Pathways to Deep Decarbonization in New York State

June 24, 2020

Energy+Environmental Economics

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Energy and Environmental Economics, Inc.
44 Montgomery Street, Suite 1500
San Francisco, CA 94104
415.391.5100
www.ethree.com

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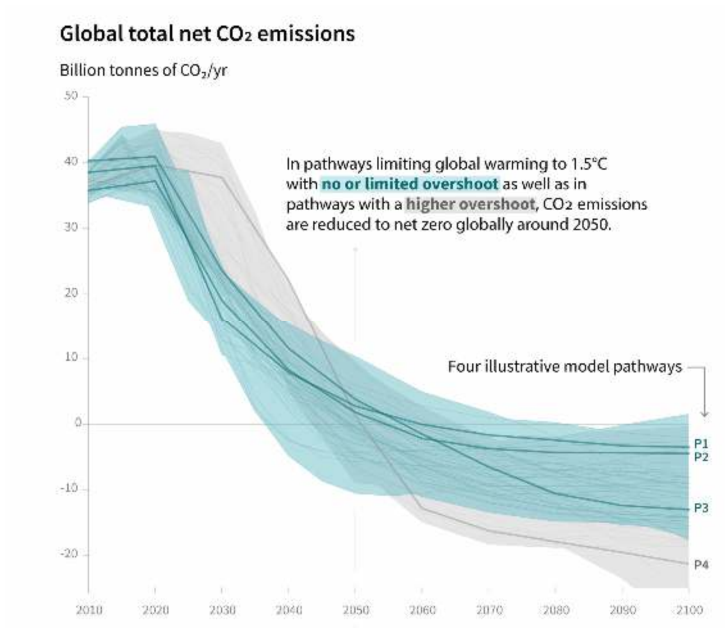
1 Background

As the global average temperature continues to climb to the highest levels in modern history, there is scientific consensus that climate change is threatening our social and economic institutions. The United Nations Intergovernmental Panel on Climate Change (IPCC), whose Fifth Assessment Report (AR5) was written by more than 830 lead authors and 2,000 expert reviewers, has found that global temperature must not increase by more than **1.5 degrees Celsius** above preindustrial levels in order to avert the increasingly damaging, irreversible effects of a changing climate. AR5 also finds that significant climate action is needed globally over the next decade in order to reach **net-zero greenhouse gas (GHG) emissions by mid-century**.

Figure 1. IPCC Analysis of Pathways to Limit Global Average Temperature Increase to 1.5 degrees Celsius[1]



In response to the latest climate science, New York State passed the Climate Leadership and Community Protection Act (CLCPA) in the 2019 legislative session. Included in the CLCPA are the most aggressive climate targets signed into law in the United States: 40% GHG reductions below 1990 levels by 2030, and carbon neutrality by 2050. The midcentury goal will be accomplished by reducing GHG emissions by at least 85% below 1990 levels with in-state carbon sequestration opportunities meeting or exceeding remaining emissions, resulting in net-zero statewide GHG emissions.

[1] IPCC Special Report on Global Warming of 1.5°C

The CLCPA also includes specific targets to decarbonize the State's electricity sector, such as:

+ 6 gigawatts (GW) of distributed solar by 2025
+ 70% renewable electricity by 2030
+ 9 GW offshore wind (OSW) by 2035
+ 100% zero-emissions electricity by 2040

In order to better understand how the State might meet its ambitious targets, the New York State Energy Research and Development Authority (NYSERDA) had engaged Energy and Environmental Economics (E3) to conduct a strategic analysis of New York's decarbonization opportunities. For this project, our analysis evaluated the emissions impact of New York's recent policies and explored additional measures that would be needed to reach the State's 2030 and 2050 targets. Results from our initial analysis, as well as our assumptions, methodology, and findings, are described in detail in this report.

Although this analysis captures economy-wide GHG emissions and mitigation opportunities, its analytic focus is on the electricity, transportation, buildings, and industrial sectors. In addition to future refinements in these sectors, additional analytic work will be needed to improve characterization of non-combustion sources and associated mitigation opportunities.

The CLCPA requires additional reporting of emissions associated with "extraction and transmission of fossil fuels imported into the state," as well as the adoption of a 20-year global warming potential, a metric that emphasizes the near-term climate impacts of short-lived climate pollutants such as methane. The calculation of a 1990 baseline that includes these new requirements is currently underway.

This analysis uses available 1990 data from prior inventory reports and adopts the GHG accounting framework from those prior reports. Future decarbonization pathways analysis will align statewide GHG emissions accounting with these CLCPA provisions and updated baseline.

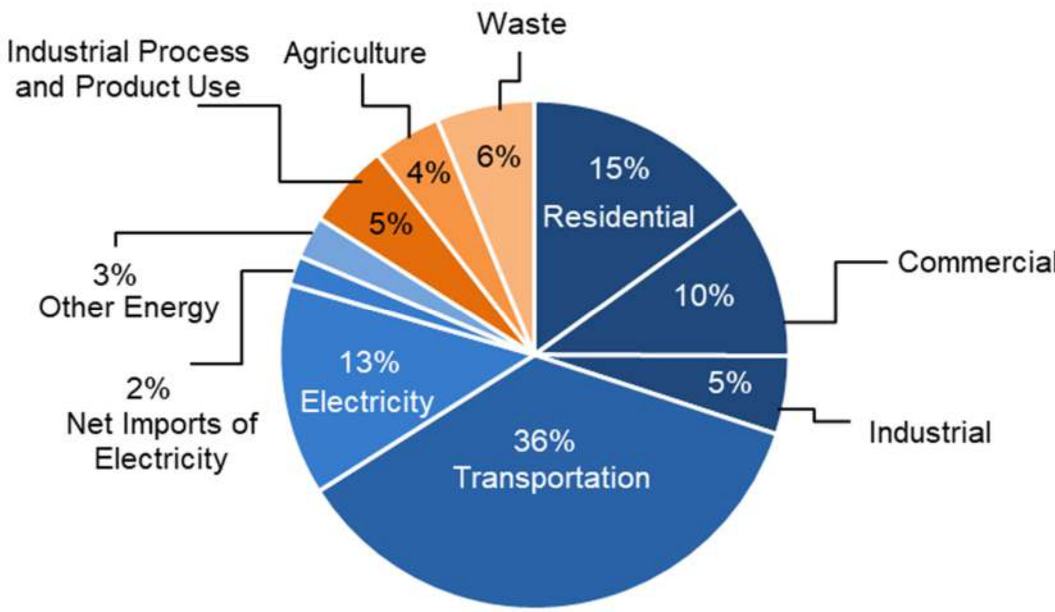
2 Progress in New York State

New York State tracks its historical GHG emissions through the New York State Greenhouse Gas (GHG) Inventory, which currently adheres to IPCC guidelines and creates a baseline against which future progress can be measured. The Inventory provides a detailed accounting of emissions beginning in 1990 until the most recent data year (currently 2016) and encompasses two overarching categories of emissions sources:

+ Energy combustion (including fossil fuel combustion, natural gas systems, and municipal waste combustion)
+ Non-combustion greenhouse gases, including industrial processes and product use, agriculture, and waste

As shown in Figure 2, the transportation sector is the State's largest source of GHG emissions, responsible for 36% of the total (Figure 2). The second-largest source, onsite combustion from residential, commercial, and industrial energy use, together contribute 30%. The next-largest category, non-energy emissions from waste, agriculture, and industrial processes and product use (15%), is equivalent to emissions from the electricity sector (15%), accounting for net-imports of electricity.

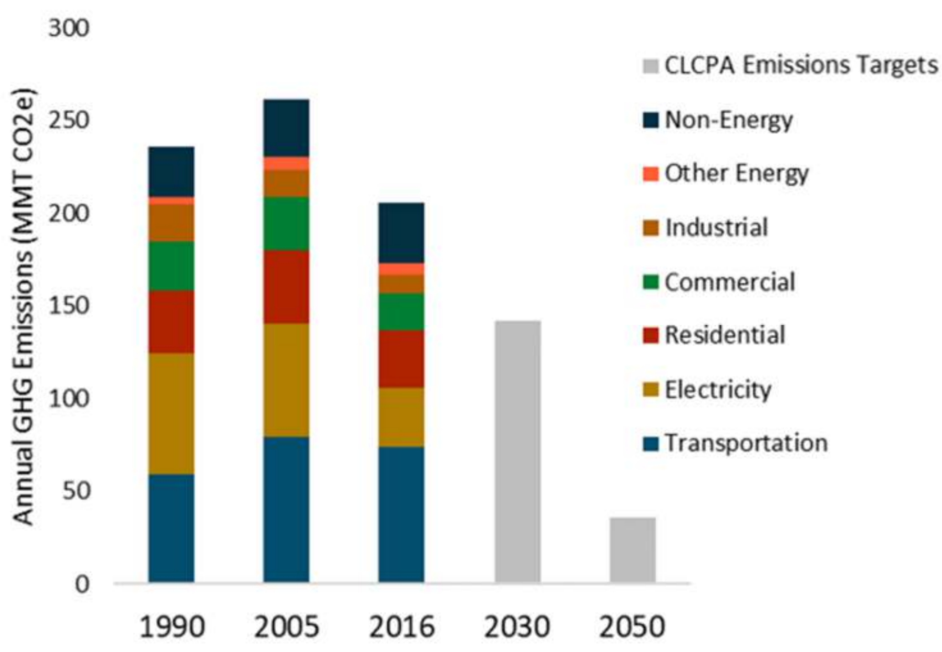
Figure 2. 2016 New York State GHG Emissions by Sector



Note: The combined contribution from all waste-related activities is approximately 8%.

New York has made significant progress in reducing GHG emissions (Figure 3). Since 1990, GHG emissions have fallen by 13%, and most of New York's GHG reductions have come from the electricity sector, which have decreased by more than 50% below 1990 levels. Reductions in emissions from onsite combustion in residential, commercial, and industrial buildings constitute the next-largest segment. While this progress is both substantial and important, significantly more action is needed to reach the reductions set out in the CLCPA – particularly in the transportation sector, where emissions have risen 25% from 1990 levels, and aviation has become an increasing share of transportation emissions.

Figure 3. NYS GHG Emissions by Sector: 1990, 2005, 2016, and CLCPA Emissions Targets: 2030 and 2050



3 Decarbonization Pathways Analysis

3.1 Analysis Overview

Meeting the CLCPA's ambitious targets requires a comprehensive analysis of GHG reduction measures across all sectors of New York's economy. Our analysis evaluated the impacts of existing policies as of December 2018 as well as portfolios of additional measures needed to meet CLCPA targets. This analysis provides an initial foundation for the State to assess decarbonization options, identify areas for additional analysis, and consider concrete next steps towards its 2030 and 2050 targets.

As part of this work, we also performed an extensive literature review on deep decarbonization and highly renewable energy systems and incorporated insights from discussions with leading subject matter experts.[2]

3.2 Model Framework

Our analysis uses E3's PATHWAYS model to create strategically designed scenarios for how the State can reach its 2030 and 2050 GHG goals. The model is built using "bottom-up" data for all emissions produced and energy consumed

[2] See Appendix B: Literature Review of Economy-Wide Deep Decarbonization and Highly Renewable Energy Systems

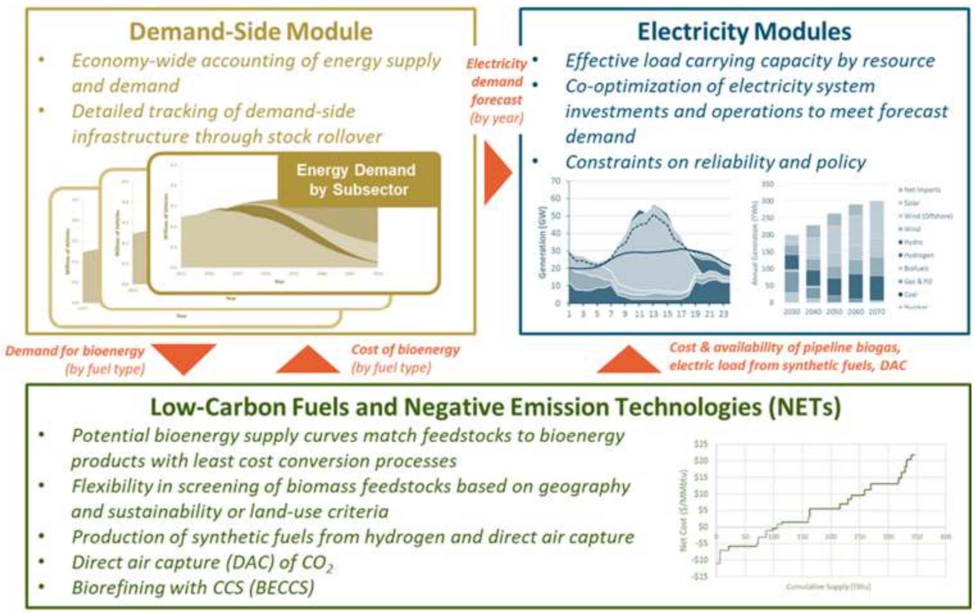
within the State. Scenarios are designed to test “what-if” questions to compare long-term decarbonization options and develop realistic and concrete GHG reduction pathways.

PATHWAYS also captures interactions between demand- and supply-side variables, with constraints and assumptions informed by existing analyses of resource availability, technology performance, and cost.

For key sectors like buildings and transportation, PATHWAYS uses a bottom-up stock rollover approach based on data from the EIA National Energy Modeling System (NEMS) that is validated through benchmarking to historical New York “top-down” energy consumption. Our modeling approach also incorporates detailed electricity sector representation using E3’s RESOLVE model. RESOLVE is used to develop least-cost electricity generation portfolios that achieve New York’s policy goals, including 100% zero-emission electricity, while maintaining reliability.

Finally, we calculate potential bioenergy supply from a variety of sustainably sourced feedstocks as well as emissions reduction potential for a variety of negative emissions technologies, including biorefining with carbon capture and storage (CCS) and direct air capture (DAC) of CO_2. Figure 4 illustrates the relationship between the different modules of the analysis.

Figure 4. E3 Modeling Framework



3.3 Scenario Development

For this analysis, E3 developed three distinct scenarios: a reference case reflecting existing state policies, and two initial pathways for achieving the CLCPA's GHG emissions goals and electric sector targets (e.g., 70% renewable electricity by 2030 and 100% zero-emissions electricity by 2040, as well as resource sub-targets). Both pathways rely on existing technology and project performance improvements consistent with deployments over the next 30 years.

+ **Reference Case**: The reference scenario includes existing sector-specific policies and targets adopted before the enactment of the CLCPA, including the Clean Energy Standard, 2025 and 2030 building energy efficiency targets, and the zero-emission vehicle (ZEV) MOU and related vehicle emission standards. This scenario serves as a counterfactual for comparison in future years.

+ **"High Technology Availability" Pathway**. This pathway relies on a diverse portfolio of GHG mitigation options, including high levels of efficiency and end-use electrification, with assets being retired at the end of useful lifetimes. This pathway includes contributions from measures that are not yet widely commercialized, such as advanced biofuels, carbon capture and storage (CCS), and bioenergy with carbon capture and storage (BECCS). It also relies on high levels of emissions reduction from non-energy sources, such as landfills and refrigerants, and high carbon sequestration from natural and working lands (NWL) within the State.
+ **"Limited Non-Energy" Pathway**. This pathway accelerates electrification and ramp-up of new equipment sales, along with early retirements of older and less-efficient fossil vehicles and building systems. This pathway also assumes advanced biofuels displace a larger share of fossil fuel, which together with the acceleration of new equipment sales, results in a larger reduction in energy sector emissions in case non-energy reductions and NWL sinks are limited.

Table 1. Key scenario assumptions

Sector	Strategy	Expressed as	Reference	High Technology Availability	Limited Non-Energy
Buildings	Building Shell Efficiency	Efficient shell sales share	75% by 2030	85% by 2030, 100% by 2045	*Same as HTA*
	Building Electrification	Electric heat pump sales share	6% by 2025	50% by 2030, 95% by 2050,	70% by 2030, 100% by 2045*
	Appliance Efficiency (non-HVAC)	Efficient appliance sales share	100% by 2025	90% by 2023, 100% by 2025	*Same as HTA*
Industry	Efficiency	Efficiency increase relative to baseline projection	10% by 2030, 20% by 2050	10% by 2030, 45% by 2045	*Same as HTA*
	Fuel Switching	Share of natural gas and LPG use electrified	None	60% by 2045	*Same as HTA*
Transportation	Corporate Average Fuel Economy (CAFE) Standards	LDV fuel economy	Extended 2021-2026	*Same as Reference*	*Same as Reference*
	Smart Growth	LDV VMT reduction relative to Reference	None	3% by 2030, 9% by 2050	*Same as HTA*
	Aviation Efficiency	Efficiency increase relative to Reference	None	10% by 2030, 40% by 2050	*Same as HTA*
	Vehicle Electrification	ZEV sales share	LDA: 25% by 2025; LDT: 8% by 2025; MDV/Bus: 2% by 2050	LDV: 60% by 2030, 100% by 2040; Bus: 60% by 2030, 100% by 2040; MDV/HDV: 35% by 2030; 95% by 2040	LDV: 70% by 2030, 100% by 2035; Bus: 70% by 2030, 100% by 2035; MDV/HDV: 50% by 2030; 95% by 2040*
Zero Emissions Fuels	Bioenergy Availability	Feedstocks supply	Reference Projection (~70 TBtu)	In-state feedstocks (~150-200 TBtu)	*Same as HTA*
	Biofuels Blend**	Share of conventional fuel use replaced with biofuels	7% aggregate ethanol blend for gasoline, 8.4% biodiesel blend for heating oil in Downstate model segment by 2034 to account for areas with biodiesel mandates	100% renewable gas in CNG vehicles by 2030, 40% renewable diesel by 2030, ~100% renewable diesel by 2050, 8% renewable gas in pipeline by 2050	100% renewable gas in CNG vehicles by 2030, 40% renewable diesel by 2030, 100% renewable diesel by 2050, 100% renewable gasoline by 2050, 68% renewable jet kerosene by 2050, 18% renewable gas in pipeline by 2050

Clean Electricity	Clean Electricity Generation	Share of renewable/zero-emission generation	50% renewable by 2030	70% renewable by 2030, 100% zero-emission by 2040	*Same as HTA*
	Technology-specific targets	Offshore wind capacity	2.4 GW by 2030	9 GW by 2035	*Same as HTA*
		Behind-the-meter solar PV	3 GW by 2023	6 GW by 2025	*Same as HTA*
		Energy storage	3 GW by 2030	3 GW by 2030	*Same as HTA*
Non-Combustion	Non-Combustion Emission Reductions****	Percent reduction from 1990 levels	38% increase by 2030, 52% increase by 2050	9% reduction by 2030, 45% reduction by 2050	-15% increase by 2030, 35% reduction by 2050
Natural & Working Lands	NWL Sequestration*****	MMT CO2 sequestered in 2050	22.5 MMT CO2e	32.5 MMT CO2e	25.5 MMT CO2e
CCSU	Carbon Capture & Sequestration/Use	MMT CO2 captured and sequestered in 2050	None	Industry CCS: 2 MMT, BECCS: 4 MMT***	BECCS: 4 MMT***

Acronyms and Abbreviations used in Table 1
LPG: Liquid petroleum gas (i.e., propane)
LDV: Light-duty vehicle; includes subcategories LDA (Light-duty auto) and LDT (Light-duty truck)
MDV/HDV: Medium-duty vehicle/Heavy-duty vehicle
CNG: Compressed natural gas
VMT: Vehicle miles traveled
TBtu: Trillion BTU (British Thermal Unit)

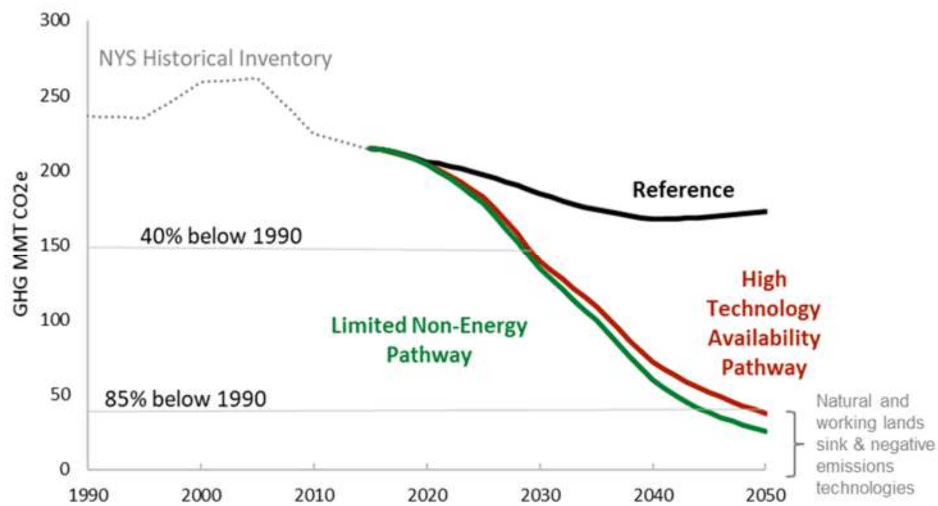
* Annually retire up to 5% of existing stock early, beginning in 2040 and continuing through 2050 as needed
** In decarbonization scenarios (high technology availability and limited non-energy), renewable diesel blend includes all demand sectors (e.g., transportation, buildings, and industry) and includes biodiesel share in downstate buildings included in the reference scenario; renewable gasoline blend in decarbonization scenarios is an advanced biofuel derived from available in-state feedstocks and displaces ethanol as well a fossil gasoline.
*** BECCS used only for bio-refining
**** Non-combustion emissions include waste, agriculture, industrial process and product use source categories. Major sources of emissions in these categories include methane emissions from landfills and HFC emissions from refrigerants.
***** NWL sequestration projections derived from estimate of forest sequestration in report prepared for NYSERDA by E&S Environmental Chemistry. *Sources and Sinks of Major Greenhouse Gases Associated with New York State's Natural and Working Lands: Forests, Farms, and Wetlands*. (2020). Projections were developed with input by subject matter experts based on historical data.

3.4 Key Results and Takeaways

E3's analysis finds that **achieving deep decarbonization with existing technologies is feasible by mid-century**. Further, this finding is consistent with all deep decarbonization studies E3 reviewed. Some technologies that have only been demonstrated in a limited number of applications will require further development to achieve widespread adoption.

Both the High Technology Availability and Limited Non-Energy Pathways reach CLCPA's long-term goal: carbon neutrality, with a reduction in emissions of at least 85%, by 2050. As shown in Figure 5, the High Technology Availability Pathway meets the 85% GHG reduction target and achieves carbon neutrality through natural and working lands and other negative emissions technologies. The Limited Non-Energy Pathway achieves greater GHG emissions reductions and relies less on negative emissions.

Figure 5. GHG Emissions by Scenario and Year

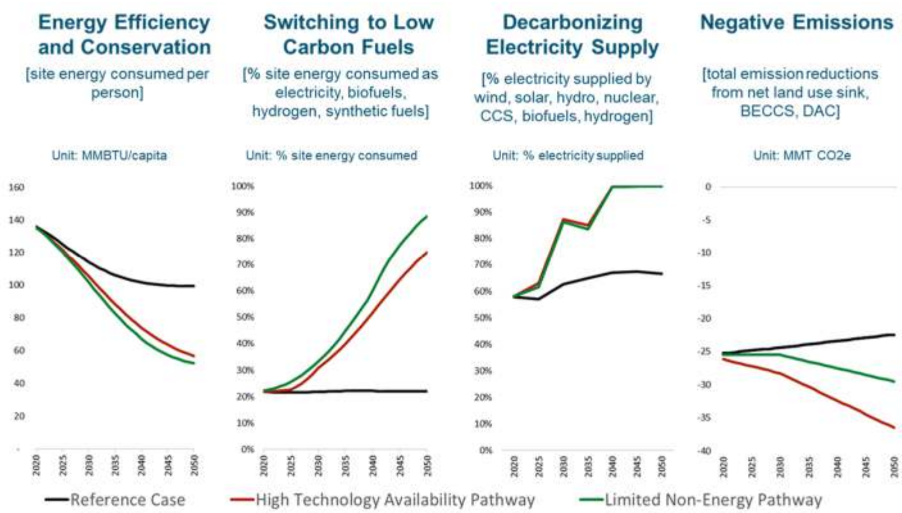


There is no single pathway to a decarbonized economy. A review of the literature, including E3's own past studies, shows that choices exist as to the extent and role of:

+ Electrification of vehicles and household appliances
+ Low-carbon fuels
+ Scale of renewable electricity
+ Carbon capture and sequestration
+ Negative emissions technologies

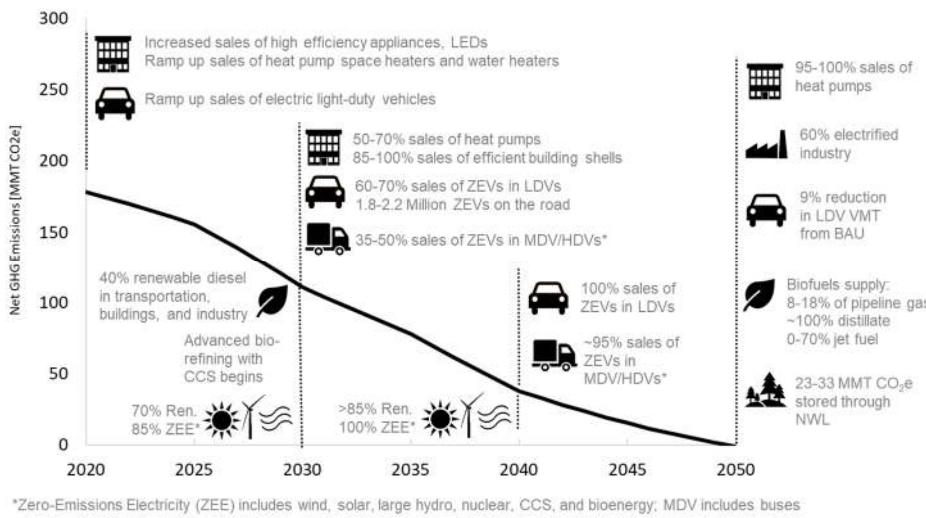
Any carbon-neutral future will require an unprecedented transformation and major investments in new infrastructure across all sectors. The scope and scale of emissions reductions to be achieved in New York across the "four pillars of decarbonization" – energy efficiency and conservation, decarbonizing electricity supply, switching to low-carbon fuels (including electricity), and negative emissions – in both modeled pathways is shown in Figure 6.

Figure 6. Four Pillars of Deep Decarbonization



A 30-year transition to carbon neutrality requires immediate and sustained action. Consumer decision-making is especially important in passenger vehicle turnover and household energy use. As shown in Figure 7, both pathways require rapid growth of electric vehicles and efficient electric household devices over the next decade.

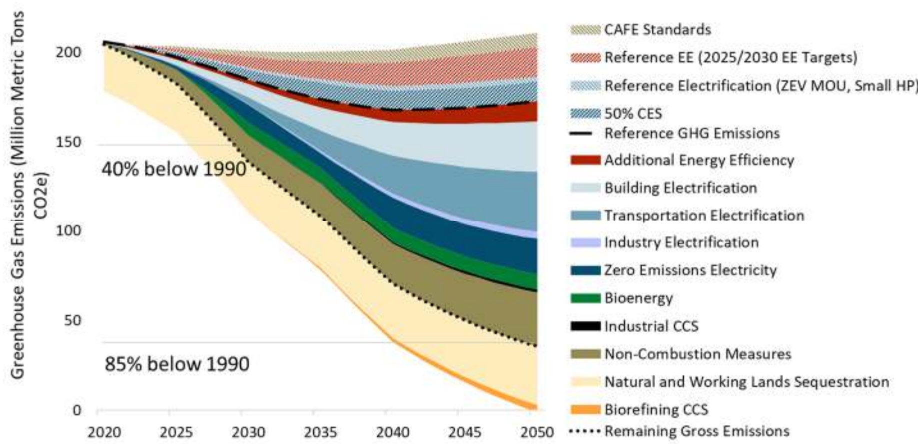
Figure 7. Timeline of Action in New York Carbon Neutral Pathways



Continued research, development and demonstration will be necessary to advance a full portfolio of options, including direct air capture of CO_2, advanced biofuels, and long-duration energy storage.

Existing New York clean energy policies are foundational to meeting a 40% GHG reduction by 2030. Figure 8 shows emissions reductions by measure in the High Technology Availability Pathway and highlights the impact of key actions such as New York's 2025 and 2030 energy efficiency and heat pump commitments, the ZEV MOU and related vehicle emission standards, and 50% Clean Energy Standard. Federal policies such as the Corporate Average Fuel Economy (CAFE) standards will also contribute to meeting New York's 2030 target provided that they are not overturned.

Figure 8. Emissions Reductions by Measure in the High Technology Availability Pathway



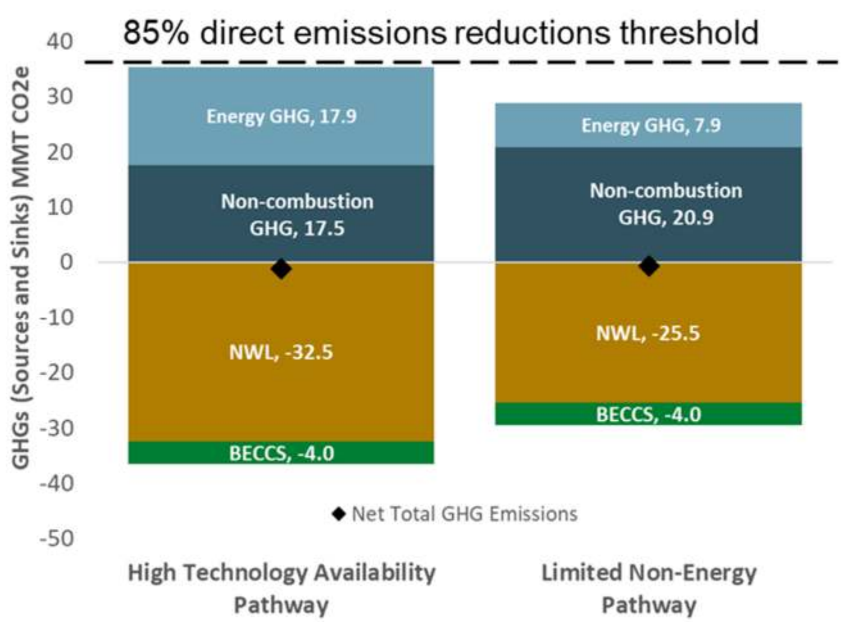
The CLCPA's electric sector targets of increasing renewable power and reaching 100% zero-emissions electricity will achieve substantial reductions in direct emissions and underpin a sustainable transition to electricity in vehicles and buildings. But additional decarbonization measures will be needed to reach New York's 2030 emissions goal:

- Additional building and transportation end-use electrification
- GHG reduction from non-combustion emissions sources such as landfills, agricultural sources, and refrigerants
- Advanced bioenergy in buildings and transportation

Looking further out to New York's 2050 target, a 100% zero-emissions electricity system is assumed to be the backbone of a decarbonized economy as fossil-fueled end-uses electrify in transportation, buildings, and industry. Carbon capture at large stationary sources, such as electric generators and industrial facilities could play a limited, but important, role in both pathways. Moreover, negative emissions strategies, both from natural and working lands and negative emissions technologies, allow New York State to reach full carbon neutrality by 2050.

The two pathways vary in the pace and extent of energy system decarbonization, extent of reduction from non-combustion emissions sources, and sequestration potential from natural and working lands (Figure 9). Additional reductions are achieved through in-state biorefining with CCS (BECCS). While carbon neutrality can be achieved without negative emissions technologies such as direct air capture (DAC), they may be required if adoption of other technologies is limited or delayed.

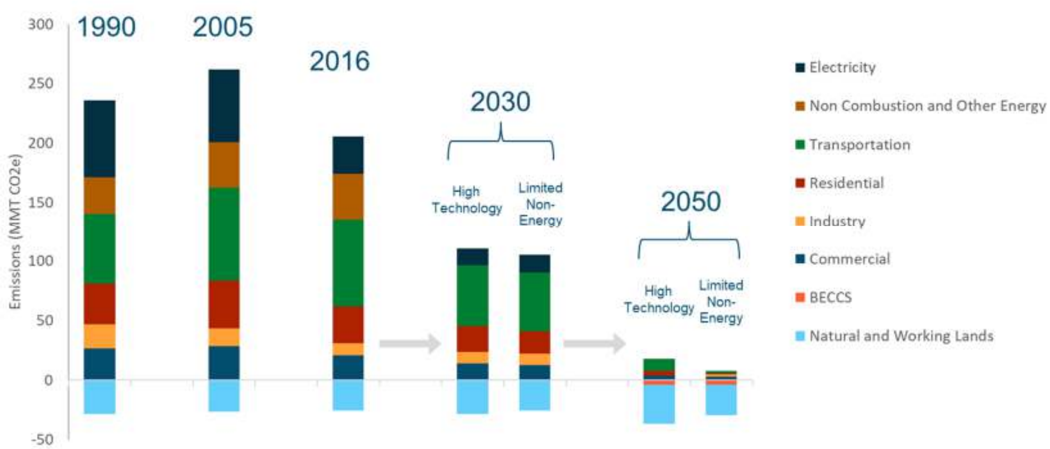
Figure 9. Remaining Emissions by Category and Pathway



4 Sectoral Findings

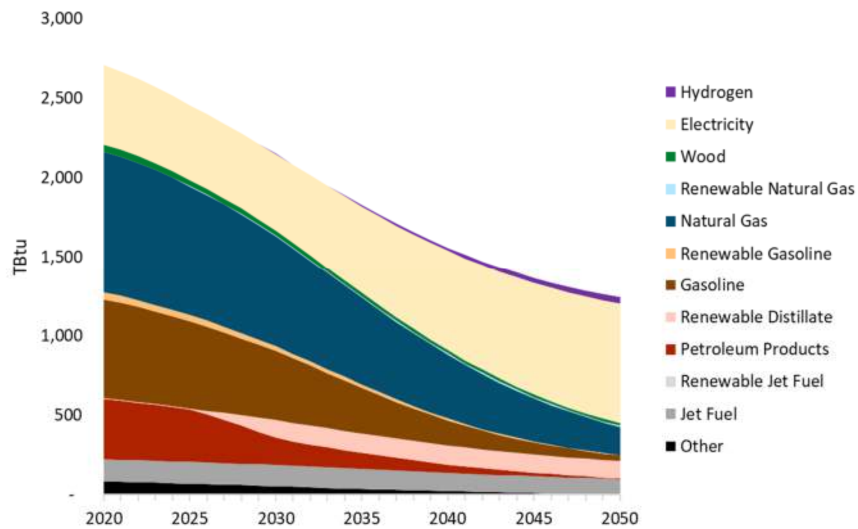
Meeting CLCPA targets requires substantial GHG emissions reductions across all sectors of New York's economy, as shown in Figure 10. The largest reductions are needed in the electricity, transportation, buildings, and industry sectors. This section presents specific sector-by-sector findings from E3's analysis.

Figure 10. New York State Greenhouse Gas Emissions by Sector



Energy efficiency, one of the "four pillars" of decarbonization, is achieved through conservation and conventional efficiency as well as through switching from fossil devices to more efficient electric technologies. Energy efficiency improvements across New York State's entire energy economy, including efficiency gains associated with electrifying building and transportation end uses, results in an 55% reduction in final energy demand by 2050 (relative to 2016 levels).

Figure 11. Final Energy Demand by Fuel, High Technology Availability Pathway



4.1 Transportation

Using the existing inventory methodology, transportation is currently New York's largest source of GHG emissions. Meeting CLCPA goals likely requires that transportation switch to electric technologies, such as electric passenger vehicles and buses. Beyond the obvious GHG benefits of reduced fossil fuel use, the transition from internal combustion engine vehicles to electric drive trains presents a tremendous efficiency benefit in terms of miles traveled per unit of energy consumed.

Our analysis assumes a transition to a mix of plug-in hybrid, battery electric, and hydrogen fuel cell vehicles, depending on the vehicle class and application. These electric vehicles add to the State's electricity demand, but also can enhance electric system reliability through temporally flexible vehicle charging patterns and utilization of vehicle batteries for grid balancing. The relative share of hydrogen fuel cell relative to battery electric vehicles over time may be affected by a number of factors, including the cost outlook for hydrogen production from zero-emission generation resources over time and the potential for regional or national initiatives to convert the long-haul fleet and develop hydrogen fueling infrastructure.

In addition to electrification, we include substantial reductions in vehicle miles traveled (VMT) for passenger vehicles, relative to a baseline projection of increasing VMT, which slows the rate and magnitude of the increase in VMT over time. These reductions would be realized through increased smart growth development, transit, and other transportation-related demand management measures. Some current trends (e.g., urbanization) may already be counteracting some growth in VMT, but more work is needed to ensure that New Yorkers have access to a wide variety of options to efficiently meet their mobility needs.

Because some medium- and heavy-duty vehicles will be more difficult to electrify, we assume drop-in renewable fuels (such as bioenergy or synthesized fuels) can be used to reduce emissions. For example, advanced renewable diesel plays a key role in decarbonizing freight transportation emissions. Non-road transportation, such as marine and aviation, are decarbonized through a combination of renewable fuels and efficiency.

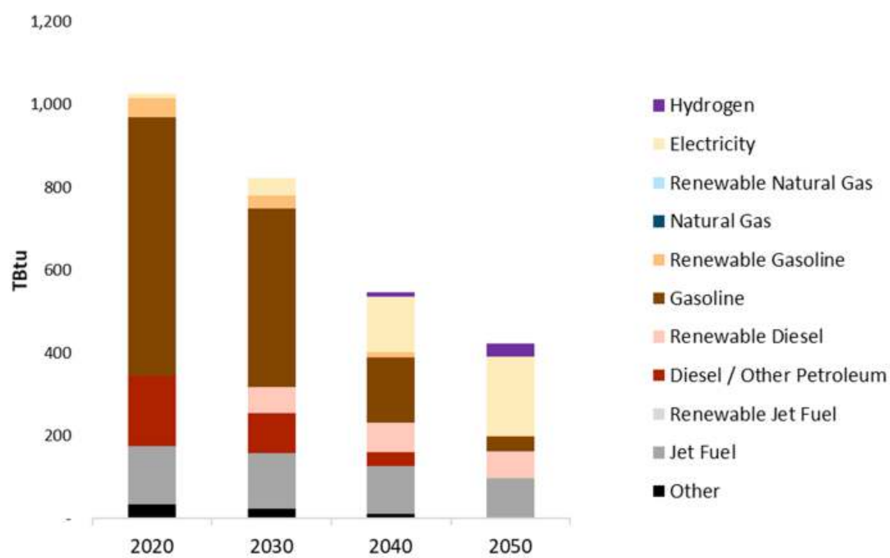
As seen in Table 2 and Figure 12, efficiency, electrification, and low-carbon fuel use decrease both energy use and GHG emissions in the transportation sector through 2030 and 2050. Note the energy and emissions reductions displayed in

Table 2 are a result of the scenario design process in this study and do not represent sectoral targets.

Table 2. Transportation Energy and Emissions Reductions Achieved in Decarbonization Pathways Scenarios

Metric	2030**	2050**
Percent GHG emissions reduction*	31%-33%	86%-97%
Percent reduction in final energy demand*	23%-24%	63%-67%
*Relative to 2016 **Range of values includes both the Decarbonization Pathways described in this report		

Figure 12. Transportation Final Energy Demand, High Technology Availability Pathway



4.2 Buildings

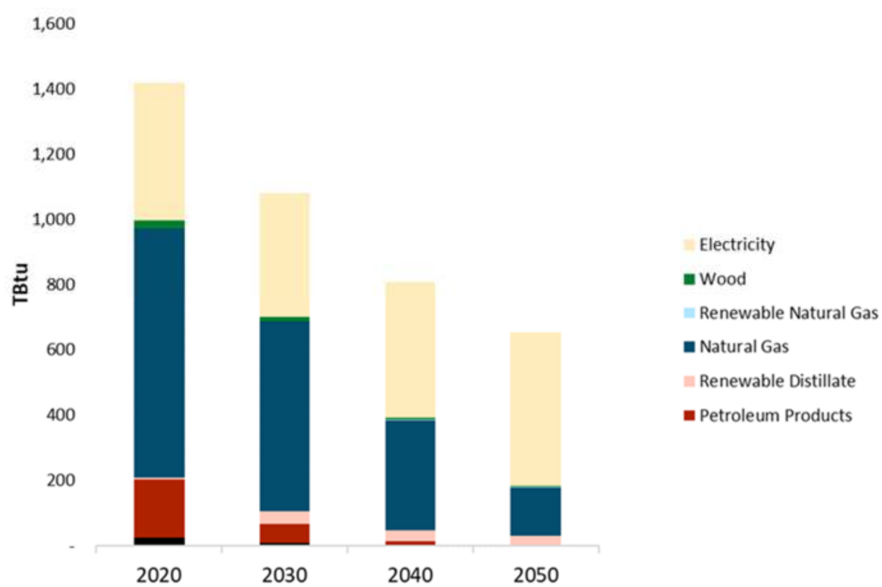
Buildings must transition from using several fuels today (i.e., natural gas, oil, electricity) to being mostly electric in a carbon neutral future. Simultaneously, aggressive energy efficiency must be pursued across multiple fronts: more efficient building shells and insulation, behavioral conservation, and efficient appliances. Although a widespread shift to electrification in buildings is a core component of decarbonization, other low carbon fuels such as renewable gas, renewable diesel (including biodiesel) and hydrogen may also play important roles, depending on the availability of sustainably-sourced bioenergy resources and the outlook for cost-effective hydrogen production from zero-emission generation resources.

As seen in Table 3 and Figure 13, efficiency, electrification, and low-carbon fuel use decrease both energy use and GHG emissions in the buildings sector through 2030 and 2050. Note the energy and emissions reductions displayed in Table 3 are a result of the scenario design process in this study and do not represent sectoral targets.

Table 3. Buildings Energy and Emissions Reductions Achieved in Decarbonization Pathways Scenarios

Metric	2030**	2050**
Percent GHG emissions reduction*	31%-39%	85%-93%
Percent reduction in final energy demand*	26%-31%	55%-59%
*Relative to 2016 **Range of values includes both the Decarbonization Pathways described in this report		

Figure 13. Building Final Energy Demand, High Technology Availability Pathway

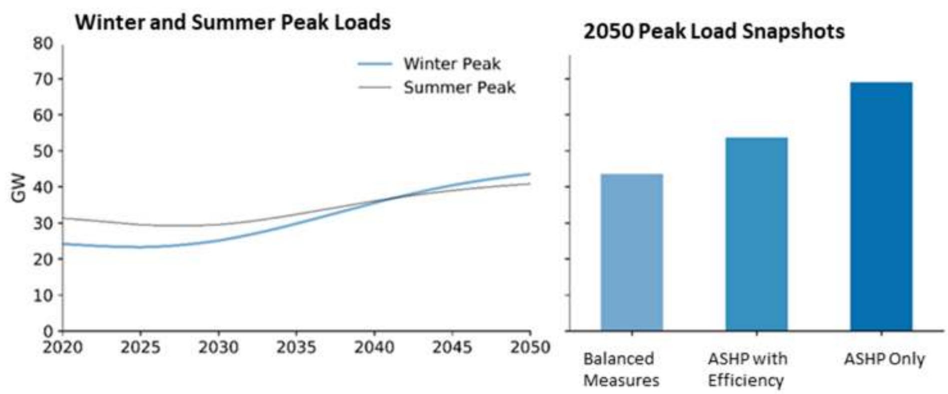


The shift to electrification is most pronounced in space and water heating, which in turn will lead to the emergence of a "winter peaking system" in New York, where electricity demands are highest in the winter (today's system demand is highest in the summer due to air conditioning loads). The magnitude of the new winter peak depends on the types of appliances that are sold and the pace of adoption, but can be mitigated by investment in ground-source heat pumps; investment in R&D to increase cold-weather performance of cold-climate air-source heat pumps; and onsite combustion backup systems using fossil fuel, bioenergy, or synthesized fuel such as hydrogen. Our study assumes that a balanced portfolio of electric space heating systems – including cold climate air-source heat pumps with and without onsite combustion backup, as well as ground-source heat pumps – would be deployed.

Much like electric vehicles, the potential for building appliances to operate flexibly can contribute to electric system reliability. Water heaters and refrigerators have a proven ability to shift load by a few hours, thus allowing the electric system to operate more efficiently and cost-effectively. Heating systems may be able to shift load, though there are open questions about how much, how long, and at what temperatures. Advanced distributed energy storage technologies may also contribute to system flexibility.

Both pathways described in this report consist of an approach that includes a mix of electric heat pumps, significant investment in efficient insulation and building shells, and flexible loads. Draft results from ongoing work for NYSERDA's Carbon Neutral Buildings Roadmap show that there would be significant additional impacts from transitioning to electric space heating without this mix of measures. For example, New York's winter peak could be substantially higher in 2050 without progress in efficiency, building shell improvements, and flexible loads, presenting additional challenges to the development of a 100% zero-emissions electricity portfolio.

Figure 14. Peak Load Implications of Heat Pump Transition: High Technology Availability Pathway System Peak Load (left) and 2050 Peak Load Under Different Space Heating Configurations (right)



We note, as well, that without regulation and innovation in refrigerant management and low-GWP refrigerants, increased reliance on heat pumps could result in a substantial increase of emissions of chemicals used in refrigerants, such as hydrofluorocarbons (HFCs). Additional analysis is needed to fully quantify this potential increase in emissions and characterize HFC mitigation opportunities in detail. Driving a shift to low GWP refrigerants will provide the highest GHG reduction benefit in the large-scale adoption of heat pumps.

4.3 Industry

Industrial energy use, though accounting for a relatively small share of New York State's current GHG emissions profile, becomes increasingly important as New

York approaches carbon neutrality.[3] We assume most industrial combustion GHG reductions occur as a result electrification and efficiency, with bioenergy and hydrogen providing drop-in fuels where necessary and CCS being available to reduce emissions from key point sources.

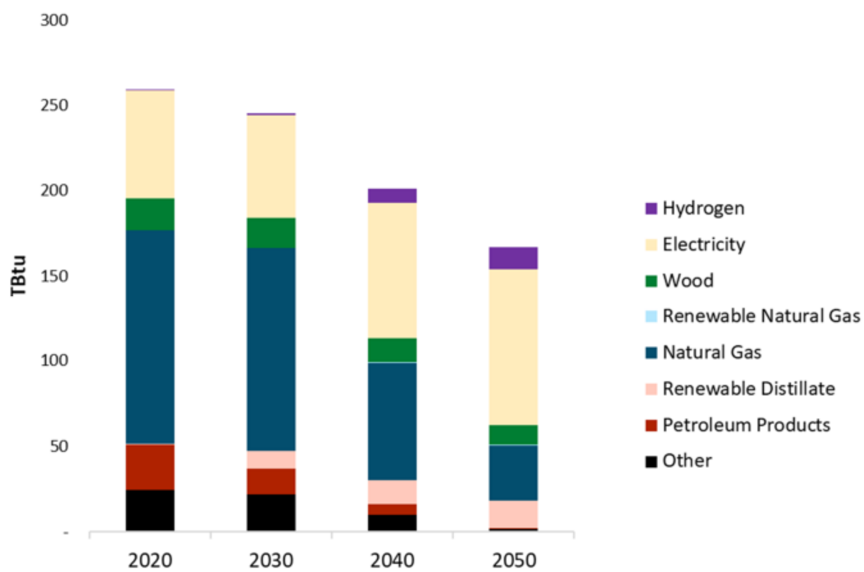
Through 2030, industrial sector GHG reduction is driven primarily by continued investment in energy efficiency and some replacement of fossil fuels with low-carbon, renewable fuels, allowing more time for innovation to meet the 2050 goals. For example, after 2030, electricity increasingly replaces fossil fuel combustion as electrification of industrial applications, such as high-temperature thermal processes, progresses over time. Note the energy and emissions reductions displayed in Table 4 are a result of the scenario design process in this study and do not represent sectoral targets.

Table 4 Industry Energy and Emissions Reductions Achieved in Decarbonization Pathways Scenarios

Metric	2030**	2050**
Percent GHG emissions reduction*	6%	81%-82%
Percent reduction in final energy demand*	4%	39%-40%
*Relative to 2016 **Range of values includes both the Decarbonization Pathways described in this report		

[3] This section focuses on industrial emissions from energy combustion only; industrial process emissions are characterized in the non-combustion section.

Figure 15. Industry Final Energy Demand, High Technology Availability Pathway



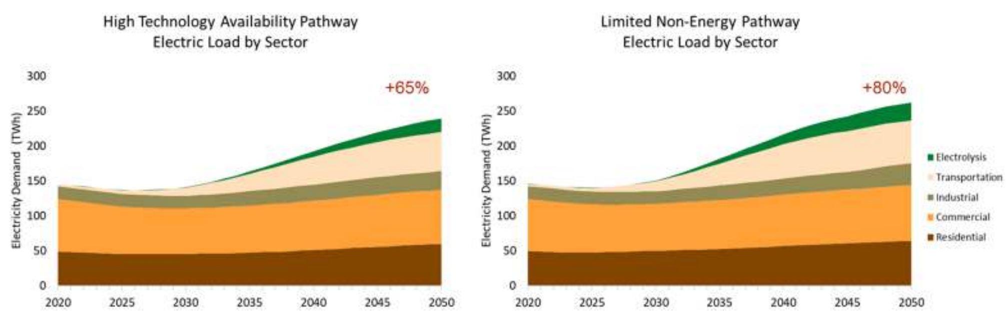
4.4 Electricity Generation

The challenge facing the electric sector in a carbon-neutral future is two-fold: (1) meeting increased electricity demand due to electrification of vehicles and buildings; and (2) reducing, and eventually eliminating, GHG emissions while serving that demand.

4.4.1 ELECTRICITY DEMANDS

Our analysis shows that electricity demand in New York may increase by 65% or 80% relative to current load levels (Figure 16), which is consistent with the range found in our literature review (20%-120% by 2050). This range depends significantly on the scale and timing of electrification; whether there is a significant role for bioenergy; and the potential for synthetic fuels, such as hydrogen, that are produced from electrolysis.

Figure 16. Electricity Demand by Sector and Scenario



4.4.2 PEAK DEMANDS AND LOAD FLEXIBILITY

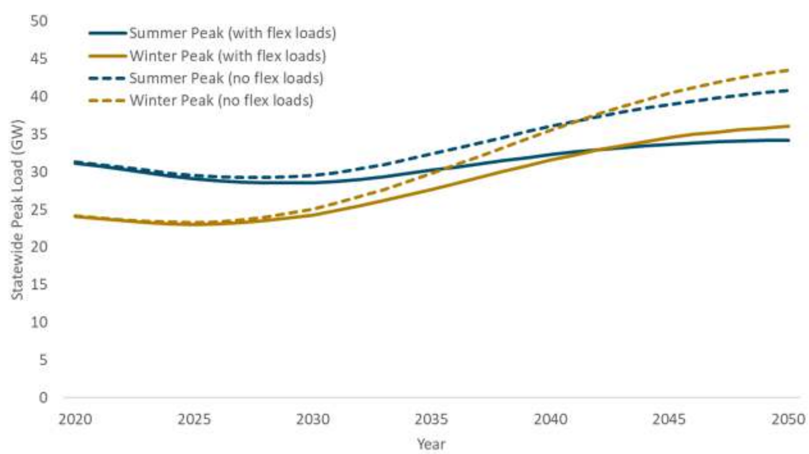
CLCPA requires 100% zero-emissions electricity by 2040. Correspondingly, the State will both reduce, and eventually eliminate, direct emissions from electricity generation and pursue GHG reductions in transportation, buildings, and industry, where consumers and businesses can transition from fossil fuels to clean electricity.

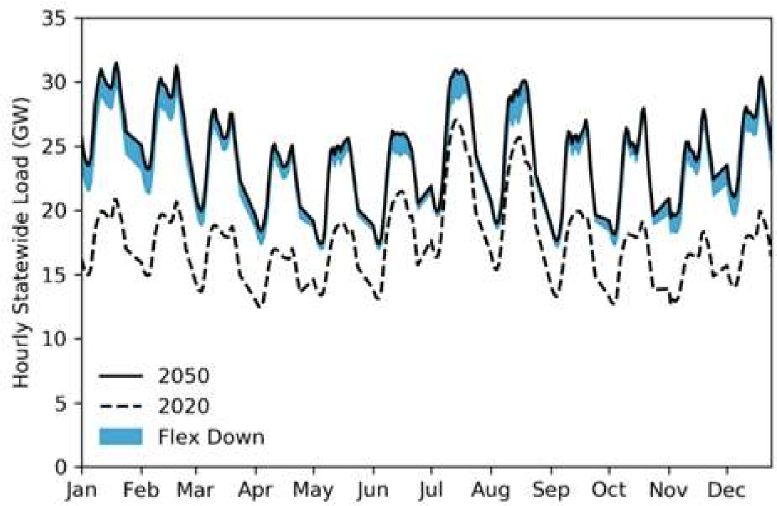
This transformation will change the timing and magnitude of consumers' electricity demands and create a "winter peaking" system in New York, owing to new demands from electric space heating, as described previously.

We find that the shift to a winter peak occurs around 2040 and is driven by the timing of heat pump and electric vehicle adoption. Flexibility in electric vehicle charging patterns and building loads can significantly reduce peak demands and the need for new electric generating capacity. Flexible loads can serve a similar role to battery storage, shifting demand to times of high renewables output.

Figure 17 illustrates this evolution of the system peak—and the impacts of electric load flexibility--over time.

Figure 17. Annual summer and winter peak electricity demands (top) and average hourly load (bottom)





Note: The chart above contains a 24-hour set of hourly loads for each month, representing an approximate monthly average hourly load; as a result, the chart does not capture seasonal peaks. The "flex down" area represents the portion of load that can be reduced in that hour and shifted to other times of day.

4.4.3 RESOURCE PORTFOLIOS

New York State has access to diverse in-state renewable energy resources and zero-emissions technology options, as well as access to adjoining states, provinces, and regional transmission systems which offer additional options for zero-emissions energy supply.

Our analysis explored the new resources required to reliably meet electricity demand in buildings, transportation, and industry with 100% zero-emissions electricity for the upstate and downstate regions of New York. The analysis includes reliability constraints and models the reliability contributions of intermittent and limited-duration resources by projecting the effective load carrying capability (ELCC)[4] of wind, solar, and battery storage resources as a function of the penetration of those resources.

Our analysis finds that New York can reliably meet growing electricity loads with 100% zero-emissions electricity by relying on a diverse mix of resources, including:

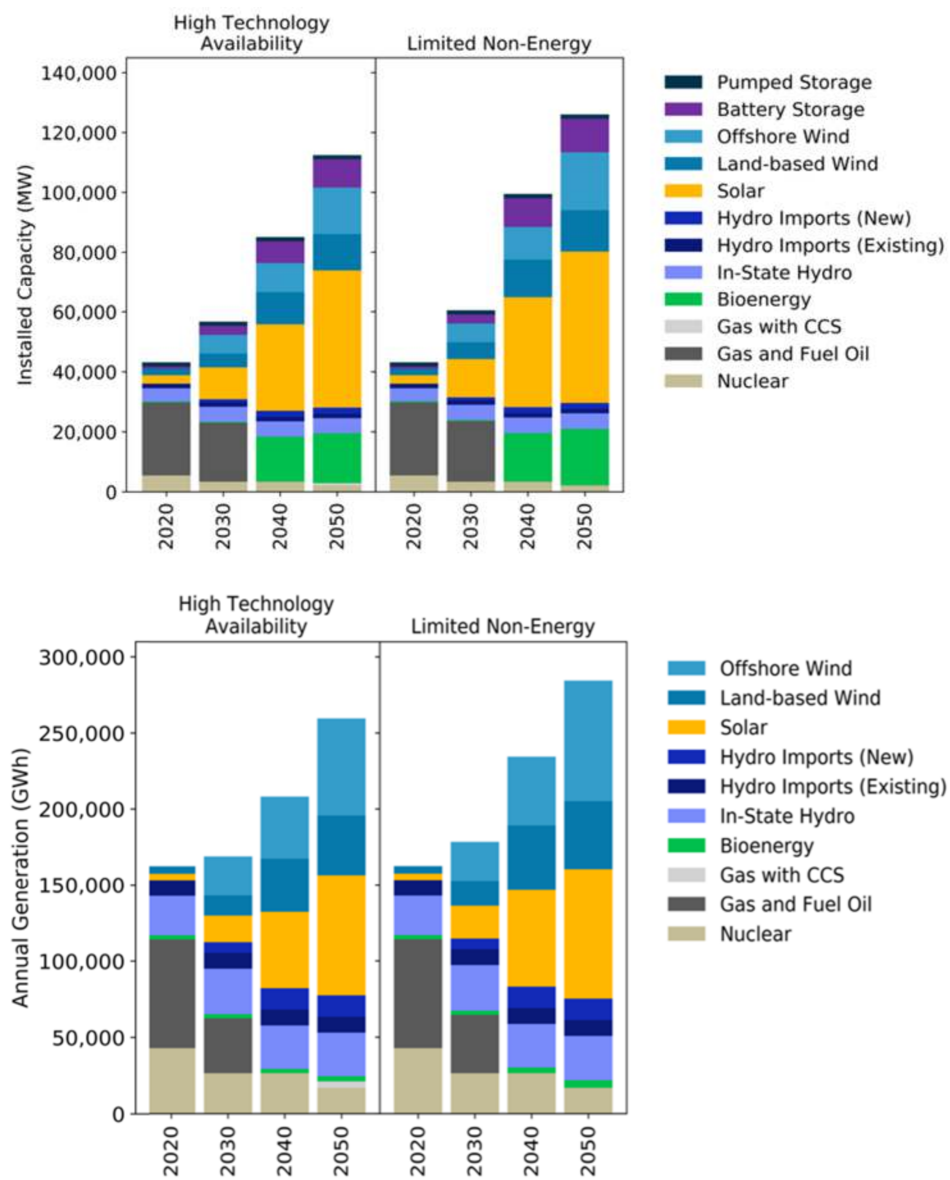
+ Onshore and offshore wind
+ Large-scale and distributed solar
+ In-state hydro and existing and new hydro imports from Quebec
+ Existing nuclear capacity
+ Existing and new combined cycles (CC) and combustion turbines (CT) utilizing zero-emissions biogas
+ New natural gas-fired combined cycles with carbon capture and sequestration (CC-CCS)

The projected least-cost resource portfolios to meet New York's electricity targets are shown in

[4] The effective load-carrying capability is the amount of "perfect capacity" that could be replaced or avoided with wind, solar, or storage while providing equivalent system reliability. The ELCC curves in this analysis were developed using E3's reliability model, RECAP.

Figure 18 below. This generation chart illustrates the two-fold challenge facing the State of (1) meeting rapidly increasing electricity demand while (2) transforming the electricity generation mix into a highly renewable system primarily powered by wind and solar resources. The contributions of renewable resources are projected to increase beyond the 70% target after 2030, while other zero-emissions generation resources will also play an important role in balancing the portfolio and ensuring year-round reliability.

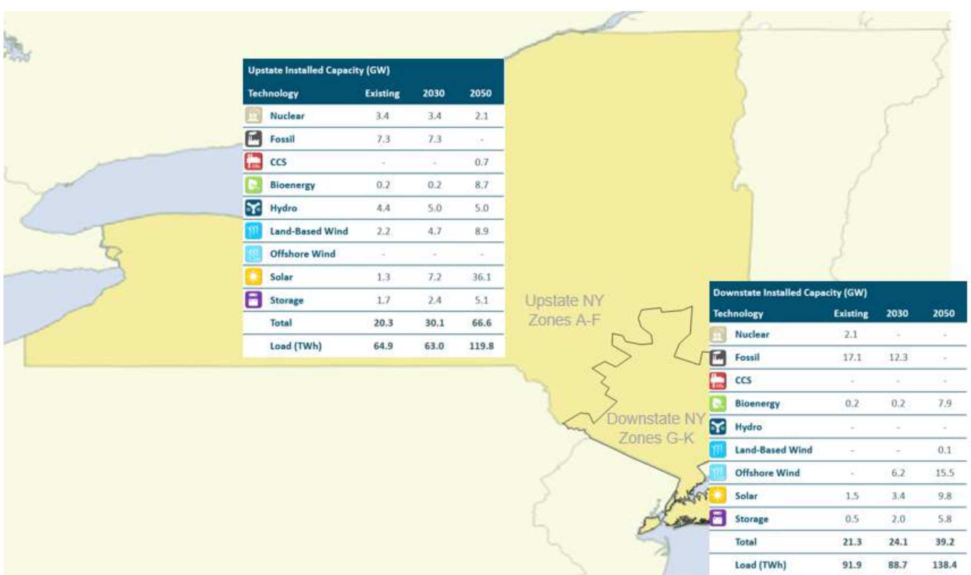
Figure 18. Projected Installed Capacity (top) and Annual Electricity Generation (bottom)



The analysis projects substantial growth in solar and wind capacity in upstate New York, as well as new offshore wind projects delivering power directly to load centers in downstate New York, exceeding the 2035 target of 9 GW in subsequent years. Significant in-state renewable development will require careful siting considerations that should be explored in depth.

Advanced energy storage deployment will also play an important role in New York's future electricity system. Even after accounting for the declining effective load carrying capability as storage penetration increases, battery storage additions can help meet New York's growing peak demands, and along with end-use load flexibility, battery storage will also play a critical role in renewables integration and intraday balancing needs.

Figure 19. In-State Resource Development in High Technology Availability Pathway



Upstate Installed Capacity (GW)			
Technology	Existing	2030	2050
Nuclear	3.4	3.4	2.1
Fossil	7.3	7.3	-
CCS	-	-	0.7
Bioenergy	0.2	0.2	8.7
Hydro	4.4	5.0	5.0
Land-Based Wind	2.2	4.7	8.9
Offshore Wind	-	-	-
Solar	1.3	7.2	36.1
Storage	1.7	2.4	5.1
Total	**20.3**	**30.1**	**66.6**
Load (TWh)	**64.9**	**63.0**	**119.8**

Downstate Installed Capacity (GW)			
Technology	Existing	2030	2050
Nuclear	2.1	-	-
Fossil	17.1	12.3	-
CCS	-	-	-
Bioenergy	0.2	0.2	7.9
Hydro	-	-	-
Land-Based Wind	-	-	0.1
Offshore Wind	-	6.2	15.5
Solar	1.5	3.4	9.8
Storage	0.5	2.0	5.8
Total	**21.3**	**24.1**	**39.2**
Load (TWh)	**91.9**	**88.7**	**138.4**

4.4.4 TRANSMISSION

New investments in transmission will be needed to enable the delivery of 100% zero-emission electricity, including:

- Local transmission upgrades to integrate new renewable resources
- Additional transmission to deliver renewable resources from other regions, especially Quebec, into New York
- Bulk transmission capacity from upstate New York to downstate load centers

The State has already begun the process of adding bulk transmission capacity through its selection of AC transmission projects,[5] although additional transmission may be needed to ensure that power can be delivered into New York City and Long Island. The level of additional transfer capacity is subject to substantial uncertainty and an important topic for future analysis.

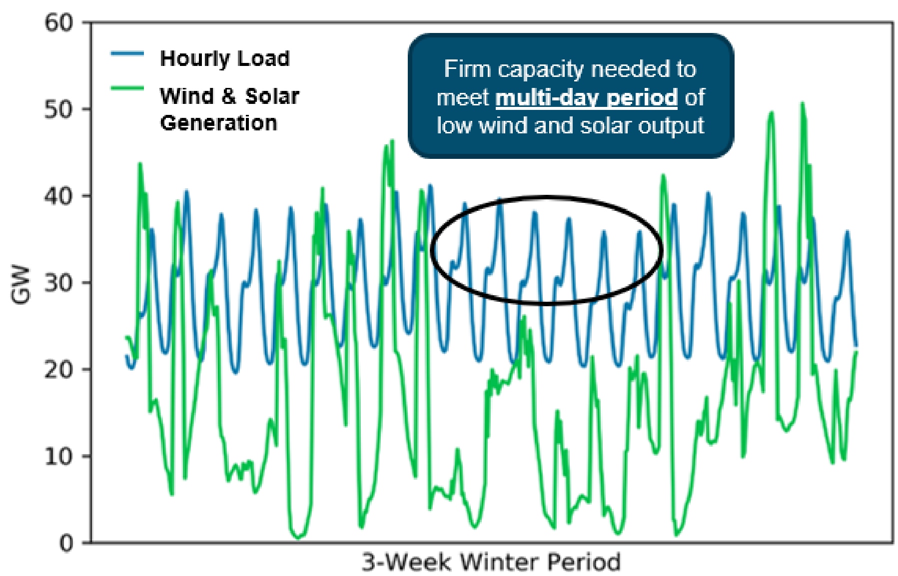
4.4.5 FIRM CAPACITY

Firm capacity is the amount of energy available for power production which can be guaranteed to be available at a given time. As the share of variable resources like wind and solar grows substantially, firm capacity resources will be needed to ensure year-round reliability, especially during periods of low renewables output.

[5] The AC Transmission projects were selected by the NYISO Board in April 2019 to address transmission needs identified by the New York Public Service Commission, as part of the Public Policy Transmission Planning Process: https://www.nyiso.com/documents/20142/5990681/AC-Transmission-Public-Policy-Transmission-Plan-2019-04-08.pdf.

Firm capacity allows the system to have adequate resources available during prolonged periods of low renewable energy output. The State's need for firm resources would be most pronounced during winter periods of high demand for electrified heating and transportation and lower wind and solar output, as shown in Figure 20.

Figure 20. Electricity Demand and Wind + Solar Generation in 2050 in the High Technology Availability Pathway



Hourly loads based on six years of historical weather 2007-2012

A number of studies suggest that complementing high penetrations of intermittent renewables with firm, zero-emission resources – such as bioenergy, hydrogen, carbon capture and sequestration, and nuclear generation – reduce total electric system costs under zero-emissions targets. Research has shown that the magnitude of this cost reduction ranges from 10%-62%.[6]

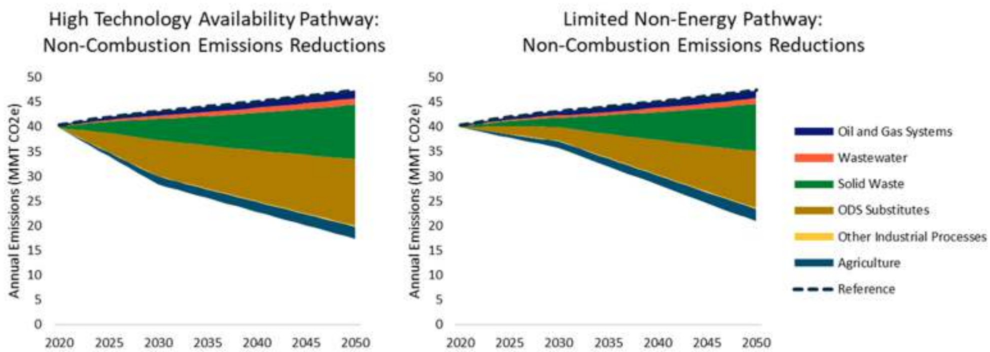
4.5 Non-Combustion Sources

Deep decarbonization strategies often focus on fossil fuel combustion. But New York State's non-combustion GHG emissions – from sources that include landfills, farms, industrial facilities, natural gas infrastructure, and refrigerants – are projected to increase over time. Reducing these will be important to meeting New York's 2030 and 2050 goals.

To bend the emissions curve downward, significant reductions are needed across non-combustion emissions sources. Mitigation of short-lived climate pollutants is key, including focus areas of New York State's methane reduction plan, such as reducing emissions from landfills, natural gas infrastructure, and agriculture, and switching to climate-friendly refrigerants (i.e., substitutes for ozone-depleting substances, or ODS), as shown in Figure 21. Identification of technological opportunities to reduce such emissions is beyond the scope of this report, but will be the subject of further analysis.

[6]Sepulveda, N., J. Jenkins, F. de Sisternes, R. Lester. (2018) The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation. Joule, 2(11), pp. 2403-2420. DOI: **https://doi.org/10.1016/j.joule.2018.08.006**.
Jenkins, J., M. Luke, S. Thernstrom. (2018) Getting to Zero Carbon Emissions in the Electric Power Sector. Joule, 2(12), pp. 2498-2510. DOI: **https://doi.org/10.1016/j.joule.2018.11.013**.
E3. 2019. Resource Adequacy in the Pacific Northwest. **https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf**

Figure 21. Non-Combustion GHG Emissions by Source and Scenario



4.6 Negative Emissions

"Negative emissions" refers to the removal of CO2 directly from the atmosphere or from the emission stream of renewable biogenic feedstock combustion (where the carbon emitted was first captured from the atmosphere in the photosynthesis process, resulting in a net decrease in atmospheric carbon). Up to 15% of New York's carbon neutrality goal can be achieved through negative emissions, which may be essential if there are portions of the economy (e.g., industry, air travel, non-combustion emissions) that prove impracticable or uneconomic to fully decarbonize. Negative emissions can come from natural and working lands (NWL) through natural processes or from technologies that capture and sequester biogenic or atmospheric CO_2.

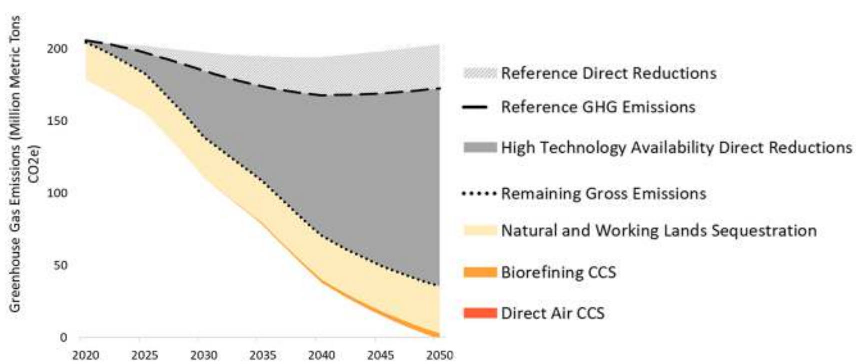
With nearly 20 million acres of forest, New York State's natural and working lands sink is projected to sequester between 23 to 33 MMT CO_2e, depending on the outlook for advances in forest regeneration and land management practices.[7] The

[7] See technical appendix section on natural and working lands (2.5.4) for more details.

extent of the contributions from natural and working lands is subject to substantial uncertainty and additional analysis is needed to improve the characterization of emissions sources, emissions sinks, and carbon sequestration opportunities.

Biorefining with CCS (BECCS) and direct air capture technologies can provide additional negative emissions to offset remaining emissions in the energy and non-combustion sectors. CO_2 is a waste product of biofuel production and can be captured and sequestered to produce negative emissions. Direct air capture (DAC) of CO_2 may prove to be an important "backstop" technology if other measures do not perform as expected. However, DAC is unproven at scale, and its cost outlook is highly uncertain.

Figure 22. Negative Emissions Contribution to GHG Targets in High Technology Availability Pathway



4.7 Low-Carbon Fuels

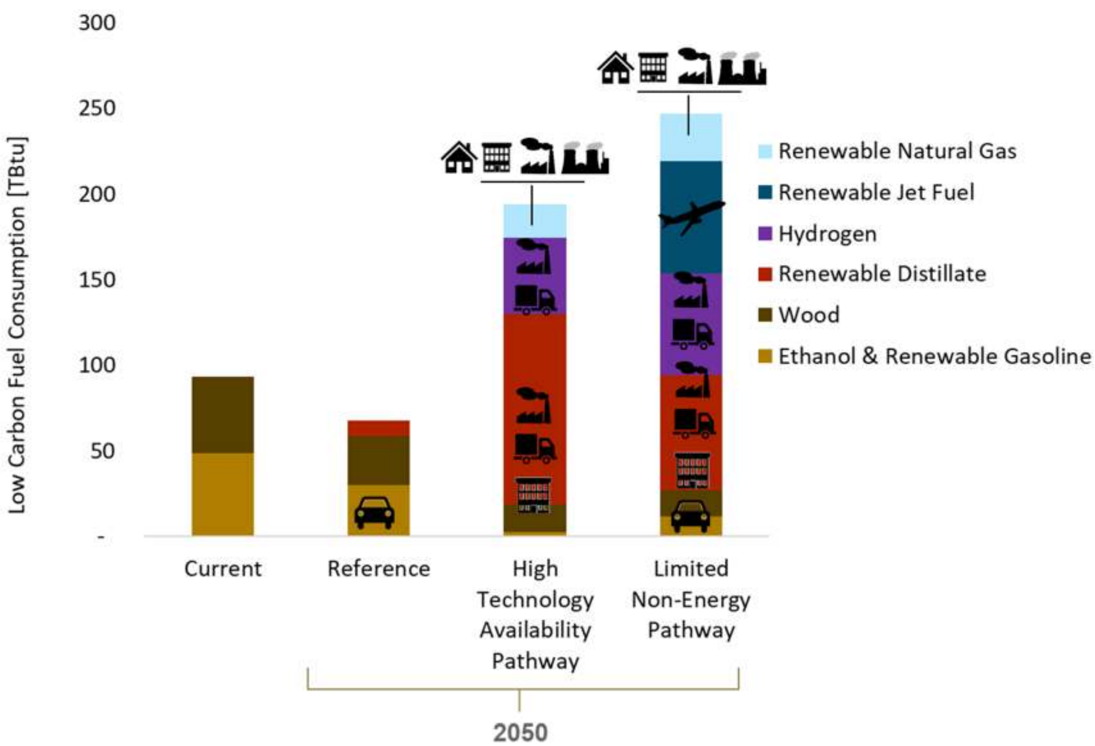
Advanced low-carbon liquid and gaseous fuels are key to decarbonizing sectors where electrification is challenging, such as freight transportation, aviation, marine, and high-temperature industrial applications. Our fuels analysis includes low-carbon advanced biofuels and hydrogen produced from electricity.

Bioenergy is used in New York today largely in the form of ethanol blended into gasoline and wood combusted in buildings for heat, with smaller quantities of biodiesel being used for vehicles and space heating. The transition to carbon neutrality will require very strategic use of limited biomass and careful screening of sustainable feedstocks to ensure that bioenergy is carbon neutral when considering its net GHG impacts.

As illustrated in Figure 23, the pathways modeled in our analysis can achieve deep decarbonization using available in-state biomass feedstocks that are assumed to be converted to advanced renewable natural gas and renewable petroleum products. We also assume that a small amount of wood consumption remains in 2050 to serve a variety of needs, including residential wood usage in the North County.[8]

[8] Both pathways retain approximately 16 TBtu of wood consumption statewide in 2050; Compare to 2016 residential wood usage in the North Country of about 3 TBtu.

Figure 23. Low-Carbon Fuel Consumption by Type and Scenario



5 Conclusions

This report presents E3's initial strategic analysis to inform New York's future decisions for meeting GHG goals under the CLCPA. Based on our detailed assessment of pathways to deep decarbonization in New York State, we find the following:

+ **Deep decarbonization in New York is feasible using existing technologies.** This reinforces the conclusion of many other studies. All needed technologies currently exist and can safely be assumed to realize incremental improvements resulting from significant deployment. A high level of innovation will make the transition easier, but the transition is already technically feasible.
+ **There are different pathways to a carbon neutral future.** A 30-year transition demands action now across all sectors of the State's economy but affords some optionality. All scenarios that achieve carbon neutrality show significant progress across the "four pillars" of decarbonization: energy efficiency and conservation, decarbonizing the electricity supply, switching to low-carbon fuels, and negative emissions.
+ **Continued research, development, and demonstration is key to advancing a full portfolio of options.** Some studies and scenarios rely on technologies that have only been demonstrated in a limited number of applications and require further progress before commercial readiness.
+ **Consumer decision-making drives the pace of decarbonization, particularly in buildings and on-road transportation.** By 2030, key technologies like plug-in electric vehicles, electric heat pump heating and hot water systems, and other electric appliances in the home (e.g.,

stoves, clothes dryers) will need to become normalized, meeting or exceeding half of new sales with accelerating adoption through midcentury.

+ **Flexibility along multiple dimensions is key to maintaining reliability and reducing cost of a 100% zero-emission electricity system**. In the electricity sector, several forms of flexibility are necessary for balancing a 100% zero-emissions grid. Flexible end-use loads and battery storage can provide sufficient short-term (intraday) flexibility to balance high levels of variable renewable output. The more difficult challenge is during winter periods with high heating loads and very low renewable energy production, which can occur over several days. This long-duration (interday) challenge can be solved through a combination of large-scale hydro resources, renewable natural gas (RNG) or synthetic fuels such as hydrogen, Carbon Capture Storage (CCS), and nuclear power.
+ **Managed electrification can help mitigate the risk of very high winter peaks.** In addition to efficiency and end-use load flexibility, investments in a balanced mix of electric heating system configurations and investment in research and development to continue the improvement in cold climate heat pump performance can help to mitigate potential risk associated with unintended consequences of unmanaged electrification.

6 Areas for Future Research

This analysis provides an important starting point for New York as it considers next steps to meeting CLCPA goals, but it also outlines potential areas of additional research and exploration, as listed below.

- Incorporate updated GHG emissions accounting methodologies developed for the statewide GHG emissions limit and reporting requirements of the CLCPA
- Continue to evaluate peak heat impacts of a transition to electric space heating in New York State, which is ongoing through the Carbon Neutral Buildings Roadmap
- Improve characterization of GHG emissions from refrigerants, including those associated with heat pump adoption, and assess mitigation options in detail with a focus on the use of low-GWP refrigerants in heat pumps
- Evaluate the impacts of electrification on the future of natural gas distribution within the State
- Analyze local transmission needs to serve customers with 100% zero-emissions electricity
- Explore in detail implications of resource portfolios on renewable development siting, considering protected and sensitive lands within the State
- Improve assessment of carbon capture and storage potential within the state, especially focusing on geographic opportunities for carbon storage and utilization

+ Improve characterization of non-combustion emissions sources, such as landfills, and associated mitigation opportunities.
+ Improve characterization of net GHG emissions from natural and working lands over time and under different future scenarios
+ Continue to assess potential quantity and cost-effective conversion pathways of sustainable bioenergy resources and develop scenarios that explore different sectoral allocation of these resources