applied Energy, 155: 440-446.

[124] Vojtisek-Lom, M., V. Beranek, P. Mikuska, K. Krumal, P. Coufalik, J. Siokrova, and J. Topinka. 2017. Blends of butanol and hydrotreated vegetable oils as drop-in replacement for diesel engines: Effects on combustion and emissions. Fuel, 197: 407-421.

[125] Singh, D. KA. Subramanian, and M.O. Garg. 2018. Comprehensive review of combustion, performance and emissions characteristics of a compression ignition engine fueled with hydroprocessed renewable diesel. Renewable and Sustainable Energy Reviews, 81: 2947-2954.

[126] Cadrazco, M., A. Santamaria, and J.R. Agudelo. 2019. Chemical and nanostructural characteristics of the particulate matter produced by renewable diesel fuel in an automotive diesel engine. Combustion and Flame, 203: 130-142.

petroleum diesel in newer (post-2007) engines.[127,128] This would indicate that there would be no reduction in $PM_{2.5}$ emissions from on-road sources.

Similarly, studies of biodiesel have found both increases and decreases in NO_x emissions compared to petroleum diesel.[129,130] Biodiesel also tends to have similar or potentially slightly lower $PM_{2.5}$ emissions compared to petroleum diesel. One study found a reduction in emissions of approximately 6% for B20 blends,[131] while the CARB studies mentioned above found no significant difference in $PM_{2.5}$ emissions in newer (post-2007) engines. The CARB studies did find reductions in $PM_{2.5}$ emissions from both renewable diesel and biodiesel compared to petroleum diesel of up to 40% in older (pre-2007) engines, many of which are still in use in non-road applications.

There is little to no research comparing biodiesel or renewable diesel to petroleum-based ultra-low sulfur diesel in boilers, such as in residential heating systems. More research is needed to determine the emissions impacts of renewable fuels in boilers.

Given the uncertainties in the emissions impacts of renewable fuels in both engines and boilers, the health analysis used the same emission rates for each fuel type. This assumption potentially conservatively underestimates the benefits of a switch to renewable fuels in the scenarios.

Assumptions about Residential Wood Combustion

The Integration Analysis used the Energy Information Administration's State Energy Data System (SEDS) as the source for residential wood energy consumption. This public health analysis also used these energy inputs to estimate the emissions from residential wood combustion. However, additional

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127 Durbin, T.D, J.W. Miller, K. Johnson, M. Hajbabaei, N.Y. Kado, R. Kobayashi, X. Liu, C.F.A. Vogel, F. Matsumura, P.S. Wong, and T.Cahill. 2011. CARB Assessment of the Emissions from the Use of Biodiesel as a Motor Vehicle Fuel in California: "Biodiesel Characterization and NOx Mitigation Study." California Air Resources Board. https://www.arb.ca.gov/fuels/diesel/altdiesel/20111013_carb%20final%20biodiesel%20report.pdf

128 Durbin, T.D., G. Karavalakis, K.C. Johnson, C. McCaffery, H. Zhu, H. Li. 2021. Low Emission Diesel (LED) Study: Biodiesel and Renewable Diesel Emissions in Legacy and New Technology Diesel Engines. California Air Resources Board. https://ww2.arb.ca.gov/sites/default/files/2021-12/Low_Emission_Diesel_Study_Final_Report_12-29-21.pdf

129 Nabi, M.N., M.M. Rahman, and M.S. Akhter. 2009. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. Applied Thermal Engineering, 29: 2265-2270.

130 Zheng, M., M.C. Mulenga, G.T. Reader, M.P. Wang, D. Ting, and J. Tjong. 2008. Biodiesel engine performance and emissions in low temperature combustion. Fuel, 87: 714-722.

131 O'Malley, J. and S. Searle. 2021. Air Quality Impacts of Biodiesel in the United States. The International Council on Clean Transportation. https://theicct.org/publications/us-biodiesel-impacts-mar2021

New York-specific data exists from a national survey of wood users conducted for the Commission on Environmental Cooperation,[132] which suggests that the baseline residential wood consumption could be 14% higher than the amount used for the analysis. Given that wood combustion results in substantial particulate matter emissions, a higher baseline estimate for wood consumption could result in a larger decrease in emissions from the policy scenarios and larger total health benefits.

In addition, the emission factors used to estimate emissions from residential wood consumption are based on those used by the U.S. EPA for the National Emissions Inventory. Recent testing by NYSERDA and the Northeast States for Coordinated Air Use Management (NESCAUM) using updated testing methods have indicated that the emission factors are higher than previously thought. This would mean that the total emissions from residential wood combustion—and the benefits from reducing wood combustion—would be higher than what has been modeled for this analysis. EPA is moving to adopt new testing protocols, developed by NYSERDA and NESCAUM, which will allow for better evaluation of real-world wood emissions from various systems and certification of cleaner systems.[133,134]

1.4 Increased Active Transportation

The public health benefits of increased active transportation were estimated using the Integrated Transport and Health Impact Model (ITHIM).[135] The analysis drew on modeling conducted for the New

[132] Council on Environmental Cooperation. 2019. Residential Wood Use Survey to Improve U.S. Black Carbon Emissions Inventory Data for Small-Scale Biomass Combustion. (Unpublished.) Montreal, Canada: Commission for Environmental Cooperation.

[133] Special Issue on Wood Combustion. Journal of the Air & Waste Management Association, 72.

Burkhard, Ellen. Introduction to Special Issue on Residential Wood Combustion. Journal of the Air & Waste Management Association, 72(7), pp. 617–618

Arthur Marin, Lisa Rector, Barbara Morin & George Allen. Residential wood heating: An overview of U.S. impacts and regulations. Journal of the Air & Waste Management Association, 72(7), pp. 619-628

Barbara Morin, Mahdi Ahmadi, Lisa Rector & George Allen. Development of an integrated duty cycle test method to assess cordwood stove performance. Journal of the Air & Waste Management Association, 72(7), pp. 629-646

[134] EPA. https://www.regulations.gov/docket/EPA-HQ-OAR-2016-0130. Accessed 11/16/2022.

[135] Available at: http://cal-ithim.org/ithim/#Home

York State Clean Transportation Roadmap,[136] which estimated the increase in walking and biking trips resulting from a decrease in VMT.

ITHIM uses U.S.-level data from the *Global Burden of Disease* study[137] and other published literature to estimate the change in the relative risk of premature mortality due to increased physical activity. ITHIM also calculates the potential increase in pedestrian mortality from vehicle collisions, and it presents the net change in mortality for a given change in walking and biking activity.

In this analysis, the ITHIM model was customized with NYS-specific data on population, baseline mortality rates, and VMT, from the same data sources discussed above for the ambient air quality analysis, as well as baseline walking and biking activity taken from the Federal Highway Administration's *National Household Travel Survey*.[138]

The analysis valued the change in mortality using the value of a statistical life from COBRA to be consistent with the ambient air quality analysis.

The analysis used NYS-specific data where possible alongside the default equations within ITHIM to estimate the net change in mortality from increased walking and biking. These equations include default parameters based on national-level data to represent the change in relative risk of mortality from change in physical activity.

This analysis was conducted at the state level, rather than modeling changes in walking and biking activity due to changes in VMT within counties or individual communities. For this reason, the results of this analysis should be considered a first-order approximation of the benefits of increased active transportation.

[136] Cadmus. New York Clean Transportation Roadmap Preliminary Results: GHGs and Energy. Presentation to the Transportation Advisory Panel to the New York State Climate Action Council. April 9, 2021. https://climate.ny.gov/Advisory-Panel/Meetings-and-Materials.

[137] Institute for Health Metrics and Evaluation (IHME). Global Burden of Disease (GBD). Seattle, WA: Institute for Health Metrics, University of Washington; 2015. http://www.healthdata.org/gbd

[138] U.S. Federal Highway Administration. 2021. National Household Travel Survey. https://nhts.ornl.gov/

1.5 Residential Energy Efficiency Interventions

Values from the published literature were used to estimate the public health and safety benefits of residential energy efficiency and weatherization interventions. Specifically, estimates of the average benefits per home in applicable weatherization programs were developed from three key studies.[139,140,141] These average benefits values were multiplied by the estimated number of homes projected to receive energy efficiency or weatherization interventions from the Integration Analysis. These benefits include reductions in thermal stress, asthma symptoms, trip and fall injuries, and carbon monoxide poisonings. These benefits are driven by different types of energy efficiency interventions. For example, reduced thermal stress results from improved air sealing and replacement of heating and cooling appliances, while reduced asthma symptoms are driven by improved ventilation.[139,140] Some health benefits are driven by interventions that provide relatively little energy benefit. For example, reduce trip and fall injuries are driven by the removal of trip hazards, such as torn carpets, roofing repairs to fix leaks, and improved lighting.[139] While the exact nature of the energy efficiency programs envisioned in the Integration Analysis is not specifically defined, the health analysis assumes these programs will provide multiple interventions, as they do today, in the homes with the potential to provide multiple benefits.

The published literature largely focuses on estimating the benefits of weatherization programs for low and moderate income (LMI) homes. For this reason, it was assumed that the estimated benefits per home were appropriate to be used only for LMI homes in this analysis. The definition of LMI is that the household income is 80 percent or less than the median income, or approximately 40 percent of homes in NYS. Therefore, the analysis calculated benefits for only 40 percent of the homes projected to receive energy efficiency or weatherization interventions. This assumption is likely conservative, as there are likely also health and safety benefits from these interventions in higher-income homes. However, due to a lack of data on the size of the benefits in higher-income homes, the analysis only included benefits for LMI homes.

[139] Tonn, B., E. Rose, B. Hawkins, and B. Conlon. 2014. Health and Household-Related Benefits Attributable to the Weatherization Assistance Program. Oak Ridge, TN: Oak Ridge National Laboratory, ORNL/TM-2014/345.

[140] Hayes, S., C. Kubes, and C. Gerbode. 2020. Making Health Count: Monetizing the Health Benefits of In-Home Services Delivered by Energy Efficiency Programs. Washington, DC: American Council for an Energy-Efficient Economy.

[141] Tonn, B. B. Hawkins., E. Rose, M. Marincic, S. Pigg, and C. Cowan. 2021. Health Benefits Attributable to Weatherizing Affordable Multifamily Buildings. Submitted manuscript.

Chapter 2. Results and Discussion

2.1 Key Health Findings

Decarbonization of New York can result in a substantial health benefits from improved air quality, up to $110 billion from 2020 through 2050 (based on reduced mortality and other health outcomes) relative to the Reference case. Approximately 91% of the air quality health benefits are projected within New York State. The remaining 9% of benefits would occur in other states downwind of New York.

- Benefits would be experienced throughout the state and downwind in neighboring states.
- Benefits of reduced fossil fuel combustion are higher in urban areas due to both higher emissions and larger impacted populations.
- Benefits of reduced wood combustion are higher in upstate areas.
- Annual benefits would grow over time as pollution rates decrease.

Two additional other potential health benefit categories were estimated:

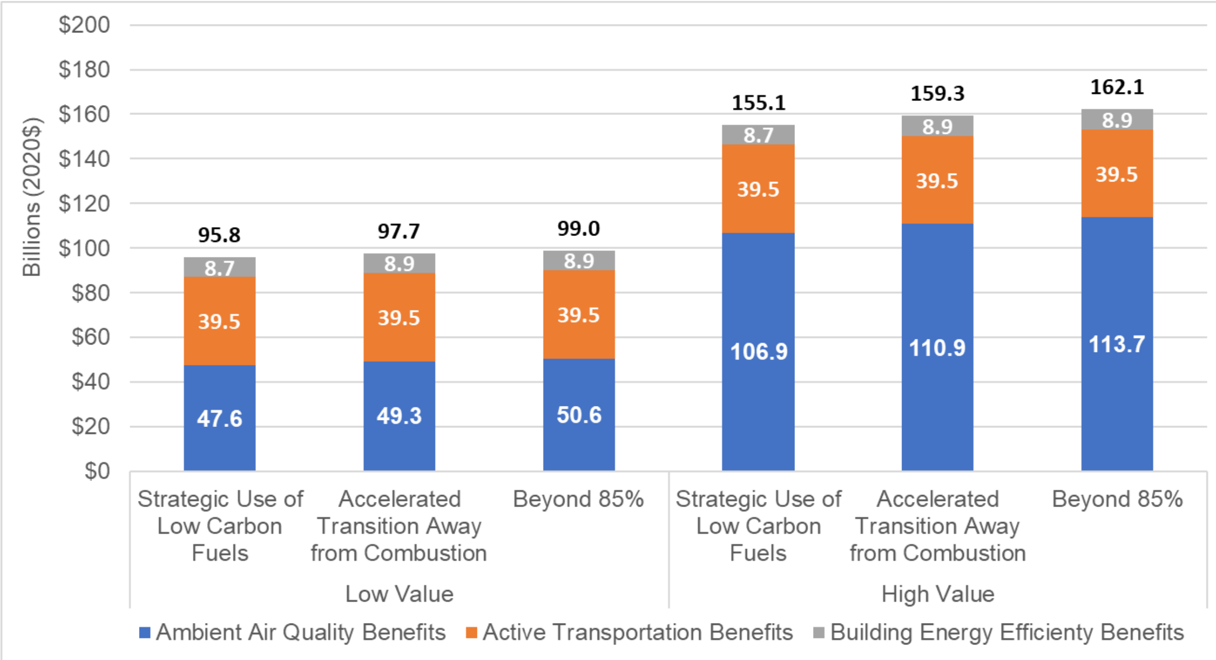
- $40 billion associated with the health benefits of increased active transportation (such as walking and cycling); and
- $9 billion associated with energy efficiency interventions in LMI homes (additional benefits, not quantified, may occur in other buildings as well).

The total projected potential health benefits associated with the scenarios analyzed are presented in Figure 2. Results are presented for the High and Low cases.

2.2 Ambient Air Quality Benefits

In all scenarios, air quality improvements can avoid tens of thousands of premature deaths, thousands of non-fatal heart attacks, thousands of other hospitalizations, thousands of asthma-related emergency room visits, and hundreds of thousands of lost workdays. This section describes the total ambient air quality health benefits across each scenario, as well as the benefits by sector and the geographic distribution of the air quality improvements and resulting health benefits.

Figure 2. Total Projected Health Benefits (Net Present Value, 2020–2050)



Total Health Benefits of Improved Ambient Air Quality

The value of the benefits by scenario are presented in Figure 3. While a small amount of benefits would occur downwind of New York in neighboring states, the vast majority of benefits would occur within New York. A large portion of the projected benefits would result from reduced wood combustion. Benefits from reduced fuel combustion (excluding wood) would be larger Downstate, and benefits from reduced wood combustion would be larger Upstate. While the reduced wood combustion represents a small amount of the total reduced fuel combustion, it has an outsized impact on particulate matter emissions, resulting in substantially high benefits.

Benefits would increase over time as policies affecting emission reductions take effect, gradually increasing up to approximately $6 billion in the Low case and under $14 billion in the High case by 2050 (Figure 4).

Figure 3. Total Projected Ambient Air Quality Health Benefits (Net Present Value, 2020–2050)

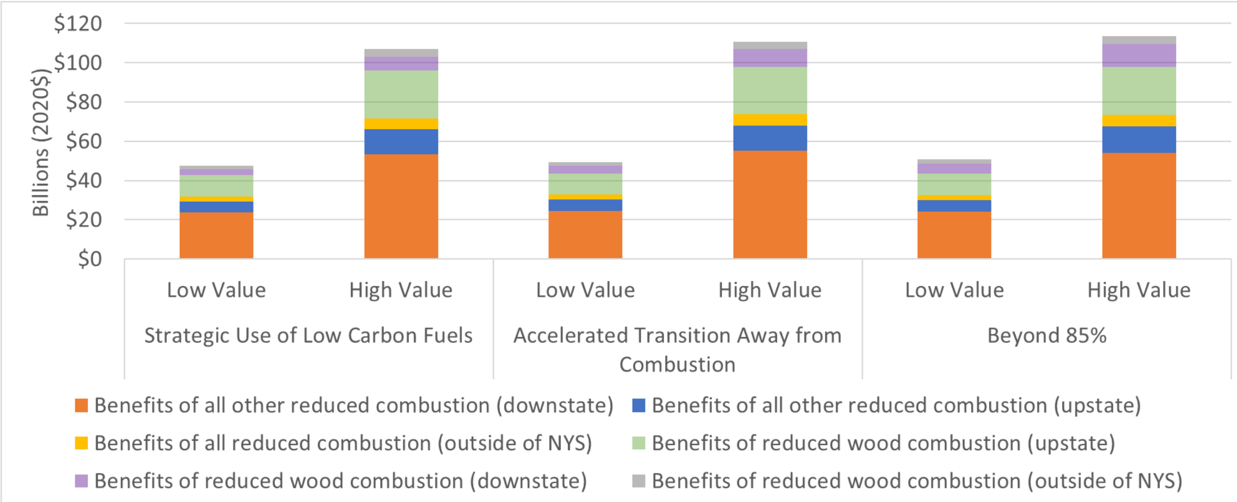
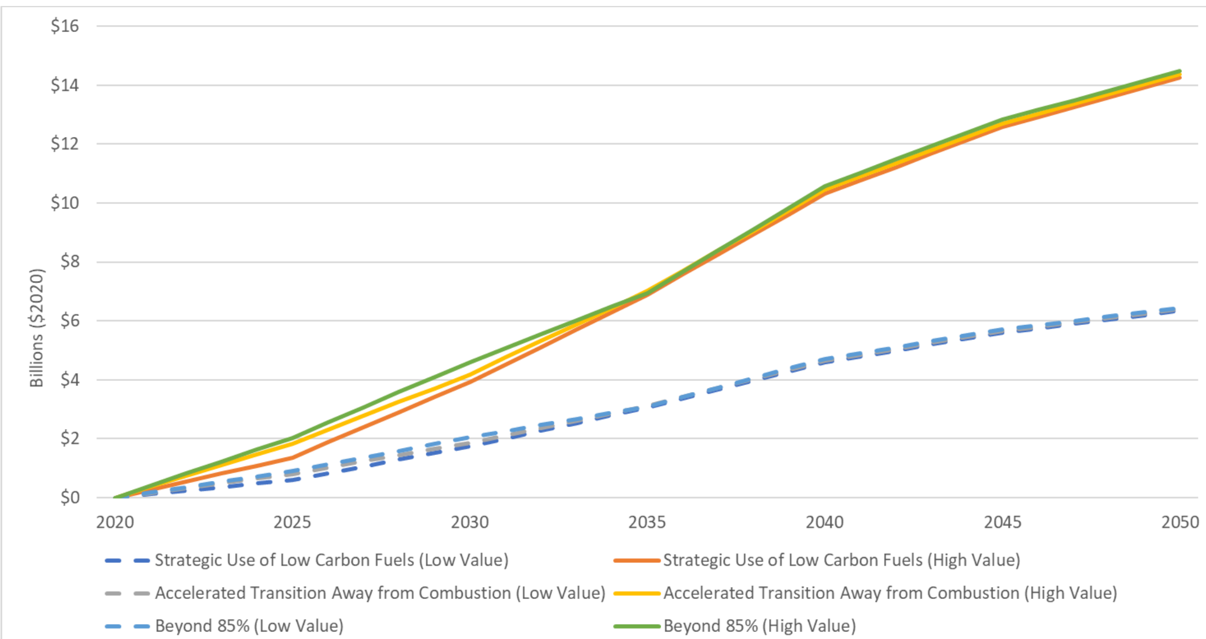


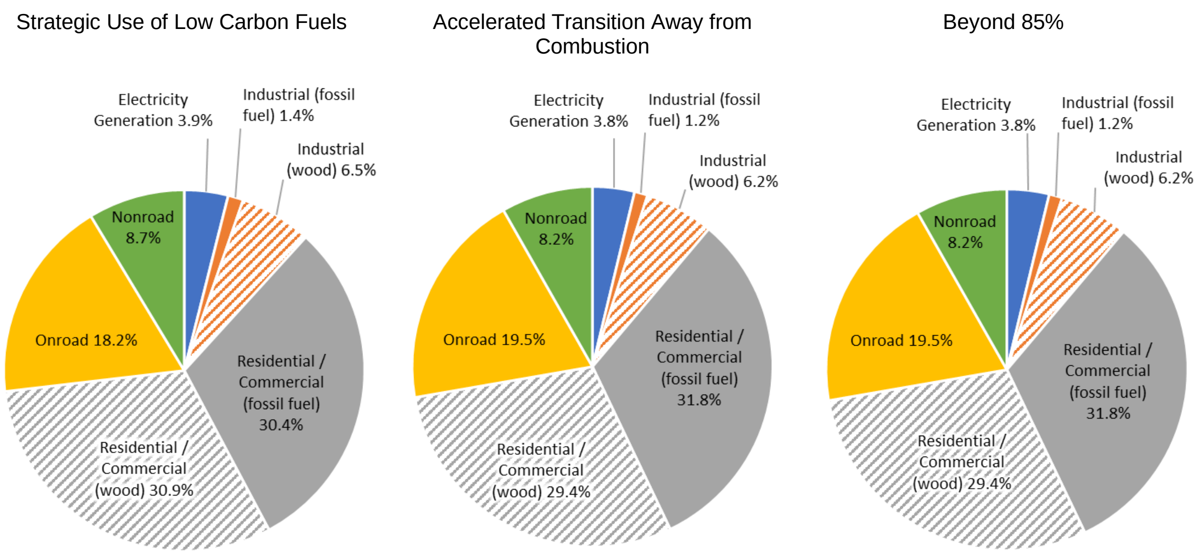
Figure 4. Annual Projected Ambient Air Quality Health Benefits (2020–2050)



Benefits by Sector

As presented in Figure 5, approximately 38% of the projected benefits are associated with reduced wood combustion in industrial, commercial, and residential uses. The remaining benefits are associated with relatively equal amounts from transportation (on-road and non-road) and building fuel combustion, and additional small fractions of the benefits are associated with reduced combustion in the electricity generation sector. While buildings and electricity generation have substantial emissions and ensuing health impacts locally, much of the building energy and power in New York is based on natural gas, which burns much cleaner and therefore has a lower impact on particulate matter emissions and public health than oil per unit of energy. Oil combustion can have a much larger health impact locally, but the quantities of oil used statewide are much smaller. However, despite having lower particulate matter emissions than wood combustion overall, those oil and natural gas emissions from buildings do have a large impact on public health because they are in more populated urban areas, while wood combustion is more heavily weighted to rural areas with less dense population, resulting in similar health benefits from reducing wood and oil/gas (this is true also for renewable oil and gas).

Figure 5. Health Benefits by Sector, 2020–2050



The health benefits are driven by reductions in all air pollutant emissions, but reductions of primary $PM_{2.5}$ are the strongest driver of the benefits. Approximately three quarters of the Reference case $PM_{2.5}$ emissions in New York are from non-combustion sources, such as dust or biogenic sources (Figure 6). Of the one quarter of the $PM_{2.5}$ emissions that is from combustion sources, nearly all of it is due to residential or industrial wood combustion.

Figure 7 shows the $PM_{2.5}$ emission *reductions* by sector across each scenario, both with and without the benefits of avoided wood combustion. When all fuels are considered, the residential and commercial sector accounts for the majority of the $PM_{2.5}$ emission reductions, due mostly to reductions in residential wood combustion. When wood combustion is excluded, the $PM_{2.5}$ emission reductions occur largely in the on-road, non-road, and electricity generation sectors.

Figure 6. Sector-level $PM_{2.5}$ Reference Case Emissions (2025)

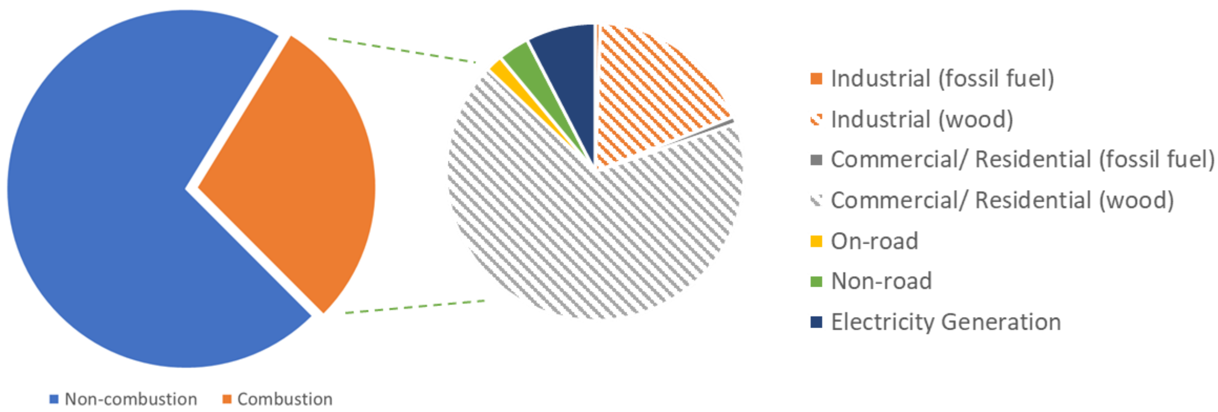
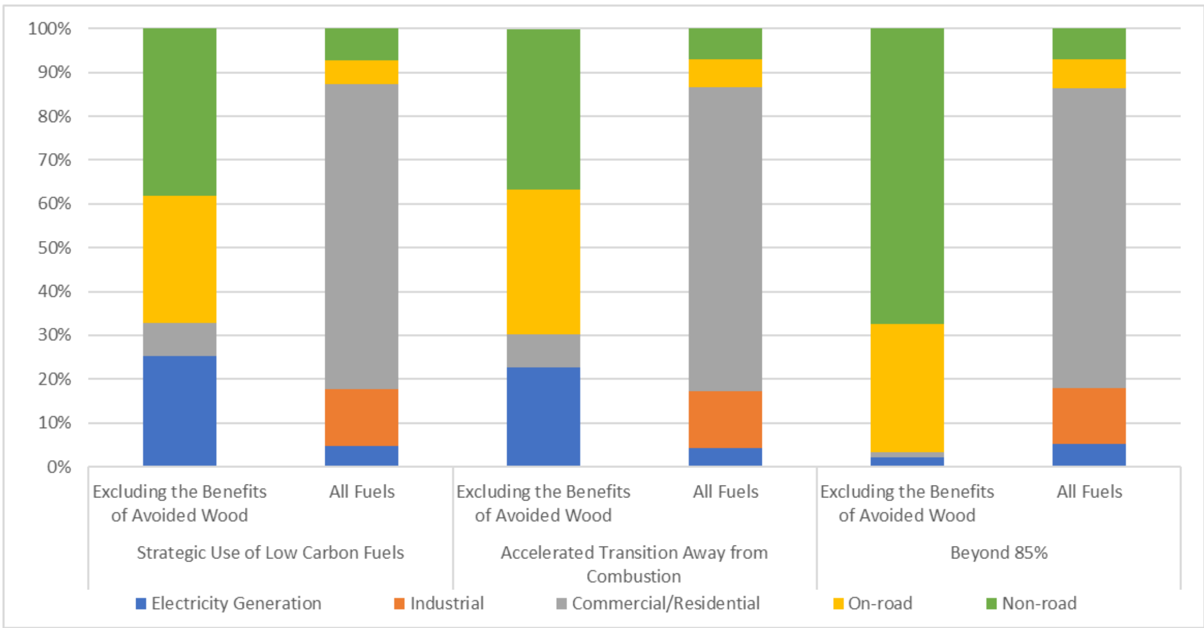


Figure 7. $PM_{2.5}$ Emission Reductions by Sector (2025–2050)



In terms of NO_x emissions, approximately three quarters of the Reference case emissions come from combustion sources (Figure 8). The combustion-related NO_x emissions are largely from the residential, commercial, on-road, and non-road sectors. Unlike $PM_{2.5}$, there are relatively little NO_x emissions from wood combustion compared to fossil fuels. Figure 9 shows that the residential and commercial sector accounts for most of the emission reductions, regardless of whether wood combustion is considered.

These emission reductions are largely due to reductions in natural gas and fuel oil combustion in buildings.

Figure 8. Sector-level NO_x Reference Case Emissions (2025)

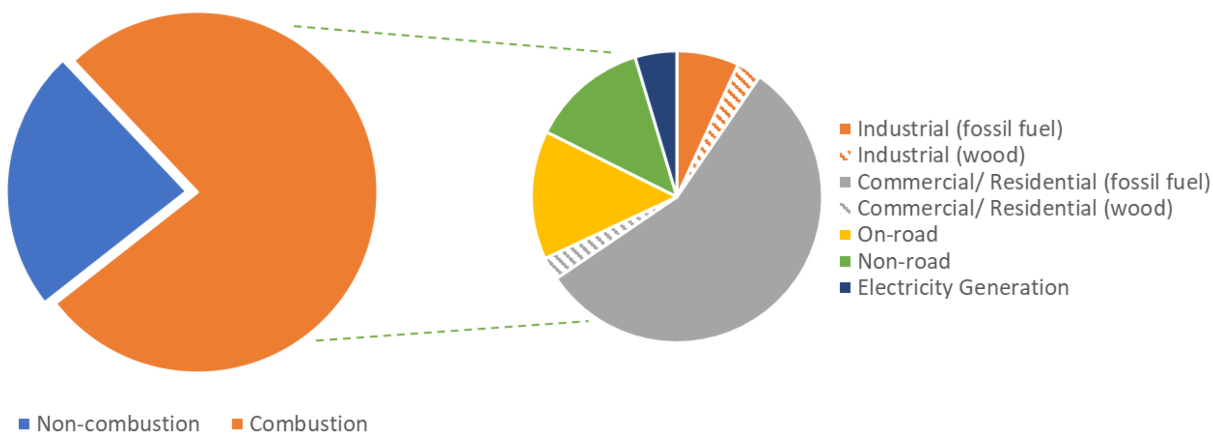


Figure 9. NO_x Emission Reductions by Sector (2025–2050)

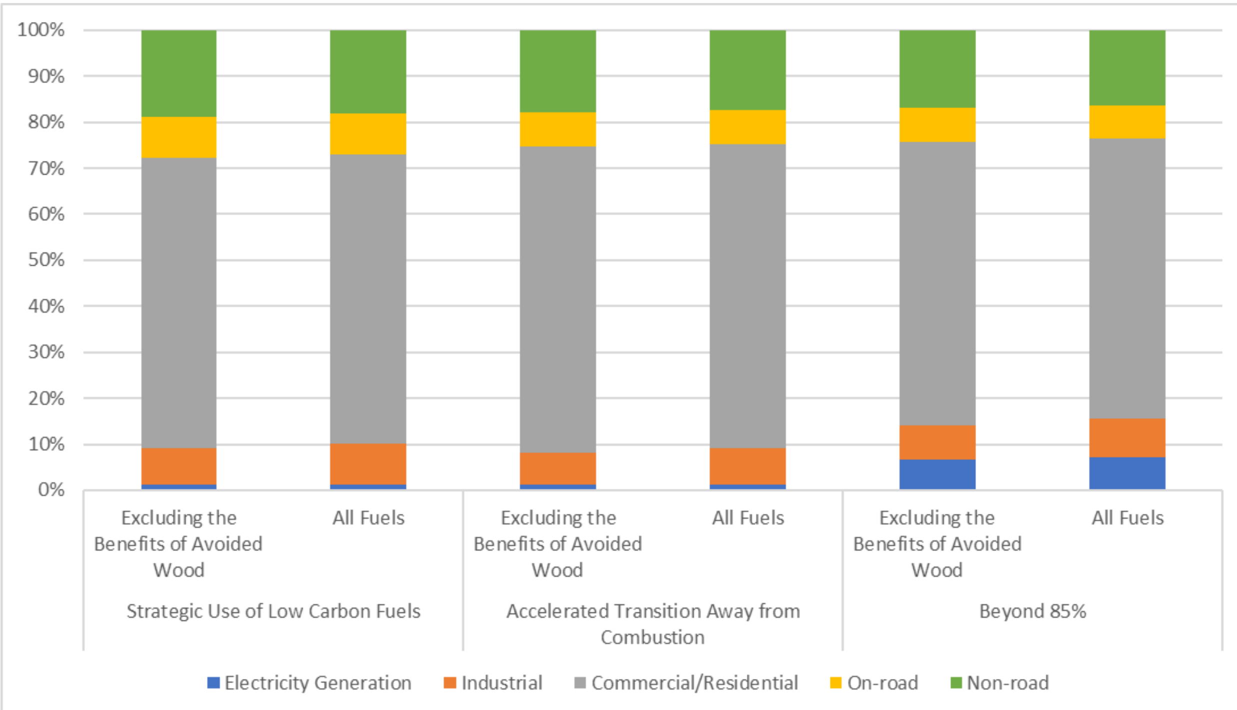
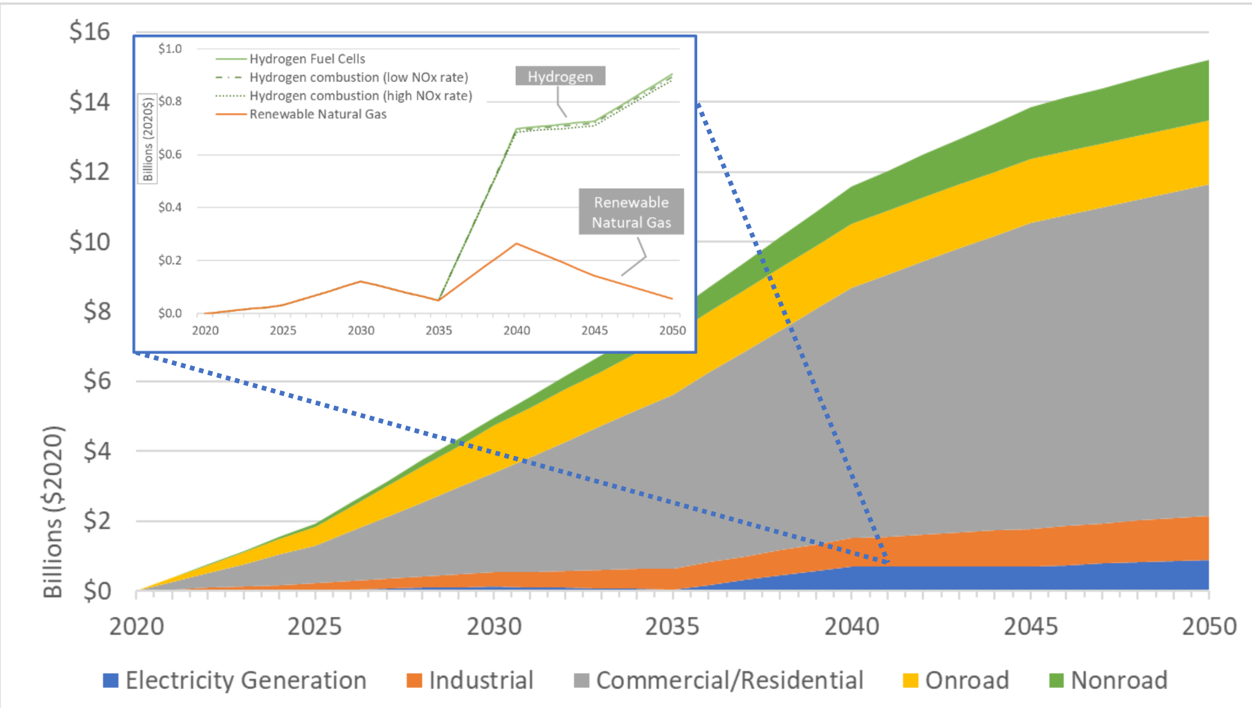


Figure 10 presents the annual health benefits (high value) by sector from the Strategic Use of Low Carbon Fuels scenario. These sectoral results show that the majority of the benefits over time are due to emission reductions in the commercial and residential sector. In addition, these results show that the benefits from emission reductions in the electricity generation sector largely begin in 2040. The inset graph in that figure shows the results of a sensitivity analysis conducted for the Strategic Use of Low Carbon Fuels scenario. While the vast majority of electricity would be generated from variable renewable resources (e.g., solar, wind), this sensitivity analysis demonstrates the effect of the use of limited renewable natural gas, hydrogen fuel cells, or hydrogen combustion for baseload electricity generation in 2040 and beyond.

Figure 10. Annual Health Benefits by Sector (high value) for the Strategic Use of Low Carbon Fuels Scenario

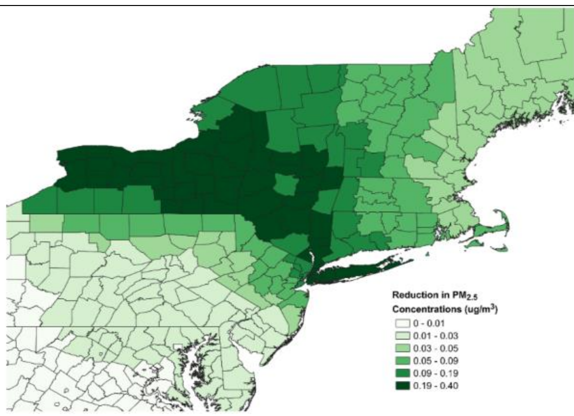


For the hydrogen combustion cases, we analyzed two different emission rates for NO_x emissions to reflect uncertainty in the NO_x emissions from hydrogen combustion. We expect that the 'high NO_x' result is likely conservative given required NO_x emission limits, and the 'low NO_x' result represents a scenario in which additional controls ensure no increase in NO_x emission relative to what is currently allowed from the use of natural gas. The results shown in Figure 10 indicate that the benefits from all hydrogen cases, including fuel cells and both combustion cases (high and low NO_x), are very similar. The difference in the total net benefits from 2020-2050 between the hydrogen fuel cell case and the high NO_x rate combustion case is $35 – 79 million (Low and High cases, respectively), or less than 0.1% of the total economy-wide air quality benefits. The renewable natural gas case shows lower benefits compared to the hydrogen cases, with $1.4 – 3.1 billion lower than the benefits from the hydrogen fuel cell case (Low and High cases, respectively), or approximately 3% of the total economy-wide benefits.

Benefits by Geographic Location

The maximum annual average $PM_{2.5}$ concentration reductions by county projected to be achieved by 2050 are presented in Figure 11. Note that the concentration reductions in all three scenarios are very similar. The distribution of benefits per capita are presented in Figure 12, both with and without the benefits of wood combustion. While much higher benefits overall would accrue in urban areas due to higher population, per-capita benefits are also higher in urban areas due to higher baseline health incidence and larger reductions in emissions (due to larger sources available to be reduced). The distribution of benefits is very similar in all three scenarios.

Figure 11. Reduction in $PM_{2.5}$ Annual Average Concentrations, Strategic Use of Low Carbon Fuels

<table>
<tr><td>all fuels (2050)</td><td>excluding benefits of avoided wood combustion (2050)</td></tr>
<tr><td>


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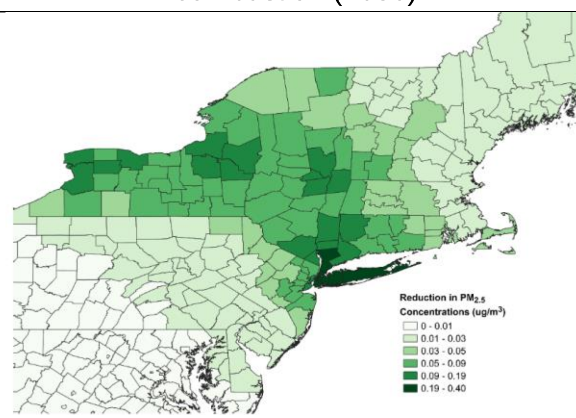
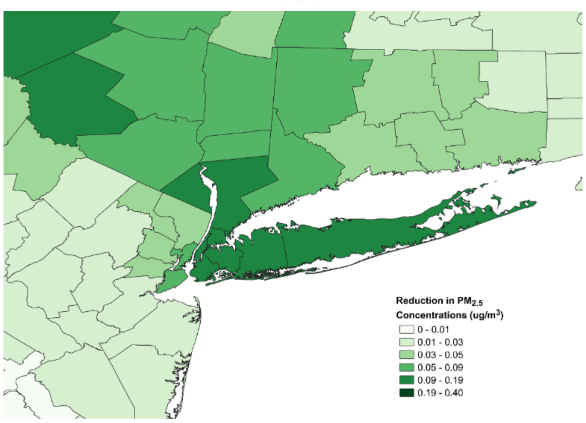


</td></tr>
<tr><td colspan="2">New York City Area — excluding benefits of avoided wood combustion</td></tr>
<tr><td>2030</td><td>2050</td></tr>
<tr><td>


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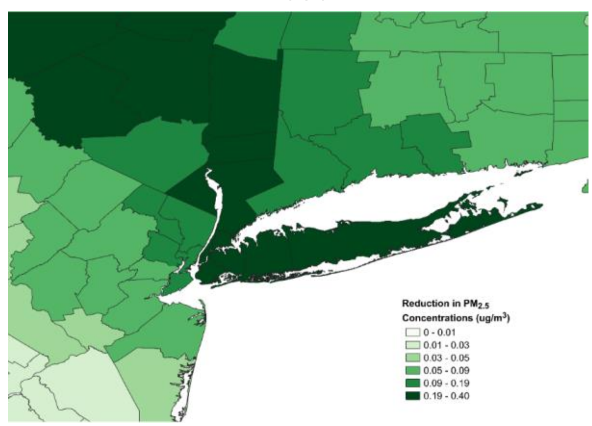
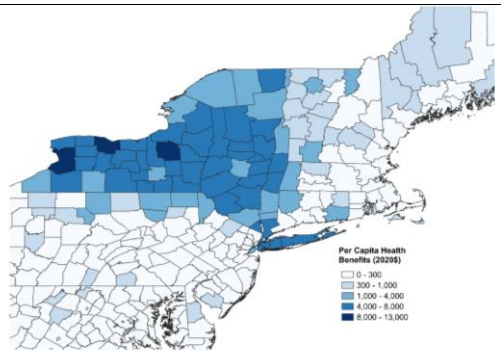
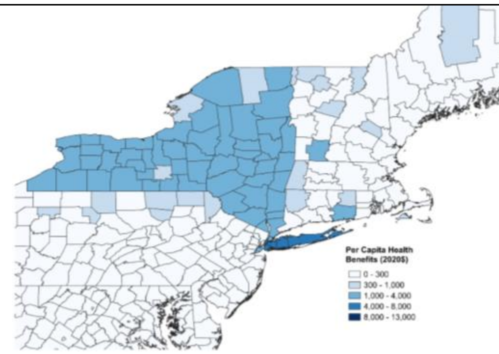
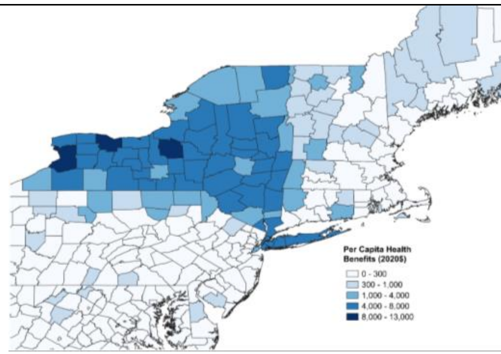
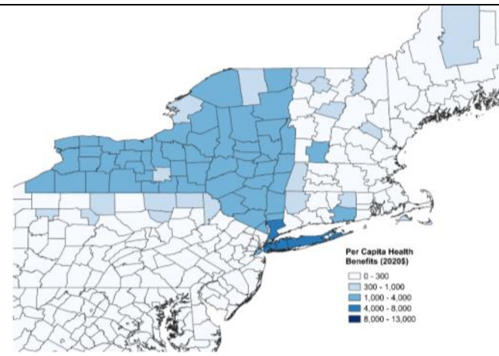
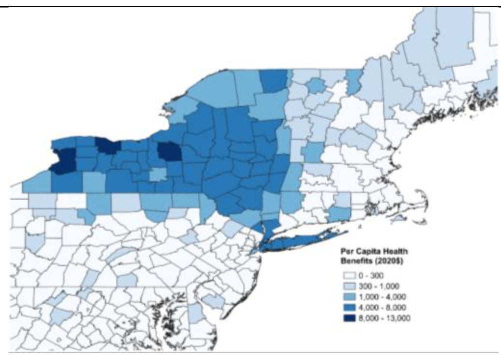
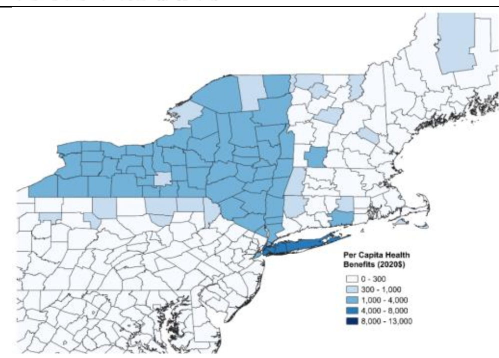


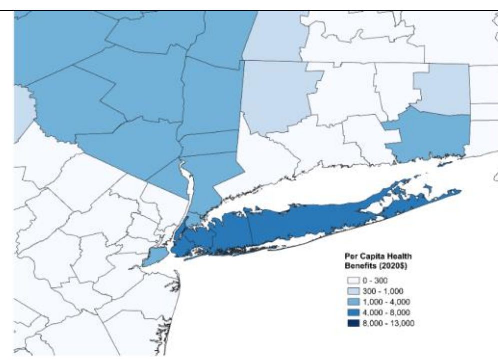
</td></tr>
</table>

Figure 12. Per Capita Health Benefits, 2020–2050

Scenario	all fuels	excluding benefits of avoided wood combustion
Strategic Use of Low Carbon Fuel		
Accelerated Transition Away from Combustion		
Beyond 85%		

New York City area – excluding benefits of avoided wood combustion

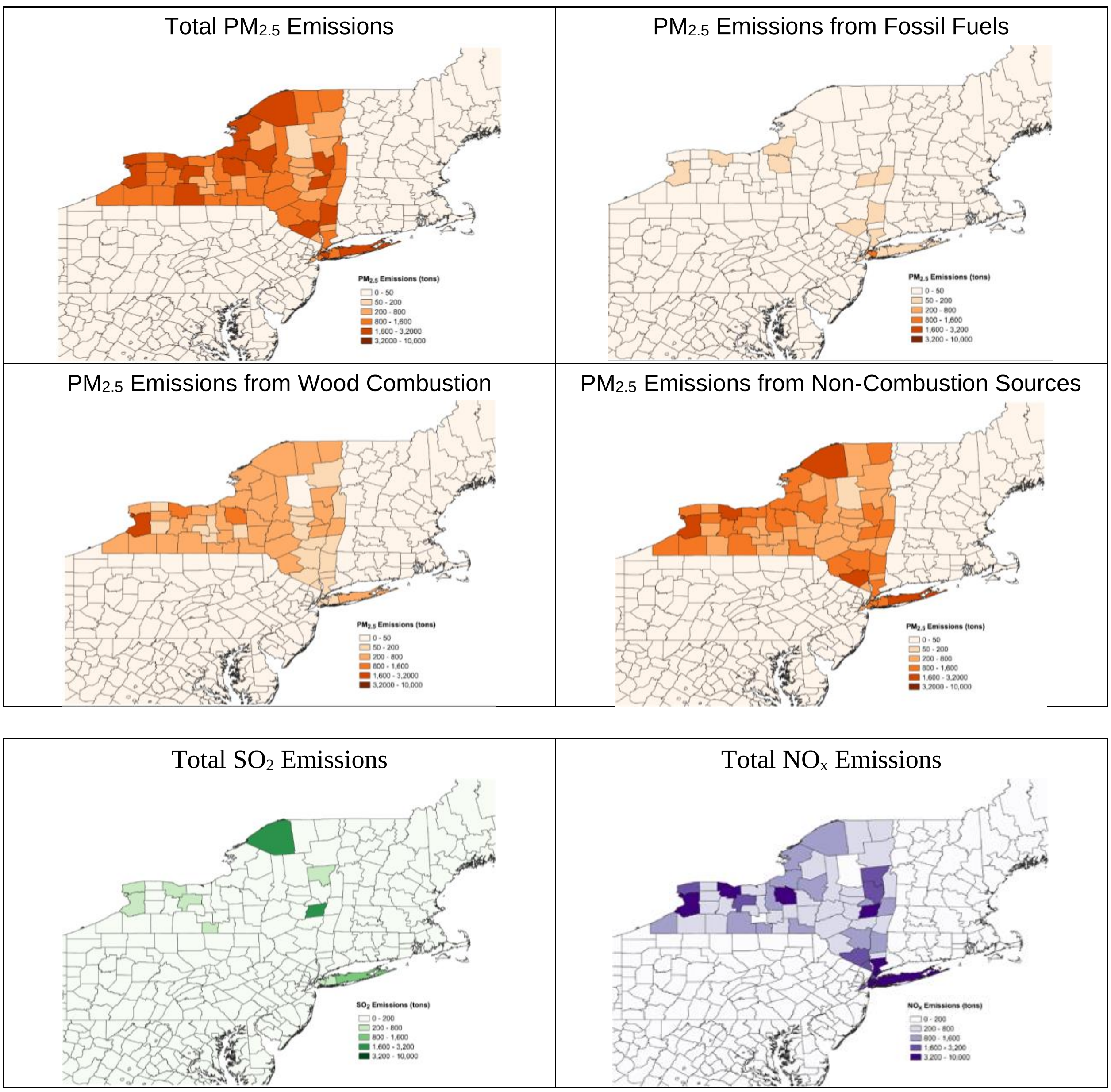
	Low Carbon Fuels	Accelerated Transition	Beyond 85%
Bronx	$3,797	$4,045	$4,106
Brooklyn	$4,647	$4,848	$4,925
Manhattan	$5,521	$5,776	$5,915
Queens	$6,079	$6,319	$6,442
Staten Island	$3,355	$3,471	$3,562



Reference Case Air Pollutant Emissions

Figure 13 displays the geographic distribution of the Reference case air pollutant emissions. The results show a trend also discussed above in the section on sector-level benefits—the majority of total $PM_{2.5}$ emissions are from non-combustion sources (such as dust or biogenic sources). The majority of $PM_{2.5}$ emissions from combustion sources is from wood combustion. The $PM_{2.5}$ emissions from fossil fuels and total NO_x emissions tend to be higher in urban areas, including in the NYC, Buffalo, Rochester, and Syracuse areas. The SO_2 emissions are highest in Albany and St. Lawrence Counties, due to the presence of industrial facilities that use coal and/or generate process emissions of SO_2.

Figure 13. Reference Case Emissions of $PM_{2.5}$, $SO_{2.}$, and NO_x (2025)

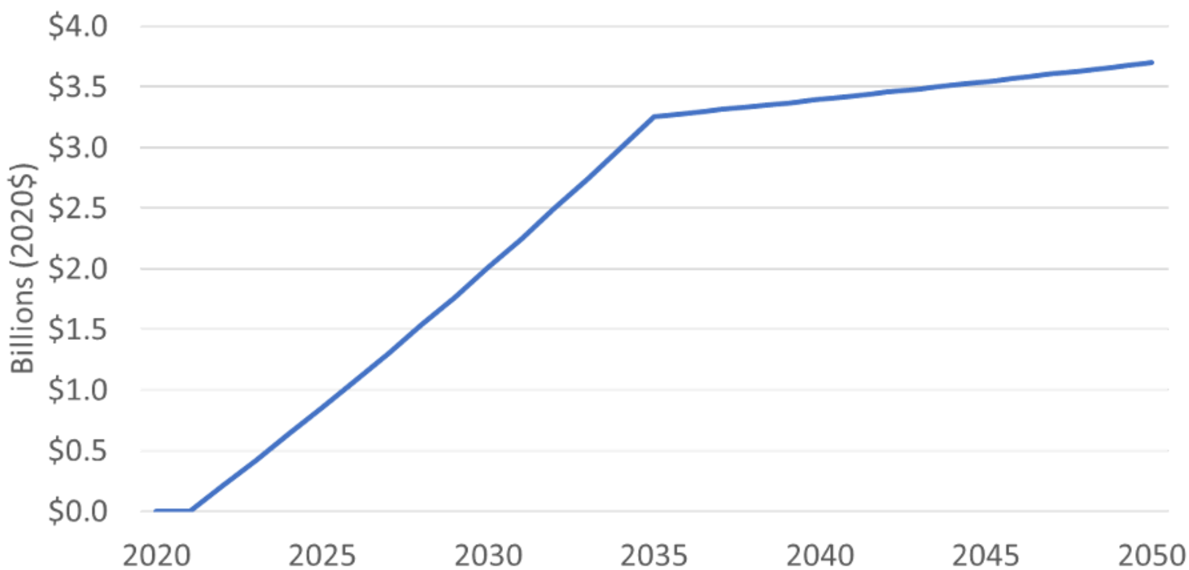


2.3 Health Benefits of Increased Active Transportation

The potential value of the net reduction in the number of deaths, including the decrease in deaths from increased physical activity and the increase in deaths from traffic collisions, is estimated to be a NPV of $39.5 billion (2020 to 2050). As presented in Figure 14, the values increase over the years as walking and cycling mode use increases with the introduction of infrastructure and other measures to encourage the use of these modes. Note that the projected decrease in premature deaths from physical activity far outweighs the potential increase in deaths from traffic collisions.

Active transportation benefits are the same for the Low Carbon Fuels and Accelerated Transition scenarios.

Figure 14. Potential Annual Value of Public Health Benefits from Increased Active Transportation



2.4 Health Benefits of Residential Energy Efficiency Interventions

Health benefits in residential energy efficiency interventions are expected to result from several factors listed in Table 1. These do not include all the potential benefits, but rather only those for which sufficient study of benefits per intervention was available to apply to the New York scenarios. Not included, for example, are benefits of indoor air quality associated with reduced indoor combustion of gas for cooking. Indoor air quality improvements can be achieved during such interventions by ensuring appropriate ventilation (often in cases where ventilation and existing conditions were not appropriate prior to the intervention) combined with heat recovery where needed. Crucial to this benefit is ensuring appropriate ventilation when tightening building envelopes.

Table 1. Health Benefits Included in the Analysis of Residential Energy Efficiency Interventions

Health-Related Measure	Causes for each Benefit	Low-Income Single Family	Low-Income Multifamily
Reduced thermal stress – heat and cold	Building envelope tightening, appliance replacements	☑	☑
Reduced asthma-related incidents or reduced asthma symptoms	Improved ventilation	☑	*
Reduced trip or fall injuries	Removal of trip hazards, roofing improvements, lighting improvements	☑	☑
Reduced carbon monoxide poisonings	Appliance replacements, carbon monoxide monitors	☑	Not available

* This was studied but no significant difference was detected.

In many cases, benefits occur due to programs ensuring that associated measures are taken at the same time, such as ensuring that carbon monoxide monitors are available where needed and that weatherization does not happen prior to fixing existing conditions such as mold caused by excess moisture in building envelopes and water leaks. Other indoor air quality considerations not related to energy efficiency interventions may include humidity control and filtration where appropriate.[142]

The analysis was undertaken at high-level, applying the number of homes to average benefits from the existing studies. Benefits were estimated only for LMI homes. There are likely also benefits for higher income homes, but data to estimate those benefits is not available.

Benefits would be highly dependent on the structure of the interventions. Energy efficiency programs differ based on whether they include appliance replacement, building shell retrofits, or other non-energy interventions (such as installing carbon monoxide detectors).

Following the current practice in NYSERDA's energy efficiency programs, the analysis assumes that a range of non-energy measures would be included as appropriate in each case.

The projected benefits by health measure and building type are detailed in Table 2 and Table 3 for the Strategic Use of Low Carbon Fuels and the Accelerated Transition Away from Combustion, respectively.

[142] For more information see ASHRAE, Indoor Air Quality Guide, https://www.ashrae.org/technical-resources/bookstore/indoor-air-quality-guide

Table 2. Potential Public Health Benefits of Energy Efficiency Intervention (2020–2050) Strategic Use of Low Carbon Fuels

Health-Related Measure	LMI Single Family (billion $)	LMI Multifamily (billion $)	Total (billion $)
Reduced asthma-related incidents or reduced asthma symptoms	$3.0	Not available	$3.0
Reduced trip or fall injuries	$1.4	$0.5	$1.9
Reduced thermal stress - cold	$0.4	$0.9	$1.2
Reduced thermal stress - heat	$0.6	$1.5	$2.2
Reduced carbon monoxide poisonings	$0.5	Not available	$0.5
Total	**$5.8**	**$2.9**	**$8.7**

Table 3. Potential Public Health Benefits of Energy Efficiency Intervention (2020–2050) Accelerated Transition Away from Combustion

Health-Related Measure	LMI Single Family (billion $)	LMI Multifamily (billion $)	Total (billion $)
Reduced asthma-related incidents or reduced asthma symptoms	$3.0	Not available	$3.1
Reduced trip or fall injuries	$1.4	$0.5	$1.9
Reduced thermal stress - cold	$0.4	$0.9	$1.3
Reduced thermal stress - heat	$0.6	$1.6	$2.2
Reduced carbon monoxide poisonings	$0.5	Not available	$0.5
Total	**$5.9**	**$3.0**	**$8.9**