Pathways to Carbon-Neutral NYC:

MODERNIZE, REIMAGINE, REACH

Executive Summary

APRIL 2021

About the Study

This study was commissioned by the NYC Mayor's Office of Sustainability (MOS), Con Edison, and National Grid. This groundbreaking partnership among the major stakeholders responsible for the city's decarbonization provides an example of the coordination and collaboration required to reach carbon neutrality at the scale and pace that climate science demands. The results of this analysis will inform future City policies and programs. The utilities—essential partners in supporting citywide decarbonization—will consider the findings to inform innovation priorities as they continue to support the communities they serve.

Drexel University, the Energy Futures Initiative (EFI), and ICF supported this effort. Drexel University surveyed and summarized the literature on deep decarbonization, contributed to the buildings modeling analysis and cost estimates, and supported project management. EFI facilitated collaboration between NYC MOS, Con Edison, and National Grid by convening a Technical Advisory Committee (TAC) to solicit expert advice, developing multiple outlines and discussion drafts of the final report, providing a range of analyses for consideration by the study participants, and supporting the study participants as they finalized the report. ICF provided independent, objective analyses of deeply decarbonized futures for NYC and led the modeling effort. ICF led NYC MOS, Con Edison, and National Grid in developing assumptions and scenarios, conducted detailed sectoral and cross-sectoral modeling, participated in the TAC, and supported the study participants in drafting and finalizing the report.

NYC MOS, Con Edison, and National Grid contributed their expertise and select data to the study and worked with the consultants to align on a common set of assumptions and the modeling approach. They reviewed interim and final modeling results, shaped the study's key findings, and contributed to finalizing the report.

Project Team

This study was made possible thanks to the following members of the project team:

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Sponsors' Note

NYC Mayor's Office of Sustainability

The City is committed to leading a just and equitable transition to carbon neutrality and acknowledges that environmental justice communities have borne a disproportionate share of the negative impacts associated with our existing economy. This technical analysis demonstrates that achieving carbon neutrality is not only feasible today but can lead to substantial benefits to New Yorkers. It underscores the need to quickly shift away from fossil fuels towards clean resources. The City will use the findings from this technical study to inform near-term and long-term policies and programs to accelerate this transition as the climate science demands. Development of those policies and programs will require extensive stakeholder engagement and collaboration and seek to drive benefits toward environmental justice communities.

conEdison

Con Edison greatly appreciates the leadership and collaboration shown in this tri-party study on the pathways to decarbonization by 2050 and the engagement provided by the Technical Advisory Committee. We support achievement of the decarbonization goals established by the City of New York and New York State, and, as this study demonstrates, no single entity can get us to the low carbon future we envision for the New York City region. It will take the combined partnership of building owners, residents, policymakers, utilities, environmental advocates, and energy suppliers to start thinking more expansively to transition our energy systems to achieve clean energy targets.

Con Edison approached this study with a viewpoint of supporting the environmental goals of our customers, who want a clean energy future. This study contributes significantly to the ongoing conversation about ways to reach regional decarbonization goals and the immense, transformative journey our society is embarking on to address climate change. As is the case today, Con Edison will be responsible for meeting the energy needs of its customers in this great city in 2050. Achieving clean energy goals will also require flexibility in implementation and periodic calibration of assumptions made with actual outcomes. The energy systems of 2050 will also need to be mindful of cost impacts to our customers, and we are confident that we will learn along this journey about ways to increase the cost-effectiveness of clean energy and the infrastructure that delivers it. System reliability planning efforts will be informed by studies such as this one but will need to consider additional factors due to the critical nature of reliable and resilient energy delivery. We will take the steps needed to deliver that clean energy in a safe, reliable and resilient manner. Today, this study shows that ambitious carbon reduction goals can be achieved via multiple pathways. Con Edison stands ready to work with our customers and partners to get us to those goals.

nationalgrid

National Grid embraces a net-zero future—it is positive for our planet, clean energy projects create jobs and spur economic development in our communities, and we want to play our part. We've underscored our commitment to reducing greenhouse gas emissions with our Net Zero by 2050 plan which outlines our approach to exploring a wide range of solutions. National Grid is aligned with New York's clean energy goals and believes this study provides insight regarding potential pathways to reach the clean energy future we all want. We recognize that success will require program and technology innovation, including advances in existing technologies and emerging technologies which are developing every day. It will also require a deeper understanding of cost impact on the customers we serve, and how we can ensure a viable and equitable transition to a clean energy future. National Grid looks forward to working with all stakeholders on solutions in addressing these challenges.

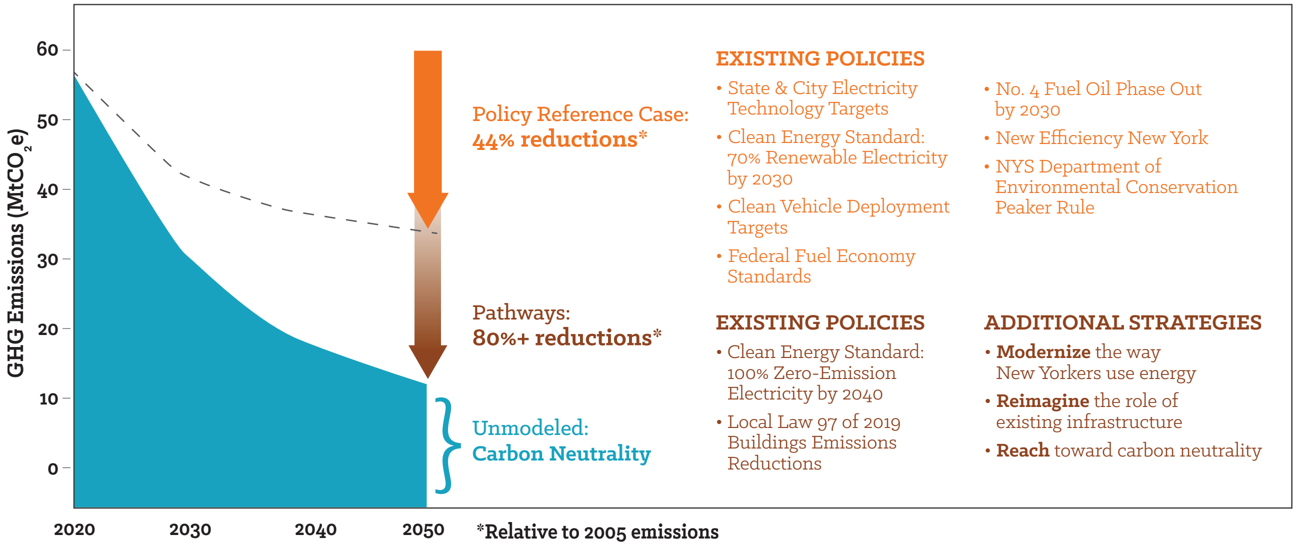
Executive Summary

New York City (NYC) is committed to achieving carbon neutrality by midcentury in a just and equitable way. In support of this goal, this study represents a historic collaboration between the NYC Mayor's Office of Sustainability and the city's two major energy utilities—Con Edison and National Grid. Modeling and analytic support was provided by ICF, the Energy Futures Initiative, and Drexel University.

NYC is already a leader in combating climate change. In September 2014, Mayor Bill de Blasio set a goal of reducing NYC's greenhouse gas (GHG) emissions 80% by 2050.[a,1] The City further increased its ambition five years later by targeting carbon neutrality by 2050.[2] This study explores multiple strategies that could help the City meet its energy and climate goals to develop insight into key decarbonization options, risks, and tradeoffs as the City transitions toward carbon neutrality.

This study finds that the City's existing policies, along with those of New York State, provide a strong foundation for climate progress; existing policies reflected in this study's Policy Reference Case are set to reduce emissions by more than 40% by midcentury. NYC can continue to support this clean energy transition and reach direct emissions reductions of 80% or more through additional actions (modeled in this study as emissions reduction Pathways) to modernize the way New Yorkers use energy, reimagine the role of existing energy infrastructure, and reach toward carbon neutrality (Figure ES-1). Achieving carbon neutrality by 2050 requires ongoing innovation, new technologies, and high-quality offsets. Unlocking the city's full potential for transformative change will require the contributions of policymakers, innovators, utilities, financiers, building owners, skilled trades and unions, and the millions of people who live and work in NYC.

FIGURE ES-1: EXISTING POLICIES AND ADDITIONAL STRATEGIES REQUIRED FOR DEEP DECARBONIZATION



A subset of existing policies (some of which are listed above) is set to reduce emissions by more than 40% by midcentury and are included in the Policy Reference Case. Each emissions reduction Pathway includes these policies as well as the State's 100% zero-emission electricity target and NYC's building sector emissions reduction policy, Local Law 97 of 2019. Combined, these policies could reduce emissions by over 80%; however, achieving the City's climate commitments requires additional strategies to modernize the way New Yorkers use energy, reimagine the role of existing infrastructure, and reach toward carbon neutrality.

a This goal was codified into law by Local Law 66 of 2014. The 80% reduction is relative to a 2005 baseline of 65 million metric tons of carbon dioxide equivalent ($MtCO_2e$).

Accelerating NYC's clean energy transition to ensure it meets its carbon reduction goals can improve the lives of New Yorkers:

Rapid adoption of energy efficient and advanced heating equipment can make homes and businesses more comfortable. Improving efficiency of buildings can lower energy bills and create thousands of new jobs.

An electrified transportation system that reduces reliance on personal vehicles, integrates zero-emission vehicles (ZEV) with ridesharing, improved public transportation, and better last-mile transportation options can reduce travel times, promote healthier living, and save New Yorkers money.[3,b]

Achieving 100% zero-emission electricity can drastically reduce emissions from electricity consumption as homes and vehicles electrify, in addition to unlocking new jobs and business opportunities with the deployment of local wind, solar, and storage resources.

Reducing fossil fuel combustion from vehicles, buildings, and electricity generation within the city will lead to cleaner air and improvements in health, especially for those currently bearing the heaviest environmental burdens.

Transforming the gas network to one that delivers low carbon gas for buildings that do not electrify could allow more businesses and homes to reduce their net carbon footprint.

This partnership among city government ("the City") and investor-owned utilities provides an example of the coordination and collaboration required to reach carbon neutrality at the scale and pace that the climate science demands. Rapidly reducing emissions from the energy systems that are central to urban life without compromising reliability is a central challenge of the clean energy transition.

This study envisions how Con Edison and National Grid's energy delivery systems could become key enablers of cleaner end uses to reach carbon neutrality:

- the electricity system can deliver 100% zero-emission electricity to a growing number of electrified buildings and more than a million ZEVs, cleaning the air and significantly reducing on-site combustion;
- the remaining gas system can transition to deliver low carbon gas (e.g., such as hydrogen or renewable natural gas) for end uses too costly and complex to fully electrify, helping mitigate increases in winter peak electricity demand, and;
- the steam system can provide low carbon heating and cooling to some of the largest and most difficult to decarbonize buildings in the city.

ANALYSIS FRAMEWORK

Building upon prior work completed by the City, this study represents the most comprehensive analysis to date of scenarios for NYC's energy supply and demand through 2050. Three emissions reduction Pathways that achieve at least 80% direct emissions reductions were designed to compare potential futures with distinct technology deployment strategies (Table ES-1). These Pathways build on the Policy Reference Case, which projects costs and emissions reductions from existing City, State, and Federal policies as of June 2019 and the 2020 New York Independent System Operator (NYISO) *Gold Book* energy efficiency projections. The directional findings based on analysis and assumptions from the Pathways are not a prediction of the future but are intended to inform near-term City and utility actions for robust, long-term emissions reduction strategies.

This partnership among city government and investor-owned utilities provides an example of the coordination and collaboration required to reach carbon neutrality at the scale and pace that the climate science demands.

b The Partnership for New York City found that excess traffic congestion costs the regional economy of the New York metro area $5 billion annually. This represents a combination of travel time costs, revenue losses, higher fuel and vehicle operating costs, and an increase in operating costs for industries.

TABLE ES-1: ASSUMED PATHWAY MEASURES

	Electrification	Low Carbon Fuels	Diversified
Description	Assumes increased reliance on electricity for buildings, transportation, and steam production.	Assumes a larger supply of biogenic renewable natural gas (RNG) and less buildings electrification; medium and heavy-duty vehicles rely on biofuels instead of electrifying.	Combines the higher electrification rates of the Electrification Pathway with the higher biogenic RNG supply of the Low Carbon Fuels Pathway.
Buildings and Industry			
Energy Efficiency Retrofits*,ǂ	41% Tier 1 37% Tier 2 8% Recladding	35% Tier 1 44% Tier 2 6% Recladding	37% Tier 1 43% Tier 2 9% Recladding
Electrification of Heating and Domestic Hot Water*	59%	31%	62%
Average Heat Pump Heating Coefficient of Performance	Air Source Heat Pump: 1.75 (residential)/2.0 (commercial) as low as 8°F; extrapolated to simulate performance at 0°F days in the modeling; no resistance heating was modeled at any temperature Gas Heat Pump: 1.33 (residential)/1.6 (commercial); no resistance heating was modeled at any temperature Dual Fuel Heating System: 1.75 (residential)/2.0 (commercial); backup heat required at <10°F with 90% efficiency (residential)/90-95% efficiency (commercial)		
Transportation			
Light-Duty Vehicle Sales	68% Battery Electric Vehicle (BEV), 12% Plug-In Hybrid Electric, and 20% Internal Combustion Engine Vehicles by 2040		
Medium- and Heavy-Duty Vehicle Sales	100% BEV by 2050	Biofuels** used to decarbonize	100% BEV by 2050
Light-Duty Vehicle Miles Traveled (VMT)	-17% VMT by 2050		
District Energy			
Con Edison Steam System Customer Base Changes	Most small buildings leave the steam system	Fewer small buildings leave and all large buildings remain on the steam system	Most smaller buildings leave the steam system
Electricity			
New York State Clean Energy Standard***	100% of electricity sales met by zero-emission sources by 2040		
Natural Gas			
Biogenic renewable natural gas (RNG) supply in 2050	26 tBtu	61 tBtu	61 tBtu

ǂ Tier 1 energy efficiency mostly includes less-extensive measures with shorter payback periods including low-flow water fixtures, high-efficiency appliances, air sealing, building controls and management systems, and lighting upgrades. Tier 2 mostly includes envelope retrofits such as insulation and window replacements. Recladding, the final tier, includes more extensive and costly building envelope upgrades such as exterior wall insulation of masonry buildings.

** As measured by total adoption across all buildings on a gross square footage basis in 2050.*

***Biofuels included 15% ethanol blend by 2025; 20% biodiesel blend by 2035; 20% renewable diesel blend by 2035; RNG for all NG vehicle demand by 2030; natural gas vehicle sales double the Energy Information Administration Annual Energy Outlook baseline.*

****Clean Energy Standard requirements only refer to in-state energy production and do not apply to out-of-state imports. The clean energy requirement was assumed to be met by renewable resources such as wind and solar power, as well as nuclear energy, hydropower, and gas-fired combustion using low carbon fuels.*

ANALYSIS LIMITATIONS

This study is designed to understand the major variables that could affect the City's climate policies and strategies and therefore uses an approach that relies on necessary simplifications to translate complex and highly dynamic challenges into a modeling framework. Any study, however, that projects energy and economic trends three decades into the future is inherently uncertain. This study uses assumptions based on historic data, which may not consistently translate into the future. Other simplifying assumptions and limitations of the analysis that warrant noting at the outset include:

- customer behavior was not considered;
- electricity system reliability was not evaluated;
- the transportation sector analysis did not assess the impacts of cold temperatures on battery electric vehicle (BEV) performance and range;
- changes to electricity wholesale market design were not assumed;
- a detailed electric, gas and steam rates analysis was not included; and
- except in select instances, technology cost and performance improvements were not considered.

PATHWAYS OVERVIEW

Three emissions reduction Pathways were developed to examine options for NYC to deeply decarbonize by midcentury. For each Pathway, this study identifies:

- the main drivers of emissions reductions;
- aggregate and sector-based costs;
- key findings by sector; and
- the associated opportunities and challenges.

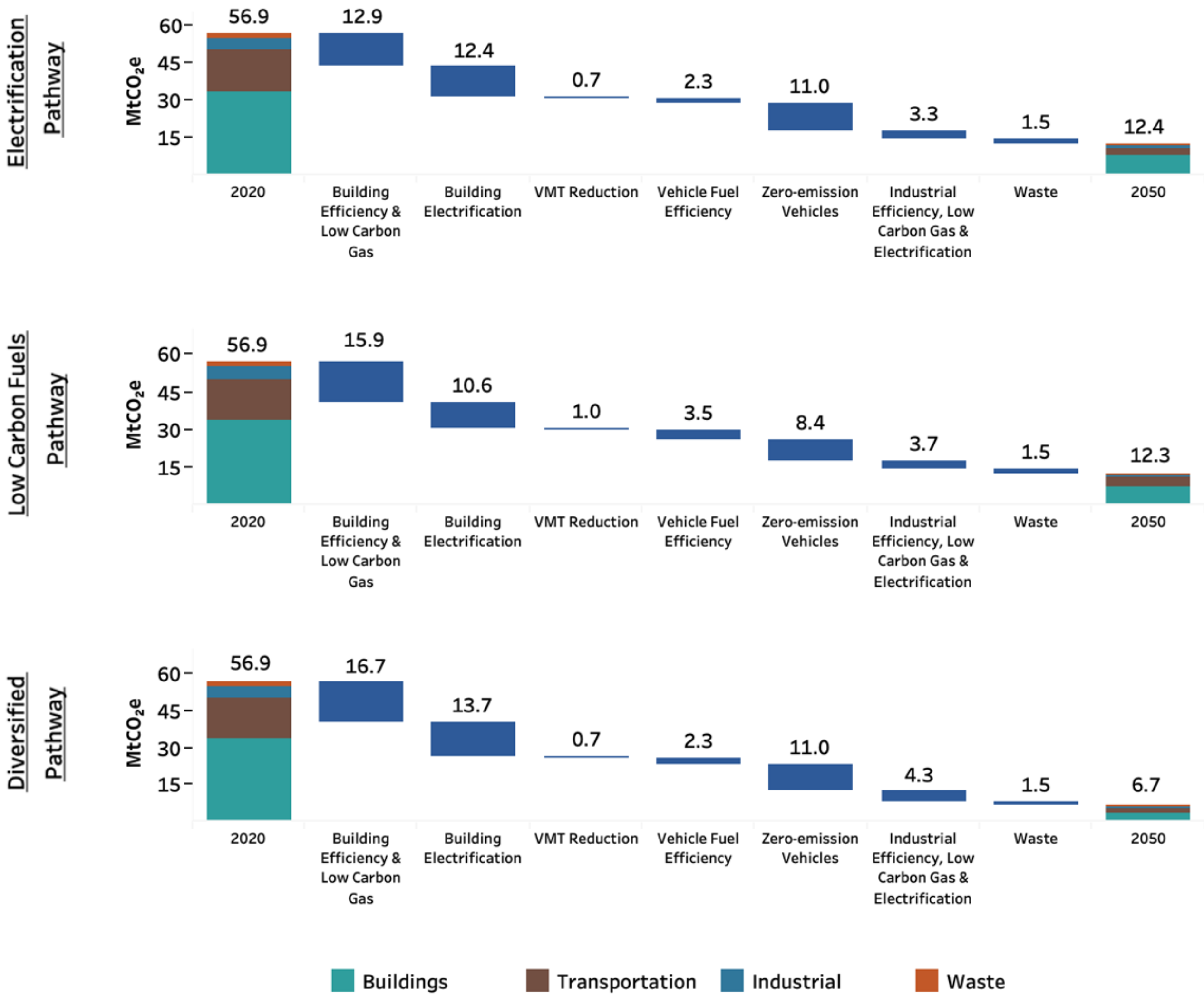
All Pathways include the policies considered in the Policy Reference Case, as well as additional measures to further reduce emissions. The sectors considered in this study are buildings and industry, transportation, electricity, natural gas, and district energy. The buildings and industrial sector includes all buildings in the city, including commercial, residential, and institutional. The transportation sector includes on-road transportation, off-road transportation, maritime transport, and aviation; however, this analysis focuses on on-road transportation, the largest source of emissions. The electricity, natural gas, and district energy sectors relate to the systems that generate and distribute power, distribute fossil natural gas and low carbon gas, and centrally generate and distribute steam to end uses in the city, respectively.

All three decarbonization Pathways rely on a common set of measures: substantial energy efficiency in buildings and transportation, 70% electricity from renewable sources by 2030, 100% zero-emission electricity by 2040, reduced personal vehicle usage and adoption of light-duty[c] ZEVs and electric buses. Building on the Policy Reference Case, the three modeled Pathways increase the extent and pace of these core measures, while adding additional, and critical activities (Figure ES-2). The first two Pathways were designed to compare a decarbonization strategy relying more heavily on electrification to one relying more on low carbon fuels. The third Pathway evaluates what might be achievable if the key elements from the first two Pathways are pursued simultaneously.

The Electrification Pathway achieves emissions reductions by electrifying a high share of building heating systems and vehicles. The Low Carbon Fuels Pathway reduces emissions by reducing the use of fossil fuels through energy efficiency and some electrification and replacing remaining fossil fuels with low carbon alternatives in the buildings and transportation sectors. Relative to the 2005 actual emissions level, these two Pathways both achieve at least 80% direct emissions reduction. The Diversified Pathway electrifies building heating systems and vehicles at high rates while using decarbonized fuels to replace fossil fuels in the buildings sector, combining effective measures of the first two Pathways. The Diversified Pathway reduces more than 90% of direct emissions (relative to the 2005 baseline). Achieving these emissions reductions requires significant amounts of new clean electricity combined with new supplies of low carbon gases—specifically biogenic renewable natural gas (RNG), hydrogen, and synthetic RNG—for the remaining gas supply.

c Light-duty vehicles are vehicles under 10,000 lbs, which includes sedans, pick-up trucks, and minivans; Medium-duty vehicles are vehicles between 10,001 lbs and 26,000 lbs, which includes local delivery trucks, walk-in trucks, and school buses; Heavy-duty vehicles are vehicles heavier than 26,001 lbs, which includes garbage trucks, tow trucks, fire trucks, and buses.

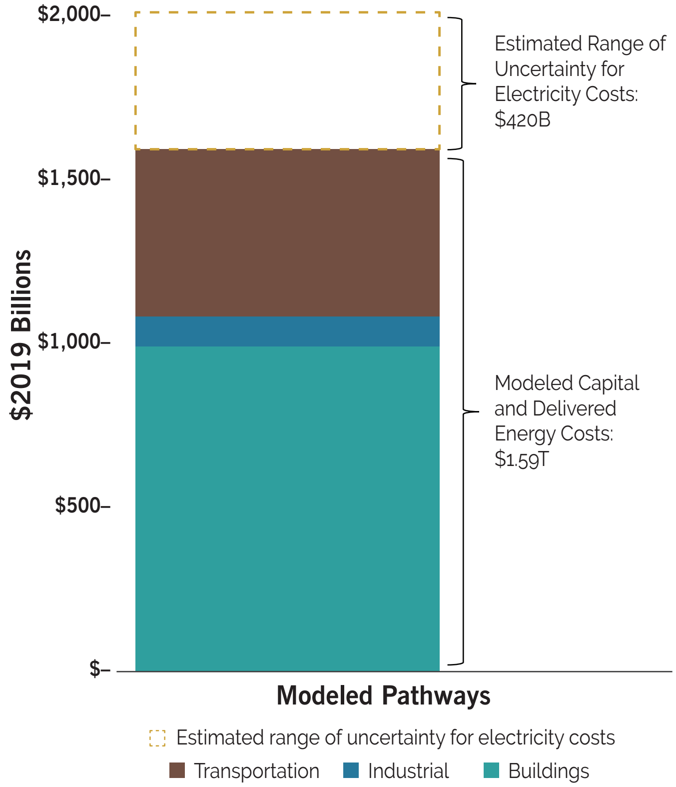
FIGURE ES-2: EMISSIONS REDUCTIONS BY MEASURE FOR EACH PATHWAY



The Electrification Pathway relies heavily on electrifying building heating systems and all vehicle classes. The Low Carbon Fuels Pathway relies heavily on switching fuel sources to low carbon alternatives for building heating and heavy-duty transportation. The Diversified Pathway relies on both electrifying building heating systems and using low carbon gas for remaining building gas use.

The total capital and delivered energy costs range from \$1.5-1.8 trillion in the Policy Reference Case (Figure ES-3) and \$1.6-2 trillion in the Pathways (Figure ES-4). Modeled capital and delivered costs are estimates of what expenditures could be needed to implement the measures modeled in the Pathways. Investments needed to maintain a reliable and safe energy system, such as planned resiliency, non-wires solutions investments, enhanced customer experience, and information technology programs, are not included in these estimates. In addition, some costs associated with generation, such as upstate electric generation investments potentially required to meet Statewide end-use emissions reductions goals, are also not included in the modeling. The estimated range of uncertainty for electricity sector costs reflects an approximation of these costs and on-going investments needed to maintain safety, reliability, resiliency, and grid capabilities.

FIGURE ES-3: MODELED CAPITAL AND DELIVERED ENERGY COSTS TO ACHIEVE THE PATHWAYS, 2020-2050



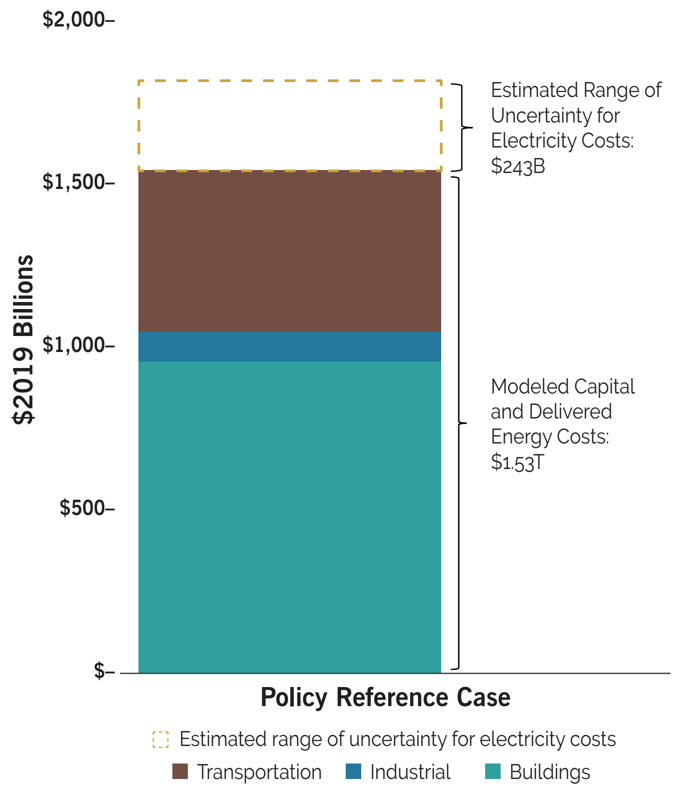
This figure shows the modeled costs for the measures in the Pathways. The sectoral bars represent modeled capital and delivered energy costs for the lowest cost Pathway. The dashed box represents an estimated range of uncertainty for electricity costs for the Pathways.

Many of these costs are not incremental to today's spending—over the course of 30 years, buildings and vehicles will need to be fueled, replaced, and upgraded and owners will invest in new equipment as it reaches the end of useful life. Such costs are not subtracted from the costs reported here. Both the Policy Reference Case and Pathways include these investments, as well as investment to achieve energy efficiency targets and the 70% renewable electricity by 2030 target. The Pathways, therefore, represent efforts and expenditures beyond the already significant expenditures in the Policy Reference Case to maximize emissions reductions, especially with the realization of 100% zero-emission electricity by 2040 and the introduction of low carbon fuels. While there were limited differences in costs among the Pathways, from today's vantage point and with currently available technologies, the modeled Low Carbon Fuels Pathway had slightly lower total costs.

Except for the transportation and electricity sectors, this study assumed that capital costs for new equipment remain constant at today's costs and did not assume any cost declines that may occur as technology performance improves. In recent years, costs for many technologies have declined faster than anticipated. These costs will continue to fall with innovations in battery storage, energy generation, production of low carbon fuels, appliances, vehicles, and building systems and design typologies over the next three decades.

Further cost analysis is required as more information becomes available on technology costs and customer behavior that may deviate from the modeling assumptions. Additionally, cost allocation principles must be developed to minimize the impacts of decarbonization on the costs of rent, transportation, and business, with special attention to already burdened low-income New Yorkers.

FIGURE ES-4: MODELED CAPITAL AND DELIVERED ENERGY COSTS TO ACHIEVE THE POLICY REFERENCE CASE, 2020-2050



This figure shows the modeled costs for the measures in the Policy Reference Case. The sectoral bars represent modeled capital and delivered energy costs for the Policy Reference Case. The dashed box represents an estimated range of uncertainty for electricity costs for the Policy Reference Case.

BUILDINGS & INDUSTRY KEY FINDINGS

The scale and pace of energy efficiency and electrification retrofits is high. Up to 92% of NYC's approximately one million buildings implement Tier 1 energy efficiency improvements by 2050, which include lighting upgrades, new and efficient appliances, minimally intrusive air sealing, and building controls and energy management systems (Table ES-2). On average across the Pathways, 500,000 of the buildings implementing Tier 1 energy efficiency improvement also adopt more significant Tier 2 energy efficiency (e.g., roof insulation and window replacement) or undergo recladding retrofits by 2050. Achieving deep decarbonization would be much more challenging without significant amounts of energy efficiency.

In the Electrification and Diversified Pathways, at least 600,000 buildings, or 60% of building square footage in NYC, are projected to fully electrify heating and domestic hot water (DHW) systems by 2050. More than 340,000 buildings, about 30% of buildings, electrify in the Low Carbon Fuels Pathway. The pace of electric heating and DHW equipment adoption from 2020 to 2050 will be influenced by a number of factors, which could shift the period of most rapid adoption to after the 2030s (Figure ES-5). Some factors influencing the pace of electrifying building end uses, like the amount of existing building equipment already beyond its useful life, are relatively certain, while others, such as technology availability, implementation feasibility, cost, future policies, and customer preferences, are highly uncertain.

TABLE ES-2: CUMULATIVE NUMBER OF BUILDINGS WITH TIER 1 ENERGY EFFICIENCY RETROFITS AND ELECTRIC HEATING AND DOMESTIC HOT WATER SYSTEMS BY 2050*

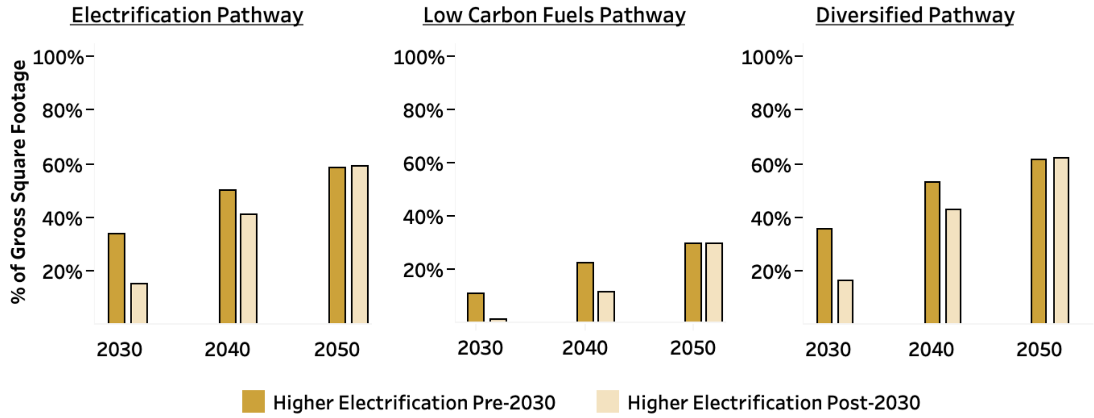
	Electrification	Low Carbon Fuels	Diversified
Number of buildings with Tier 1 energy efficiency retrofits in 2050	909,000	910,000	958,000
Number of buildings with electric heating and domestic hot water systems in 2050**	607,000	340,000	642,000

**Relative to total NYC building stock of approximately one million buildings.*

*** Modeling included a portion of customers converting to electric cooking.*

Up to 92% of NYC's approximately one million buildings implement Tier 1 energy efficiency improvements by 2050.

FIGURE ES-5: CUMULATIVE SPACE HEATING AND DOMESTIC HOT WATER ELECTRIFICATION ADOPTION SCENARIOS, SELECT YEARS



This graphic shows the cumulative square footage of building stock that installs new electrified space heating and DHW equipment over time across two scenarios that employ different adoption rates. Both achieve the same amount of 2050 electrification. The "Higher Electrification Pre-2030" scenario was used in the Pathways modeling.

Building energy efficiency significantly reduces sector energy use by 2050. Electrification of heating and DHW systems and energy efficiency measures reduce energy use in the buildings sector. Of the two, energy efficiency upgrades most significantly drive total building sector energy use declines in the Pathways between 2020 and 2050, reducing energy consumed by buildings by roughly half by 2050.

Electrifying heating and domestic hot water systems has the potential to provide immediate emissions benefits in efficient buildings. Applying the average 2019 NYC grid emissions factor to energy efficient buildings shows that the installation of highly efficient air source heat pumps (ASHPs) provides key building emissions benefits relative to adopting high-efficiency fossil natural gas boilers today. This finding does not account for the potential future use of low carbon gas in buildings.

Building retrofits are capital intensive but they help manage rising delivered energy costs. In the Pathways, modeled delivered energy costs increase over time. Energy efficiency measures and updated heating and DHW systems are critical to reducing energy consumption and managing fuel costs in the buildings sector through 2050. Overall, energy consumption in the building sector is slated to decrease nearly 50% between 2020 and 2050. This can reduce the fuel needs of households and businesses and help to alleviate increasing energy costs.

Technologies that can help manage peak electricity demand in the winter can have vital roles in a future with higher rates of electrification. Absent management, winter electric peak loads in the Electrification Pathway more than double by 2050, implying major upgrades and expansions of the electricity system. There are several technologies and strategies that offer opportunities to shave peak electricity demand, including tariff design and dual fuel heat pumps. Lower peak demand translates directly into reduced capital and generation costs for the electricity sector, as well as reduced reliance on peaking power generation resources. In the Electrification Pathway, if dual fuel heat pump systems that use electricity for all but the coldest periods when fuels are burned to provide additional heat replaced ASHPs that only rely on electricity in 6% of the city's building stock, fuel switching from electricity to gas during very cold weather would reduce peak winter electric demand by 7%.

Use of low carbon gases in the buildings and industrial sector could provide emissions benefits today as well as valuable system benefits. Replacing fossil gas with low carbon gases—which include RNG from biogenic sources, synthetic RNG, and hydrogen produced from renewable electricity—could play a key role in reducing emissions in buildings that do not electrify. For example, displacement of fossil gas with low carbon gases when combined with 100% zero-emission electricity and installation of highly efficient equipment drives emissions reductions of between 70-90% for the industrial sector. Leveraging the remaining gas network to provide low carbon gases can also offer overall system benefits, like managing peak electric demand and reducing the need for certain investments to the electricity network.

Energy efficiency and heating system retrofits provide substantial non-energy benefits. Weatherization and other energy efficiency upgrades can limit indoor allergens and provide better temperature control in buildings. Electrification of building systems can help improve air quality.

The rented building stock faces specific implementation challenges in planning, financing, and managing misaligned incentives between tenants and landlords. Two-thirds of NYC's residential units and most commercial units are rented. If a tenant pays the utility bills, the landlord cannot use energy savings to recoup the cost of efficiency measures. If the landlord pays the utility bills, the landlord benefits from lower energy costs but a tenant has no financial incentive to monitor energy use and could continue energy-wasting practices that negate the benefits of the energy-saving measures. In-unit renovation can also be logistically complicated.

Energy efficiency can be a large driver of inclusive economic opportunity. To achieve deep emissions reductions by midcentury, energy efficiency measures are needed at an unprecedented scale. Energy efficiency retrofits can create new businesses and numerous job opportunities that require specialized skills and training.

TRANSPORTATION KEY FINDINGS

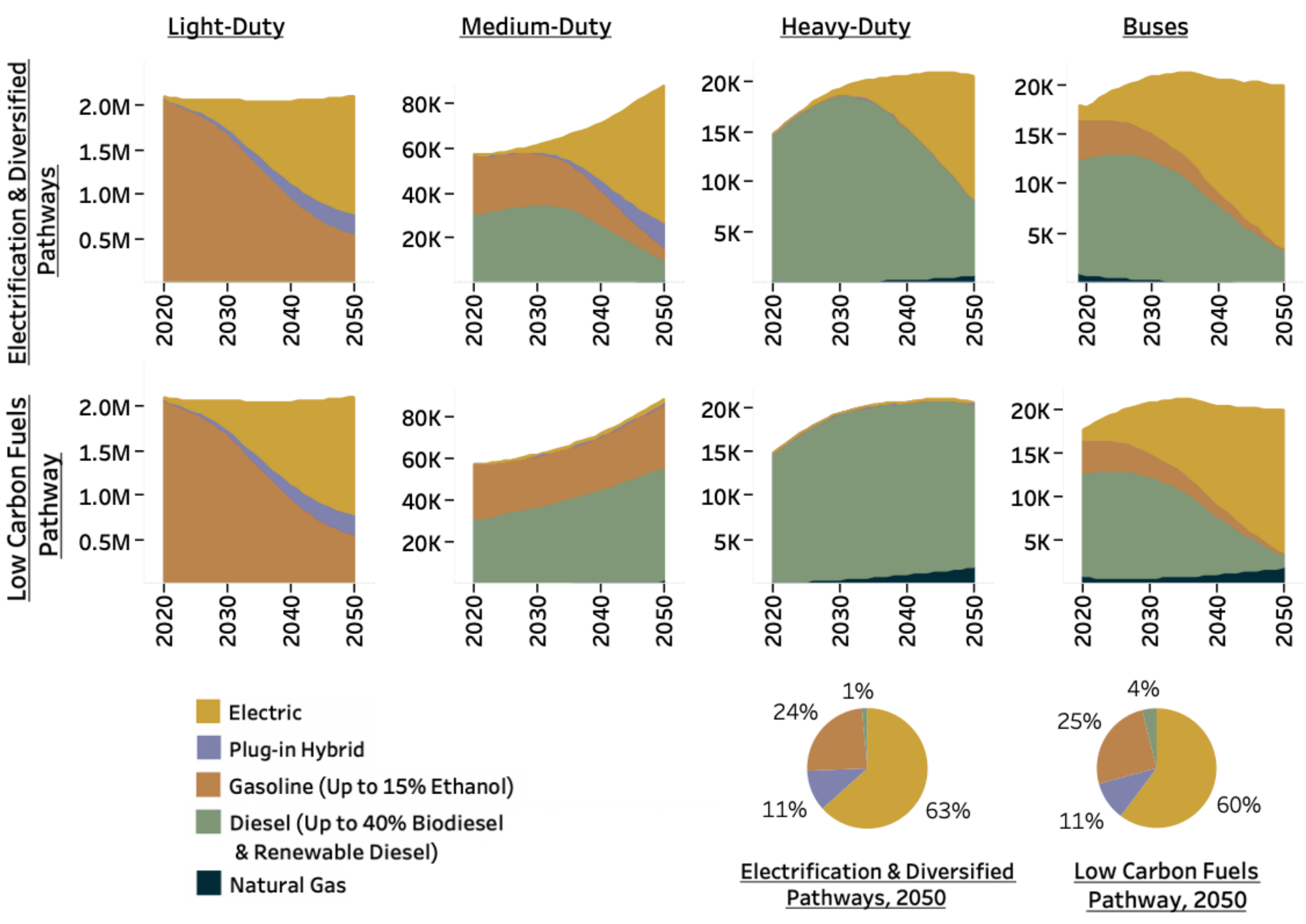
Reducing private vehicle usage and replacing gasoline vehicles with more than 1.5 million battery electric vehicles (BEV) and some plug-in hybrid electric vehicles (PHEV) would reduce 2020 transportation emissions approximately 80% by 2050. To meet carbon neutrality goals, the pace of light-duty ZEV[d] adoption must be very high, reaching 375,000 vehicles [18% of all light-duty vehicles (LDV)] by 2030 and 1.5 million vehicles by 2050 (74% of all LDVs) (Table ES-3, Figure ES-6).

TABLE ES-3: LIGHT-DUTY ZEVS ON THE ROAD

	2030	2040	2050
Policy Reference Case	273,000	425,000	475,000
All Pathways	375,000	1,090,000	1,560,000

As active and shared mobility options reduce dependence on personal vehicles and the sales of BEVs increase, ZEVs represent an increasingly high share of vehicle stock over time.

FIGURE ES-6: VEHICLE FLEET COMPOSITION, 2020-2050



ZEVs are deployed at rapid rates in all Pathways. Medium- and heavy-duty vehicles are assumed to mostly electrify in the Electrification and Diversified Pathways, while they rely on high shares of biofuels in the Low Carbon Fuels Pathway. Natural gas vehicles are less than 0.25% of the entire vehicle stock in all scenarios.

d A zero-emission vehicle (ZEV) is a vehicle that is eligible for New York State's Zero Emission Vehicle Credit, which includes battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), fuel cells, and other vehicle types with very low emissions.

ZEVs typically have lower fuel costs compared to traditional internal combustion engine vehicles (ICEV).[4] In the Pathways, the upfront costs for light-duty ZEVs decline over time as a result of increased adoption and technological improvements. While the Pathways see a slight cumulative increase in the cost of vehicles compared to the Policy Reference Case, fuel costs and maintenance costs decline. The cost premium for ZEVs is initially greater for medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs) than for LDVs but this premium decreases to match the up-front cost of an equivalent ICEV.

Electric vehicles provide significant and immediate air quality benefits. Fine particulate matter ($PM_{2.5}$), a harmful local air pollutant, mostly comes from the transportation sector in NYC. Electrifying vehicles and reducing total miles traveled (VMT) can reduce $PM_{2.5}$ up to 50% for this sector.

Cutting GHG emissions from MDVs and HDVs can depend on either electrifying or increasing low carbon fuel availability but electrification significantly reduces air pollutants and yields greater public health benefits. Obstacles remain for both strategies: electrification requires significant deployment of new charging infrastructure and relies on technology that is not yet deployed at scale for large drivetrains, while some low carbon fuels require adapted distribution infrastructure and fueling station renovations.

Improved vehicle efficiency and active transportation alternatives play an important role in reducing on-road emissions. In the Policy Reference Case, fuel economy improves to reflect federal corporate average fuel economy (CAFE) standards. In the Pathways, efficiency is assumed to increase by an additional 20% in LDVs and 15% in MDVs and HDVs by 2050. In addition to improved efficiency, vehicle use is reduced in favor of more sustainable modes of transportation, thereby reducing congestion and improving public health.

Deployment and management of vehicle charging infrastructure is critical for making electrified transportation possible at scale. About 800,000 Level-2 charging stations[e] are needed for public and private charging of LDVs across all Pathways. About 60,000 direct-current fast charging (DCFC) stations are needed to charge MDVs and HDVs in the Electrification and Diversified Pathways (Table ES-4).

TABLE ES-4: ZEV CHARGER DEPLOYMENT

	2030	2040	2050
Level-2 ZEV chargers (LDV only), all Pathways	207,000	603,000	864,000
DCFC stations (all vehicles), Electrification and Diversified Pathways only	6,000	28,000	60,000

The timing and prevalence of vehicle charging will become an increasingly important issue for utilities to manage. The charging of over 1.5 million BEVs can add more than 6,000 gigawatt-hours (GWh) per year of electricity demand to the grid by 2050. In every Pathway, BEV charging is shifted from evening, when citywide peak power demand typically occurs, to overnight. This managed charging profile shaves winter peak electricity demand by approximately 2 gigawatts (GW) in 2050 in the Electrification and Diversified Pathways. Time-managed vehicle charging will be critical to mitigating electricity peaks at the distribution level and for the bulk grid.

e Level-2 charging stations are the most common type of public BEV or PHEV charger. Level-2 chargers use a higher voltage and have a faster charging time than Level-1 chargers, which typically use a conventional wall outlet.

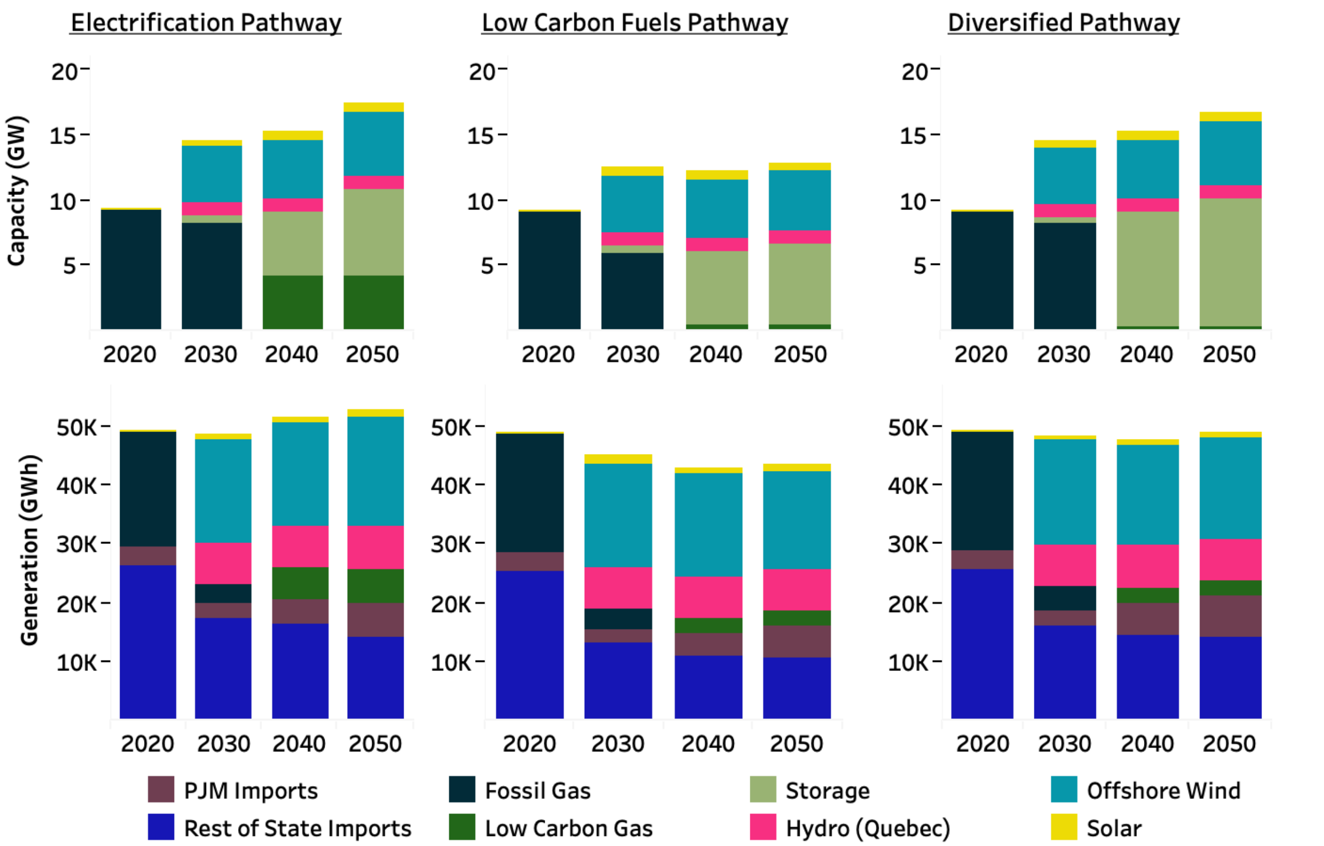
ELECTRICITY KEY FINDINGS

Electricity generation in the city is reimagined in order to meet City and State targets; renewables accompanied by storage play a lead role, most existing power plants retire by 2040, and fossil gas at remaining plants is replaced by low carbon gas. By 2040, the proportion of NYC's electricity demand met by fossil fuels falls to 0% from 60% in 2019, driven by new wind, solar, and hydropower resources. (Figure ES-7). It is important to ensure that the electricity system remains resilient and reliable as existing fossil units are phased out.

Battery storage and low carbon gas-fired generation are sources of dispatchable capacity that could provide reliability for a decarbonized grid. While battery storage and low carbon gas can conceivably supply dispatchable power to the grid, additional innovation is needed as battery storage technology and low carbon gas supply chains are untested and undeveloped at the scale required to decarbonize NYC.

Peak demand increases in scenarios with high electrification rates, driven by higher demand in winter months, underscoring the need for aggressive energy efficiency and demand management measures. New loads from electrified building end uses, ZEVs, and possibly steam generation can significantly change the electricity demand profile (Figure ES-8). In the Electrification and Diversified Pathways, over 60% of building space heating is electrified, resulting in peak demand in winter, reaching 14.5 GW by 2050. In the Low Carbon Fuels Pathway, the system remains summer peaking, with an electric peak of 11 GW in 2050.

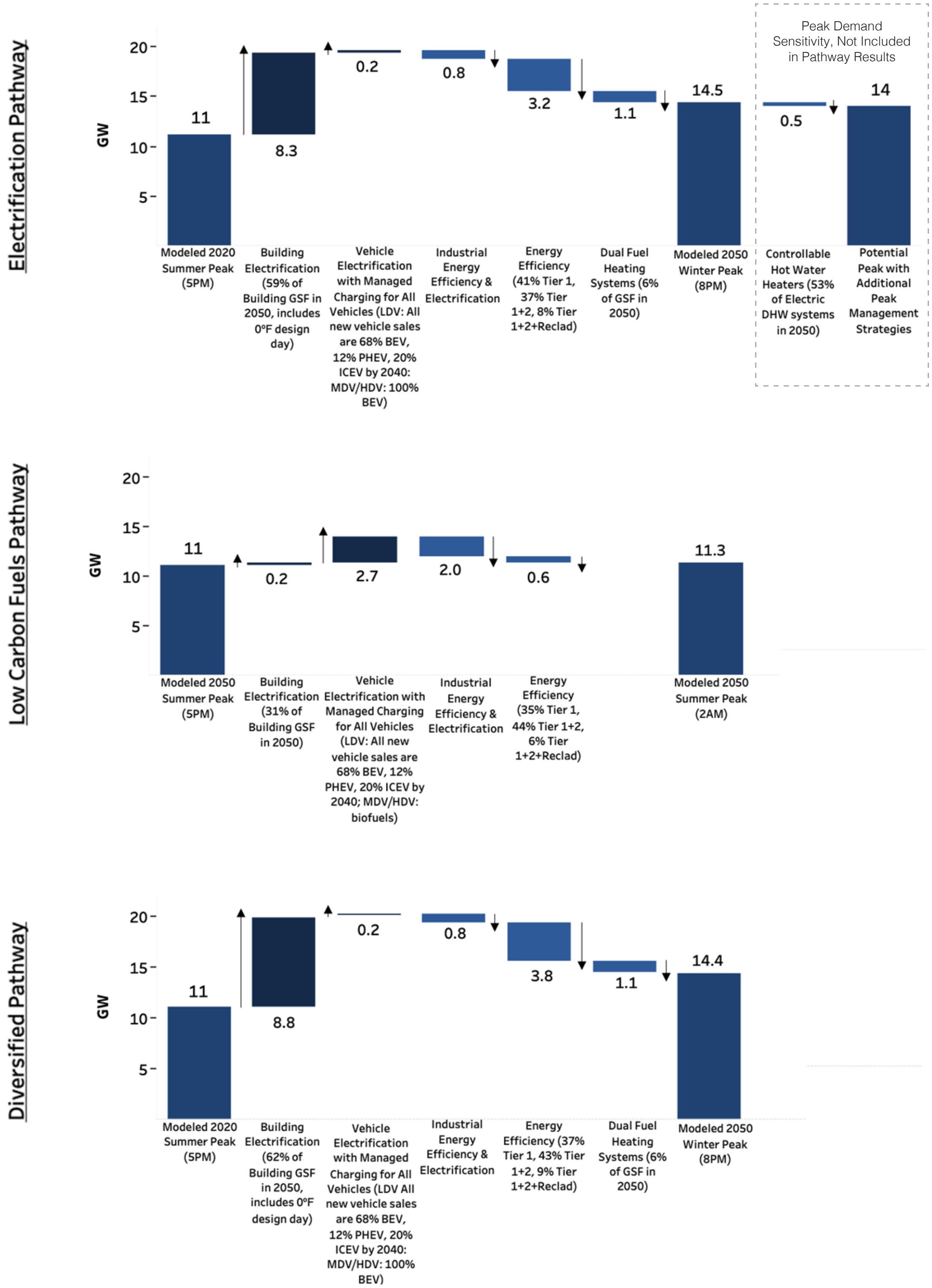
FIGURE ES-7: NYC ELECTRICITY CAPACITY AND GENERATION IN PATHWAYS, SELECT YEARS[f]



Within NYC, gas-fired electricity generating capacity declines precipitously across all Pathways. The gas-fired units that remain online use low carbon gas. Significant offshore wind and battery storage is also installed across all three Pathways. By 2030, offshore wind contributes the largest share of any electricity generation source across all Pathways, followed by a mix of imports, hydro, low carbon gas, and solar.

f Statistics related to NYC's electricity generating capacity, peak demand, and total usage refer to the New York Independent System Operator's (NYISO) designation for the city: Zone J.

FIGURE ES-8: IMPACT OF KEY MEASURES ON PEAK ELECTRICITY DEMAND IN THE PATHWAYS, 2050 COMPARED TO 2020



Winter peaks increase in all Pathways but this is most stark in the Electrification and Diversified Pathways due to the number of buildings switching from gas to electric heating and domestic hot water.

NATURAL GAS KEY FINDINGS

Non-fossil low carbon gas can be an important emissions reduction strategy for end uses that are not electrified across all Pathways. In the Electrification Pathway, RNG is allocated to the electricity sector, therefore, the buildings that are more challenging to electrify still largely rely on fossil gas for building heating systems. The Low Carbon Fuels Pathway prioritizes non-fossil low carbon gas use to the buildings sector. As a result, even with half the number of buildings electrifying in this Pathway compared to the Electrification Pathway, the building GHG emissions of the Low Carbon Fuels Pathway in 2050 are 11% lower than building GHG emissions in 2050 of the Electrification Pathway. In addition to providing a solution for buildings that do not electrify, a low carbon gas network improves overall system reliability by offering optionality and flexibility within the energy system.

Continued maintenance and state-of-good-repair investment in the gas system is required to provide safe, reliable service and reduce emissions. Gas utilities must provide safe, reliable service to customers and are responsible for pipeline infrastructure in their service territories. Ongoing basic support to replace leak-prone pipes in the gas system is currently required by regulators to minimize gas leaks from pipes for safety reasons, no matter the volume and composition of fuel flowing through the pipes.

The supply availability and cost of biogenic RNG, a low carbon gas, are uncertain at this time. For emissions reductions from the use of any non-fossil low carbon gas to materialize, adequate amounts must be imported into the city. However, biogenic RNG availability is uncertain. Farms, industries, and municipalities could benefit from additional income by capturing their emissions and converting them to a commodity fuel. However, NYC's supply of and cost for RNG depends on production and pipeline construction to facilities like farms, wastewater treatment plants, and landfills, the vast majority of which fall outside of City boundaries and jurisdictional control. Biogenic RNG at its medium and low supply potential is projected to cost about five to seven times more than fossil gas in 2050 due to limited feedstock.

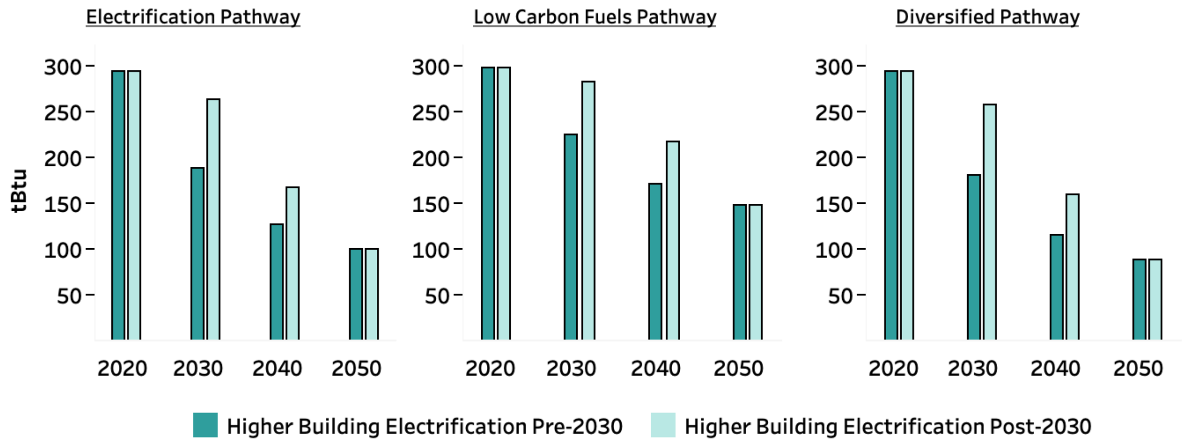
Synthetic RNG and hydrogen have the potential to further decarbonize remaining gas use. Hydrogen and synthetic RNG can be blended into the remaining gas supply to supplement the limited supplies of biogenic RNG available in each Pathway. Today, carbon-neutral hydrogen technologies and markets are nascent; supply and costs are uncertain. Hydrogen costs are currently projected to be about seven times higher than fossil gas commodity cost in 2050, and synthetic RNG is projected to be about nine times as costly (Table ES-5). However, State and Federal research programs and incentives, increased renewable-generated electricity supply over time, and a global focus on hydrogen development could reduce the cost of hydrogen and synthetic RNG relative to biogenic RNG.

TABLE ES-5: USE AND COMMODITY COST OF FOSSIL & LOW CARBON GASES, ALL PATHWAYS

	2030	2040	2050
Biogenic RNG Cost ($/MMBtu)	14-18	16-21	14-19
Synthetic RNG Cost ($/MMBtu)	40	26	21
Hydrogen Cost ($/MMBtu)	32	21	18
Fossil gas Cost ($/MMBtu)	2.5	2.8	2.5
Low carbon gases used as a percentage of total gas use	9-22%	28-52%	34-67%

Total gas demand across all sectors falls more than 60% while delivered energy costs increase. Gas demand falls across all Pathways as buildings implement heating electrification and significant energy efficiency (Figure ES-9). The total delivered cost of gas increases due to sustained infrastructure maintenance and state-of-good repair needs, lower total gas demand, and higher fuel costs from blending of low carbon gas into the gas supply. As delivered costs increase, more customers may find it economical to electrify end uses. This fuel-switching can further shrink the gas customer base, putting additional upward pressure on cost. Customers who are most likely to face continuous cost increases include those who cannot afford to install electrified end uses and those who live in buildings that are more difficult to electrify.

FIGURE ES-9: ANNUAL GAS USE (FOSSIL AND LOW CARBON) IN BUILDINGS SECTOR, SELECT YEARS



Gas use in the buildings sector, inclusive of fossil and low carbon gas, falls 51-70% across the Pathways with the smallest decline in the Low Carbon Fuels Pathway. This figure shows the impact on gas use of alternative building electrification scenarios in which electrification mostly occurs before 2030 or after 2030. The specific pace and rate of gas use decline between 2020 and 2050 will be driven by a variety of factors, including the pace of electrification and energy efficiency, and what policies, incentives and disincentives may exist to realize these measures. The "Higher Building Electrification Pre-2030" scenario was used in the Pathways modeling.

DISTRICT ENERGY KEY FINDINGS

Continued district steam use for very large commercial buildings, institutional buildings, and industrial facilities avoids costly retrofits. Buildings currently served by the Con Edison or Brooklyn Navy Yard steam systems[g] do not have their own heating equipment installed in-building. To leave these systems, each building would need to install on-site electrified or high-efficiency gas-fired heating systems, which could require significant capital investments.

Demand for the Con Edison steam system falls steeply by 2050, presenting challenges for managing infrastructure and associated costs. District steam demand falls as customers leave to electrify or generate steam on-site and remaining customers adopt substantive energy efficiency measures (Table ES-6). A shrinking customer base could make it more difficult to recover costs related to steam system maintenance and upgrades while maintaining a safe and reliable system.

TABLE ES-6: PROPORTION OF NYC BUILDING SPACE THAT USES CON EDISON DISTRICT STEAM

	2019 (Actual)	2050 (Modeled)
Electrification Pathway	812 million sq. ft. (16%)	328 million sq. ft. (7%)
Low Carbon Fuels Pathway		646 million sq. ft. (13%)
Diversified Pathway		328 million sq. ft. (7%)

g The Con Edison and Brooklyn Navy Yard steam systems are centralized heating and cooling systems that serve multiple buildings via water or steam distribution pipes.

FROM INSIGHT TO ACTION: MODERNIZE, REIMAGINE, AND REACH

Achieving the City's decarbonization goals, as demonstrated in the Pathways, requires modernizing the way New Yorkers use energy, reimagining the role of existing infrastructure, and reaching toward carbon neutrality.

The Pathways highlight the need for modernizing the way New Yorkers use energy with increased adoption of building energy efficiency, reduced reliance on personal vehicles while electrifying the vehicles that remain, and heating electrification. Unlocking rapid adoption of ZEVs is possible through financial incentives and programs to support charging infrastructure and managed charging. Achieving the levels of building efficiency and electrification identified in the Pathways may be achieved through financial incentives, pilot projects, stakeholder outreach, codes and regulations, and workforce and business development interventions.

The Pathways also demonstrate the value of reimagining existing infrastructure with a transition to 100% zero-emission electricity and integration of low carbon fuels into the gas network for the remaining end uses that are most difficult to electrify. Achieving 100% zero-emission electricity requires multi-stakeholder coordination for siting and interconnecting a growing share of wind, hydro, solar, and storage. Developing a policy framework for low carbon gases and deploying local pilot projects can enable decarbonization in hard to electrify end uses, like industry, steam, and large buildings.

This study highlights limitations with current technologies that necessitate concerted action to reach toward carbon neutrality. This analysis modeled at least 80% direct emissions reductions by 2050, and additional efforts are necessary to fill the remaining gaps. Pursuing a variety of policies simultaneously and regularly assessing progress toward decarbonization can keep NYC on track to achieving carbon neutrality by 2050. Further study of a variety of topics, such as the resiliency of a zero-emission grid, advanced demand management, costs, and the role of geothermal and district energy, is needed to inform the path ahead. Innovation in long duration and seasonal storage, geothermal districts, hydrogen blending, carbon dioxide removal, and other technologies can help fill decarbonization gaps and drive down costs. Developing a framework for high quality offsets is an important step towards carbon neutrality to offset the hardest to reduce emissions. Ultimately, this study demonstrates that given the scale and breadth of the challenge, deep decarbonization by midcentury can only be achieved through ongoing collaboration between the City, utilities, State and Federal government, and local communities.

Pursuing a variety of policies simultaneously and regularly assessing progress toward decarbonization can keep NYC on track to achieving carbon neutrality by 2050.

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