Pathways to Carbon-Neutral NYC:

MODERNIZE, REIMAGINE, REACH

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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Drexel University: Pavel Beirnarovich, Adrienne Cheung, Patrick Gurian, Hugh Johnson, Joel Krakower, Atiq Rahman, Mahsa Safari, Emily Simkovich, Thomas Stief, and Emma Zhang

Energy Futures Initiative: Alex Breckel, Anne Canavati, Tomas Green, Joe Hezir, Melanie Kenderdine, Alex Kizer, Alex Maranville, and Nicole Pavia

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We would also like to thank the following individuals for their contributions to this study:

Jami Butler Designs – jamibutler.com

Sarah Johnson – New York City Department of Health and Mental Hygiene

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.

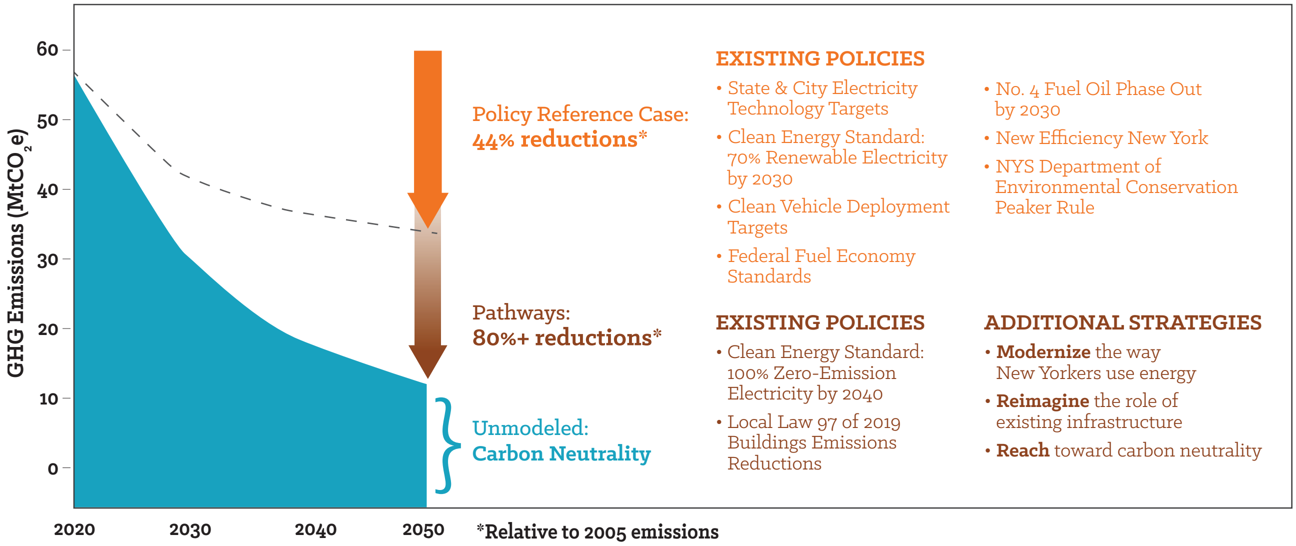
Executive Summary

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.

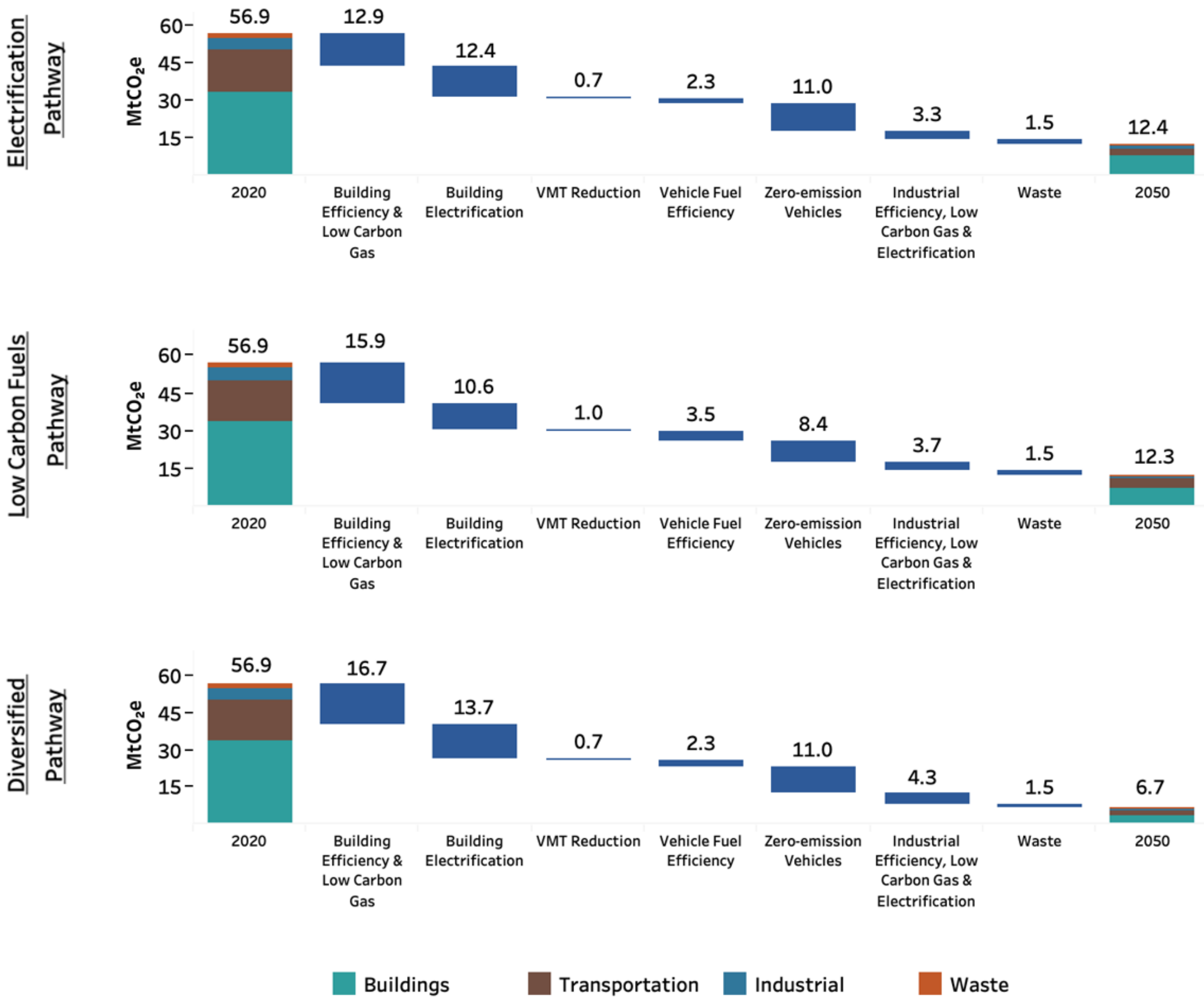
All Pathways include the policies considered in the Policy Reference Case, as well as additional measures to further reduce emissions. The sectors considered in this study are buildings and industry, transportation, electricity, natural gas, and district energy. The buildings and industrial sector includes 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.

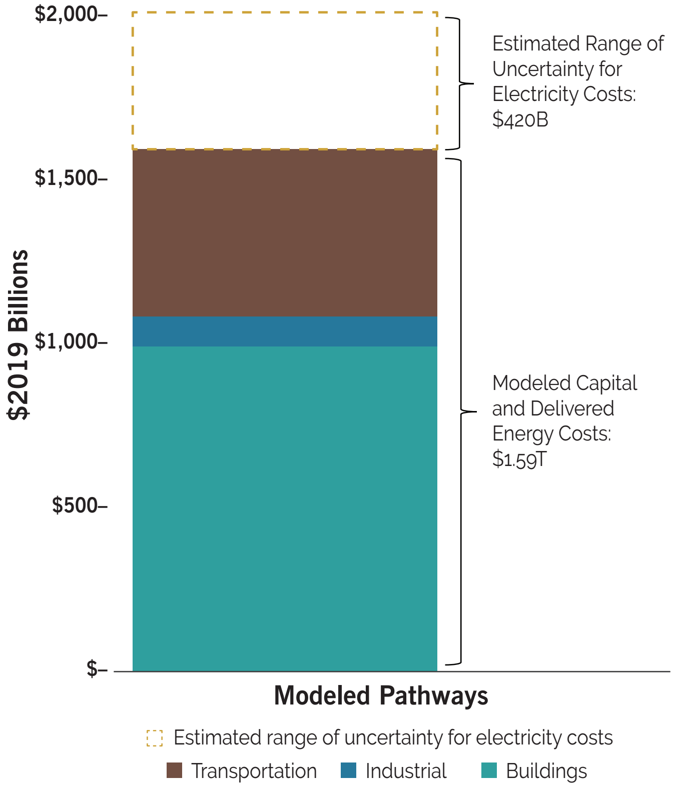
FIGURE ES-2: EMISSIONS REDUCTIONS BY MEASURE FOR EACH PATHWAY



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



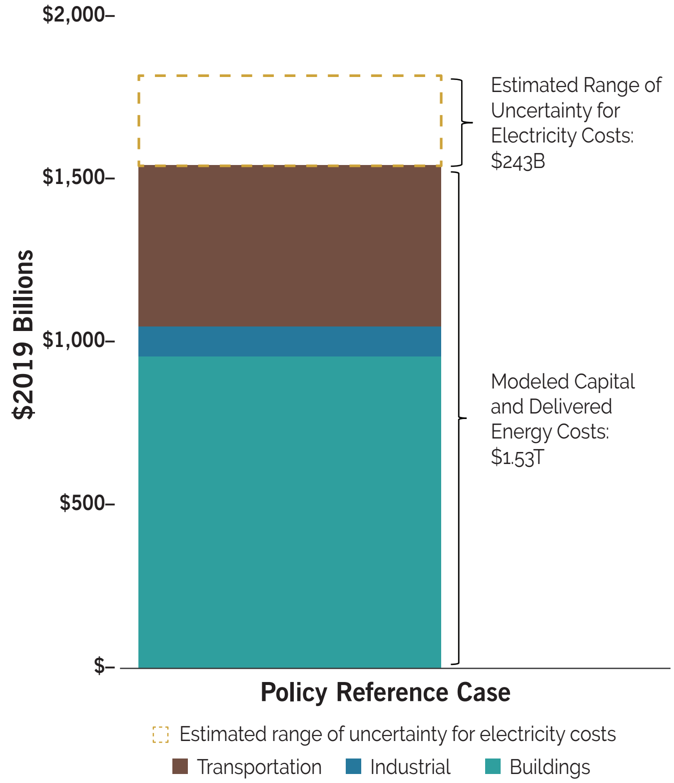
This figure shows the modeled costs for the measures in the Pathways. The sectoral bars represent modeled capital and delivered energy costs for the lowest cost Pathway. The dashed box represents an estimated range of uncertainty for electricity costs for the Pathways.

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*

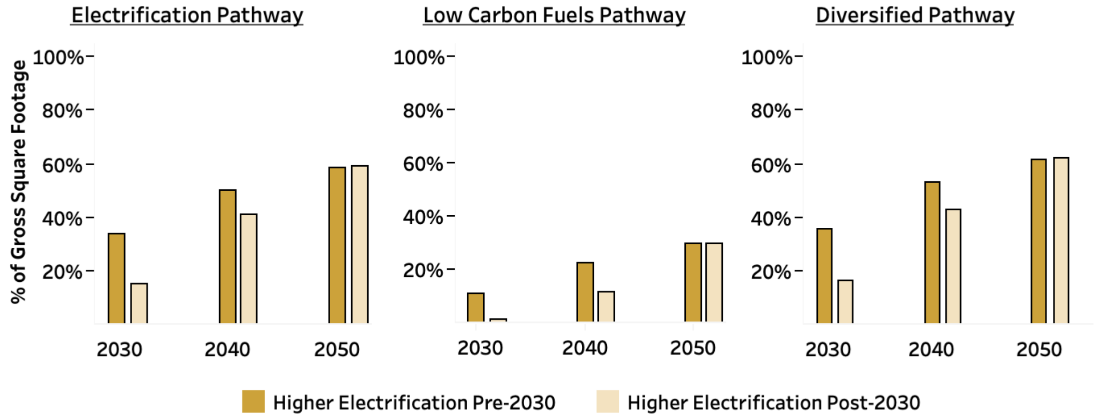
	Electrification	Low Carbon Fuels	Diversified
Number of buildings with Tier 1 energy efficiency retrofits in 2050	909,000	910,000	958,000
Number of buildings with electric heating and domestic hot water systems in 2050**	607,000	340,000	642,000

**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.

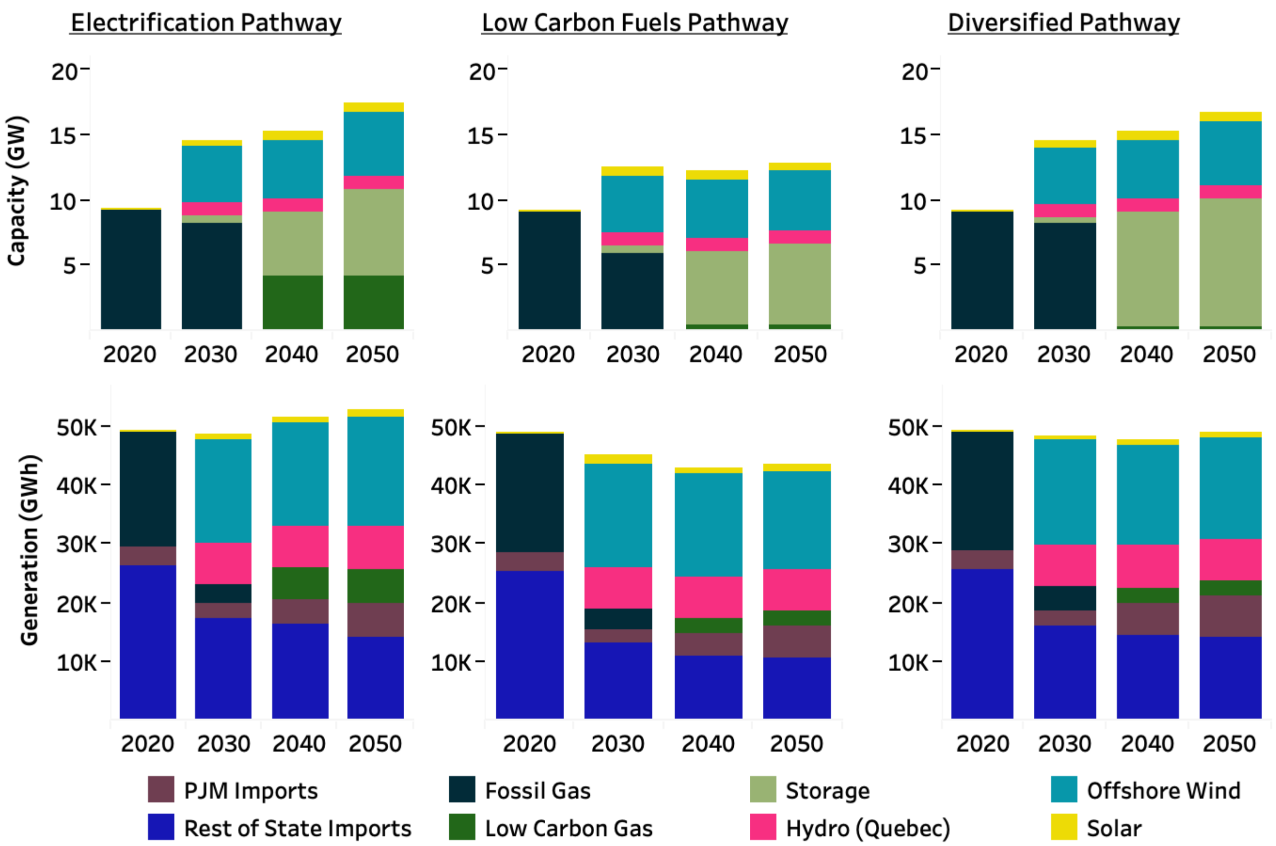
ELECTRICITY KEY FINDINGS

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.

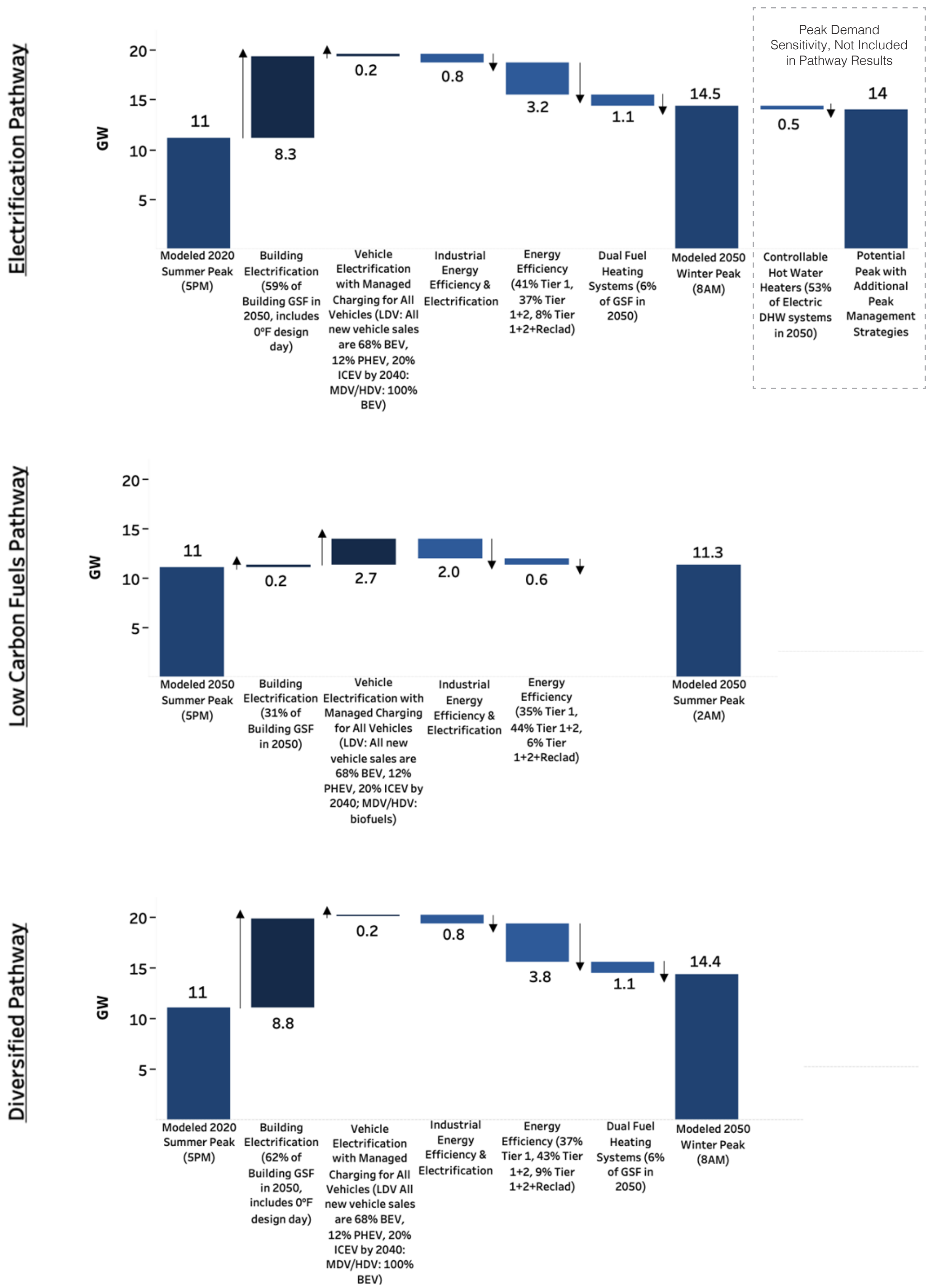
FIGURE ES-7: NYC ELECTRICITY CAPACITY AND GENERATION IN PATHWAYS, SELECT YEARS[f]



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.

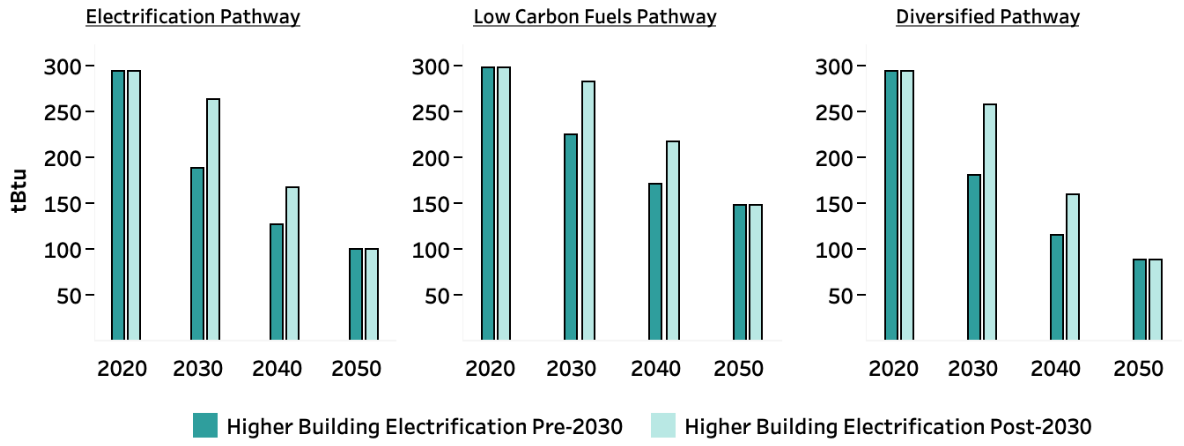
Synthetic RNG and hydrogen have the potential to further decarbonize remaining gas use. Hydrogen and synthetic RNG can be blended into the remaining gas supply to supplement the limited supplies of biogenic RNG available in each Pathway. Today, carbon-neutral hydrogen technologies and markets are nascent; 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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4 Harto, Chris. "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers". *Consumer Reports*. October 2020. Accessed Online: https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf

Acronyms

˚C – Degrees Celsius

˚F – Degrees Fahrenheit

ASHP – Air Source Heat Pump

BEV – Battery Electric Vehicle

BNY – Brooklyn Navy Yard

BNYCP – Brooklyn Navy Yard Cogeneration Plant

Btu – British thermal unit

CAFE – Corporate Average Fuel Economy

CHP – Combined Heat and Power

CLCPA - Climate Leadership and Community Protection Act

CNG – Compressed Natural Gas

CO_2e - Carbon Dioxide Equivalent

DCFC - Direct-Current Fast Chargers

DER - Distributed Energy Resource

DHW – Domestic Hot Water

EE – Energy Efficiency

EFI – Energy Futures Initiative

EIA – Energy Information Administration

EU – European Union

FHV – For-Hire Vehicle

GHG – Greenhouse Gas

GSF – Gross Square Footage

GW – Gigawatt

GWh – Gigawatt-Hour

HDV – Heavy-Duty Vehicle

HVAC – Heating Ventilation & Air Conditioning

IBZ - Industrial Business Zone

ICEV – Internal Combustion Engine Vehicle

kW – Kilowatt

kWh – Kilowatt-Hour

LDV – Light-Duty Vehicle

LL97 – New York City Local Law 97 of 2019

MDV – Medium-Duty Vehicle

MMBTU – Million British thermal units

MOS – New York City Mayor's Office of Sustainability

MSW – Municipal Solid Waste

MTA – Metropolitan Transportation Authority

$MtCO_2e$ – Million Metric Tons of Carbon Dioxide Equivalent

MW – Megawatt

MWh – Megawatt-Hour

NO_x - Nitrogen Oxides

NWS – Non-Wires Solutions

NYC – New York City

NYCHA – New York City Housing Authority

NYCDOT – New York City Department of Transportation

NYCDEP – New York City Department of Environmental Protection

NYMTC – New York Metropolitan Transportation Council

NYSDEC – New York State Department of Environmental Conservation

NYSDOT – New York State Department of Transportation

NYISO – New York Independent System Operator

NYSERDA - New York State Energy Research and Development Authority

PHEV – Plug-in Hybrid Electric Vehicle

$PM_{2.5}$ - Fine Particulate Matter

PSC – New York State Public Service Commission

PV - Photovoltaic

RNG – Renewable Natural Gas

T – Metric Tons

TAC – Technical Advisory Committee

TBTU – Trillion British thermal units

TWG – New York City Buildings Technical Working Group

TWh – Terawatt-hour

V2G – Vehicle-to-Grid

VMT – Vehicle Miles Traveled

ZEV – Zero-Emission Vehicle

Definitions

BUILDINGS TERMINOLOGY

The **buildings sector** includes all buildings in the city, including commercial, residential, industrial, and institutional.

This study uses the 21 Building Typologies and four Building Groupings that were defined by the NYC Technical Working Group:[a]

Building Grouping	Building Typology
1-4 Family	1-4 Family, Freestanding
	1-4 Family, Row House
Multifamily	Multifamily, Post-1980, greater than 7 stories
	Multifamily, Post-1980, up to 7 stories
	Multifamily, Post-war, greater than 7 stories
	Multifamily, Post-war, up to 7 stories
	Multifamily, Pre-war, greater than 7 stories
	Multifamily, Pre-war, up to 7 stories
	Multifamily, Very Large
Commercial	Commercial, Post-1980, greater than 7 stories
	Commercial, Post-1980, up to 7 stories
	Commercial, Post-war, greater than 7 stories
	Commercial, Post-war, up to 7 stories
	Commercial, Pre-war, greater than 7 stories
	Commercial, Pre-war, up to 7 stories
	Commercial, Very Large
Institutional	Institutional, General
	Institutional, Hospitals & Health
	Institutional, K-12
	Institutional, Religious
	Institutional, University

In this study, buildings are often classified based on their size:

- **"Small"** buildings are multifamily and commercial buildings up to 7 stories;
- **"Large"** buildings are multifamily and commercial buildings greater than 7 stories; and
- **"Very large"** buildings are multifamily and commercial buildings greater than 500,000 square feet.

Most buildings across the city are anticipated to implement energy efficiency measures by 2050. This study applied three "tiers" of energy efficiency, which increase in cost and difficulty of installation:

- **Tier 1 energy efficiency measures** include less-extensive measures with shorter payback periods, including low-flow water fixtures, high-efficiency appliances, building controls and management systems, air sealing, and lighting upgrades. For large multifamily and commercial typologies, Tier 1 can also include more expensive upgrades like elevator and control systems replacement;
- **Tier 2 energy efficiency measures** include envelope retrofits, like insulation and window replacements; and
- **Recladding** includes more extensive and costly building envelope upgrades, such as exterior wall insulation of masonry buildings.

These energy efficiency tiers are assumed to be implemented in sequence; for example, every building with Tier 2 energy efficiency upgrades would also have Tier 1 energy efficiency upgrades implemented.

a "One City Built to Last Technical Working Group Report: Transforming New York City Buildings for a Low-Carbon Future," NYC Mayor's Office of Sustainability, Accessed January 15, 2021, https://www1.nyc.gov/assets/dcas/downloads/pdf/energy/reportsandpublication/One_City_Built_To_Last_TWGreport.pdf

Space heating and domestic hot water system upgrades were also applied across building typologies and include the following:

- **Electrification** of buildings refers to the replacement of fossil-fueled building systems with electric alternative. Buildings undergoing electrification had existing space heating and domestic hot water systems replaced with electrified equipment like air source heat pumps or electric boilers;
- Other buildings upgraded existing equipment to **high efficiency, gas-fired equipment**, such as gas boilers; and
- Some buildings underwent a **hydronic conversion**, in which existing steam distribution systems inside a building are converted into hot water distribution systems. This type of conversion included a high-efficiency boiler upgrade.

TRANSPORTATION TERMINOLOGY

The **transportation sector** includes on-road transportation, off-road transportation, maritime transport, and aviation, as defined in the City's greenhouse gas inventory.[b]

This study focuses on on-road transportation, which is comprised of the following vehicle classes included in the standards used by the U.S. Department of Energy:[c]

- **Light-duty vehicles (LDV)** are defined as vehicles under 10,000 lbs, which includes sedans, pick-up trucks, and minivans.
- **Medium-duty vehicles (MDV)** are defined as vehicles between 10,001 lbs and 26,000 lbs, which includes local delivery trucks, walk-in trucks, and school buses.
- **Heavy-duty vehicles (HDV)** are defined as vehicles heavier than 26,001 lbs, which includes garbage trucks, tow trucks, fire trucks, and buses.[d]

Off-road transportation includes rail (including the subway system), marine transport, and aviation.

This study also discusses a variety of traditional and alternative fuel vehicles and related fueling infrastructure as defined below:

- An **internal combustion engine vehicle (ICEV)** is a vehicle that combusts fuel in an engine to power a drivetrain. The fuel used for combustion can be gasoline, diesel, natural gas, or an equivalent low carbon fuel or blend.
- A **battery electric vehicle (BEV)** is a vehicle that uses a fully electric drivetrain and does not have an internal combustion engine. BEVs are charged via a plug connected to the electric grid and do not have tailpipe emissions.
- A **plug-in hybrid electric vehicle (PHEV)** is a vehicle that has an electric motor and a battery that is charged using the electric grid in addition to an internal combustion engine. PHEVs generally use battery power until the battery is depleted, then switch to use gasoline.
- A **compressed natural gas (CNG)** vehicle is an internal combustion engine vehicle that runs on natural gas and that stores natural gas, or RNG if available, in a high-pressure vessel.
- A **zero-emission vehicle (ZEV)** is a vehicle that is eligible for New York State's Zero Emission Vehicle Credit, which includes BEVs, PHEVs, fuel cells,[e] and other vehicle types with very low emissions[f]
- **For-hire vehicles (FHV)** include yellow and green taxis, app-based ride hailing vehicles, and other black car and livery services.
- A **direct current fast charger (DCFC)** is a type of BEV or PHEV charging station that uses high voltage to provide faster vehicle charging. DCFCs typically have a charging capacity of at least 25 kW and up to over 250 kW.
- A **level-2 charger** is a type of BEV or PHEV charging station that typically has a capacity of 3-10 kW and charges faster than Level-1 chargers which has a capacity of 1-3 kW and typically uses a conventional wall outlet. Level-2 chargers are the most common type of public BEV or PHEV charger.

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b "Inventory of New York City Greenhouse Gas Emissions," NYC Mayor's Office of Sustainability, accessed January 12, 2021, https://www1.nyc.gov/site/sustainability/reports-and-data/ghg-inventory.page

c Alternative Fuels Data Center. "Vehicle Weight Classes & Categories". Accessed Online: https://afdc.energy.gov/data/10380

d While buses are considered HDVs in the DOE's vehicle class definitions, they are not included in the HDV emissions in the City's Greenhouse Gas Inventory (city buses are managed by the State) and are modeled separate from HDVs in this study.

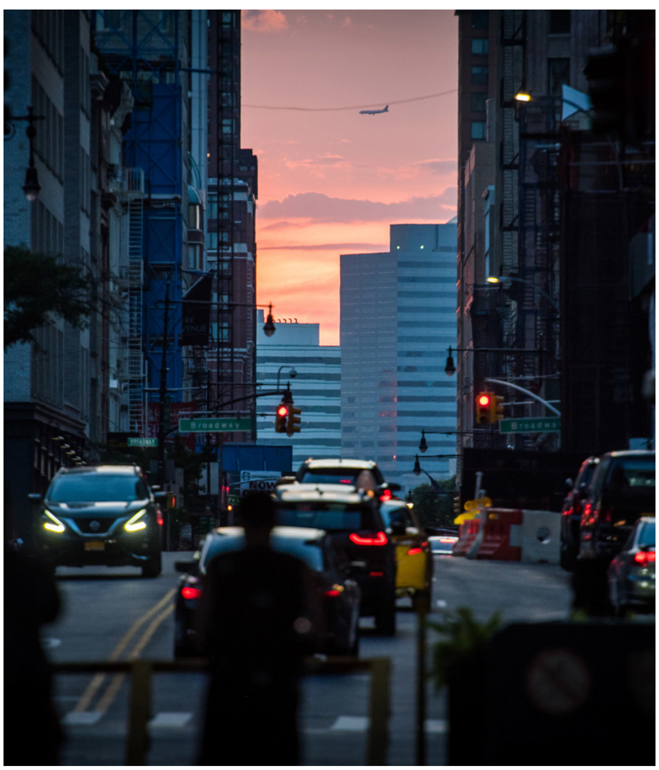
e Fuel cell vehicles are not considered in this analysis due to regulatory limits on their usage in New York State.

f New York Department of Environmental Conservation. "Light-Duty Low and Zero Emission Vehicles". Accessed Online: https://www.dec.ny.gov/chemical/8575.html

DISTRICT ENERGY TERMINOLOGY

The **district energy sector** includes any system that generates steam, hot water, or chilled water at a central location and distributes it across a large or small network of buildings for heating and/or cooling.

- **District steam systems** are used in New York City to deliver steam to buildings that do not have boilers. District steam is generated by a central boiler and delivered through underground steam tunnels. District steam is used to heat and cool spaces, heat water, and provide sanitation services.
- **Con Edison district steam system** is the largest and oldest district steam system in the city. Con Edison operates boilers that generate steam that is distributed throughout lower Manhattan.
- **The Brooklyn Navy Yard district steam system** is the second largest district steam system in the city and generates steam used by industrial and non-industrial customers. Some of the steam generated for this system is sold to Con Edison's steam system.
- **The East River Cogeneration station** generates both power for the electricity sector and steam for the Con Edison district steam system.



GAS & FUELS TERMINOLOGY

- **Fossil natural gas (or fossil gas)** is a hydrocarbon gaseous fuel consisting mostly of methane produced from the decay of organic material over millions of years.
- **Low carbon gas** refers to biogenic renewable natural gas (RNG), "green" hydrogen, and synthetic RNG:
    - **Biogenic RNG** is a pipeline compatible gaseous fuel derived from sustainable biomass feedstocks that has lower lifecycle carbon dioxide equivalent (CO_2e) emissions than fossil natural gas.
    - **Green hydrogen** is hydrogen produced from dedicated or curtailed renewable electricity via electrolysis.
    - **Synthetic RNG** is RNG produced from green hydrogen and CO_2 synthesis.
- **Biomass feedstock** refer to biogas feedstocks like municipal solid waste landfills, digesters at water resource recovery facilities, livestock farms and food production facilities.
- **Low carbon fuels** refers to low carbon gases and liquid fuels like ethanol and biodiesel. Low carbon gas was modeled in the buildings and electricity sectors and liquid fuels were modeled in the transportation sector.
- **Biodiesel** is a fatty acid methyl ester that can be synthesized from vegetable oils, waste oils, fats, and grease, typically used in low-level blends.
- **Renewable diesel** can be produced from the same biomass used to make biodiesel or other sustainable biomass feedstocks but via different production approach that creates fuel that meets the specification requirements of fossil petroleum diesel.
- **Ethanol** is a gasoline additive that is sourced from biomass and makes up approximately 10% of most gasoline supply by volume. Gasoline supply containing up to 15% ethanol requires infrastructure and fueling stations that are robust to corrosion.
- **Thermal gasification** is the breakdown of biomass material into component gases and ash in an enclosed reactor. This process is not modeled in any Pathway.

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Introduction

New York City (NYC) is committed to achieving carbon neutrality by midcentury in a just and equitable way. This requires accelerating the city's adoption of clean sources of energy, maximizing energy efficiency measures in all buildings, and innovating to update today's infrastructure to meet the carbon-neutral needs of the future.

NYC is already a leader in combating climate change in the United States. In September 2014, Mayor Bill de Blasio set a goal of reducing NYC's greenhouse gas (GHG) emissions 80% by 2050.[a,1,2] In April 2019, NYC government ("the City") further increased its ambition by targeting carbon neutrality by 2050.[b,3] As of 2019, NYC achieved a 15% emissions reduction relative to 2005 levels.[4] While existing policies provide a strong basis for climate progress, this study finds that NYC must take additional bold and immediate actions to adopt strategies that modernize the way New Yorkers use energy, reimagine the role of existing energy infrastructure, and reach toward carbon neutrality.

The City's climate commitments are in line with keeping global temperature increases below 1.5 degrees Celsius (°C) by the end of the century, a target necessary to avert the worst consequences of a warming world. Climate change is already impacting NYC, its infrastructure, and its residents. The *New York City Panel on Climate Change 2019 Report* noted that temperatures in NYC have increased nearly four degrees Fahrenheit (°F) since the early 1900s. Relative to 2020, NYC could experience an additional temperature increase of 2°F to more than 4°F by the 2050s.[5] The frequency of heat waves could increase up to four-fold in some parts of the city, putting vulnerable New Yorkers at risk of heat stress.[6] Furthermore, wetter weather, higher storm surges, and rising sea levels are a serious threat for a city with 520 miles of waterfront.[7] If the status quo continues, NYC is likely to experience 0.9-1.75 feet of sea level rise in the first half of this century.[8]

Accelerating NYC's clean energy agenda to ensure it meets its emissions reduction goals can improve the lives of New Yorkers. Reducing fossil fuel combustion from buildings, vehicles, and electricity generation within the city can lead to cleaner air and better health, especially for those currently bearing the heaviest environmental burdens. 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 integrates zero-emission vehicles (ZEV) with ridesharing, improved public transportation, and better last-mile transit options can reduce travel times, promote healthier living, and save New Yorkers money.[9,c]

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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 ($MtCO_2e$).

b Carbon neutrality refers to reducing emissions as much as possible and offsetting any unavoidable emissions with high-quality carbon offsets to bring net emissions to zero. Carbon offset projects should meet specific environmental integrity principles: unambiguously owned and independently auditable projects should result in real, additional, permanent, transparent, and measurable emissions reductions.

c The Partnership for New York City found that excess traffic congestion costs the regional economy of the New York City 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.

Unlocking a 100% zero-emission electric grid can spur new investment in wind, solar, and batteries and reduce dependence on in-city fossil-fueled power plants, improving local air quality. Transforming the gas network to one that delivers low carbon fuels to help decarbonize remaining gas use allows businesses and homes to reduce their GHG emissions without the need for major retrofits and supports reliable power generation. By creating a clean energy economy, NYC can also attract new businesses and industries.

To explore the opportunities and challenges associated with alternative clean energy futures that reach at least 80% direct GHG emissions reduction while putting the city on a path to carbon neutrality, this analysis models a Policy Reference Case and three distinct low-carbon Pathways.

*The **Policy Reference Case** projects costs and emissions reductions from existing City, State, and Federal policies as of June 2019. The Policy Reference Case acts as a baseline against which the Pathways can be compared to show the additional effort needed to achieve the City's deep decarbonization goals.*

*The **Electrification Pathway** explores increasing the reliance of buildings, transportation, and steam production on electricity and electrically-generated low carbon gas.*

*The **Low Carbon Fuels Pathway** assumes a greater supply of biogenic renewable natural gas (RNG) and hydrogen and less electrification of buildings and medium- and heavy-duty vehicles, which in turn rely on biofuels.*

*The **Diversified Pathway** achieves the electrification rates of the Electrification Pathway along with the higher biogenic RNG supply of the Low Carbon Fuels Pathway prioritized for buildings.*

This study represents a historic collaboration between the NYC Mayor's Office of Sustainability (MOS) and the city's two major energy utilities—Con Edison and National Grid. Modeling and analytic support for the report was provided by ICF, the Energy Futures Initiative (EFI) and Drexel University. The purpose of this study is to create a body of work that can provide insight into key decarbonization options, risks, and tradeoffs as NYC transitions toward carbon neutrality. 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 (Box 1).

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 climate science demands. Unlocking the city's full potential for transformative change requires the contributions of policymakers, innovators, utilities, financiers, building owners, unions, and the millions of people who live and work in NYC.

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 climate science demands.

Box 1: NYC's Utilities—Con Edison and National Grid—are Pivotal to the Clean Energy Transition

National Grid, the utility that provides natural gas service to Staten Island, Brooklyn, and the southern part of Queens,[d] has developed its own 80x50 study that explores clean energy, electrification, and energy efficiency measures to reduce emissions across New England and New York State.[10] In November 2019, National Grid committed to reducing its operational emissions to net-zero by 2050.[11] In October 2020, it increased its 2050 net-zero commitment to include its Scope 3[e,12] GHG emissions from the electricity and gas it sells to customers.[13] The company also works with governments and regulators in all markets it serves to support local emissions targets, such as New York City's carbon neutrality goal evaluated in this study.

Con Edison provides electricity service to all five boroughs and natural gas service throughout Manhattan, the Bronx, and the northern part of Queens, as well as steam in Manhattan south of 96th Street.[14,15] Con Edison has recently conducted two studies that inform how the grid will operate in the future. The first, *Electrification Scenarios for New York's Energy Future*, estimates how electricity demand and supply are likely to respond under various policy, economic, and technology scenarios.[16] The second, *Climate Change Vulnerability Study*, was undertaken to inform future measures Con Edison will take to adapt the distribution grid, steam system, and its gas network to the impacts of climate change.[17] These studies and other work undertaken at Con Edison informed the development of its *Clean Energy Commitment*, which identifies commitments Con Edison will take to work toward a clean energy future, specifically: (1) Tripling energy efficiency by 2030; (2) Pursuing programs to work toward 100% zero-emission electricity by 2040; (3) Providing all-in support for electric vehicles; and (4) Accelerating reduction of fossil fuels for heating.[18]

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d Most of the Queens service territory is served by National Grid's NYC operating company, KEDNY. The Rockaway Peninsula in Queens is instead served by National Grid's Long Island operating company, KEDLI.

e Scope 3 emissions refer to GHG emissions from sources not owned or directly controlled by a company but are related to a company's activities. Scope 3 emissions are often referred to as "value chain" emissions and include emissions outside the Scope 1 (direct emissions) and Scope 2 (emissions attributable to the generation of electricity, heat or steam purchased by the company) boundaries.

POLICY CONTEXT

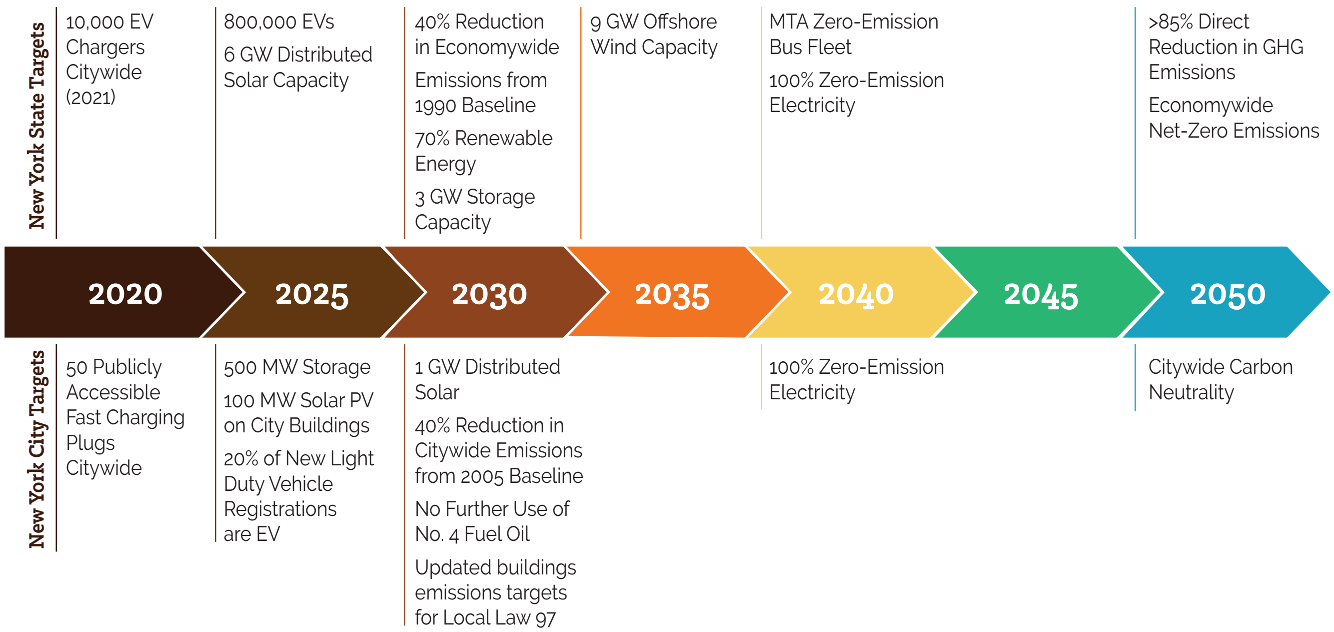
Ensuring all New Yorkers have access to clean, reliable energy services and resilient infrastructure in the face of a changing climate is a critical social equity issue and a high priority for the City. One way NYC is ensuring an equitable transition is through the April 2019 *Green New Deal*, which includes $14 billion in investments and groundbreaking legislation to address the climate crisis and add good paying energy efficiency retrofit jobs.[19] Important elements of this climate agenda, outlined in *OneNYC 2050: Building a Strong and Fair City*, include: expanding building energy efficiency and reducing emissions from buildings; confronting income inequality; procuring zero-emission electricity for City operations; cleaning up the vehicle fleet; and implementing congestion pricing.[20] The *Green New Deal* also made NYC one of the first global cities of its size to commit to carbon neutrality by 2050.

The *Climate Mobilization Act of 2019*, the City's landmark legislative package that accompanied the Green New Deal announcement, contained several laws focused on reducing building sector emissions. These laws require green roofs and/or solar photovoltaics (PV) on new buildings, enhance energy efficiency scoring criteria, and create clean energy financing programs. Perhaps most notably, Local Law 97 of 2019 (LL97) is a first-in-kind law that requires buildings larger than 25,000 square feet to meet gradually declining emissions limits from 2024-2050.

Climate leadership is occurring at the state level as well (Figure 1). New York became the third state in the country to commit to economywide carbon neutrality in June 2019 with the passage of the Climate Leadership and Community Protection Act (CLCPA). Among other targets, the CLCPA requires New York State to achieve an 85% reduction in emissions economywide with the goal of reducing all anthropogenic emissions to net-zero by 2050.[f] The law sets a target of 100% zero-emission electricity by 2040 with an interim goal of 70% electricity from renewable sources by 2030, along with specific renewable energy, electric battery, and energy efficiency resource targets.[21]

These State and City climate goals provide a solid policy foundation for greatly reducing GHG emissions and are highly complementary: State clean energy goals, for example, can help buildings and vehicles in NYC decarbonize over time. Many of these policies are explicitly modeled in this study as discussed in the following chapter.

FIGURE 1: NEW YORK CITY AND STATE CLIMATE TARGETS



New York City and New York State have made ambitious climate goals for 2050, accompanied by sector- and technology-specific interim targets.

f The CLCPA indicates that the remaining 15% of emissions can be reduced through local offsets.

Analysis Approach

This study was conducted from mid-2019 to Spring 2021. It was a highly collaborative and iterative process performed as part of the City's "Town+Gown" university-community partnership program that brings academics and practitioners together to create actionable analysis.

This study relied on the buildings expertise of Drexel University's College of Engineering, overall modeling and supporting expertise from ICF, and additional analytic support and facilitation of report development from the Energy Futures Initiative (EFI). The NYC Mayor's Office of Sustainability (MOS), National Grid, and Con Edison worked together to align on the modeling approach; review interim and final modeling results; shape the key findings; and contribute to finalizing the report.

This study was advised by a Technical Advisory Committee (TAC) comprised of subject-matter experts in buildings, transportation, energy modeling, finance, and policy, as well as local stakeholders and advocacy groups (Box 2). The TAC convened four times to provide input on interim study design, modeling assumptions, and components of the report. TAC members served as expert resources throughout the study.

Box 2: The Technical Advisory Committee

The following individuals, representing their respective organizations, contributed subject-matter expertise over the course of this study. This advisory committee was chaired by Joe Hezir, Executive Vice President of the Energy Futures Initiative (EFI). Committee participation does not imply endorsement of the analysis approach or conclusions.

Sally Benson, Stanford School of Earth, Energy, and Environmental Sciences

Jacob Brouwer, University of California, Irvine

Chris Cayten, CodeGreen Solutions

Donna DeCostanzo, Natural Resources Defense Council

Anthony J. Fiore, New York City Department of Citywide Administrative Services

Robert Freudenberg, Regional Plan Association

Jane Gajwani, New York City Department of Environmental Protection

Hillel Hammer, New York State Energy Research & Development Authority

Kevin Harrison, National Renewable Energy Laboratory

Hal Harvey, Energy Innovation

Annel Hernandez, New York City Environmental Justice Alliance

John Mandyck, Urban Green Council

Ron Minsk, Columbia Center on Global Energy Policy

Justin Pascone, New York Building Congress

Zachary Schechter-Steinberg, The Real Estate Board of New York

Bruce Schlein, Citi

Zach G. Smith, New York Independent System Operator

Elizabeth Stein, Environmental Defense Fund

Robert Thornton, International District Energy Association

Julie Tighe, New York League of Conservation Voters

James Wilcox, New York State Energy Research & Development Authority

Jim Williams, University of San Francisco

Marc Zuluaga, Steven Winters Associates

ANALYSIS FRAMEWORK

Building on prior work completed by the City,[a] 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 at minimum achieve 80% direct emissions reductions were designed to compare potential futures with distinct technology deployment strategies. These Pathways build on a Policy Reference Case that 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.

A sector-specific, quantitative modeling approach was designed to reflect unique aspects of the city that present distinctive challenges for achieving significant direct emissions reductions while putting the city on the path to carbon neutrality. All Pathways reach at least 80% emissions reductions by 2050, while remaining emissions were assumed to be addressable by improved abatement technologies and high-quality offsets by 2050. 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 about robust, long-term emissions reduction strategies.

This study builds on previous work by:

- estimating costs across multiple illustrative Pathways;
- conducting detailed buildings and on-road transportation modeling through updated literature review, expert input from the TAC and manufacturers, and new modeling efforts;
- assessing the opportunities, barriers, and limitations of adopting electrification technologies for different building typologies, including cost estimates, through extensive desktop research and consultations with the TAC and manufacturers;
- modeling electricity sector impacts of future buildings and transportation investments and new clean energy resource targets on an hourly basis;
- exploring renewable natural gas (RNG) and hydrogen as clean fuel options; and
- analyzing the opportunities, tradeoffs, and risks of certain aspects of the Pathways, as well as highlighting common measures across all Pathways.

This analysis used the New York City Greenhouse Gas Inventory to calibrate the modeling, though there are several differences in how emissions were calculated and allocated. In this study:

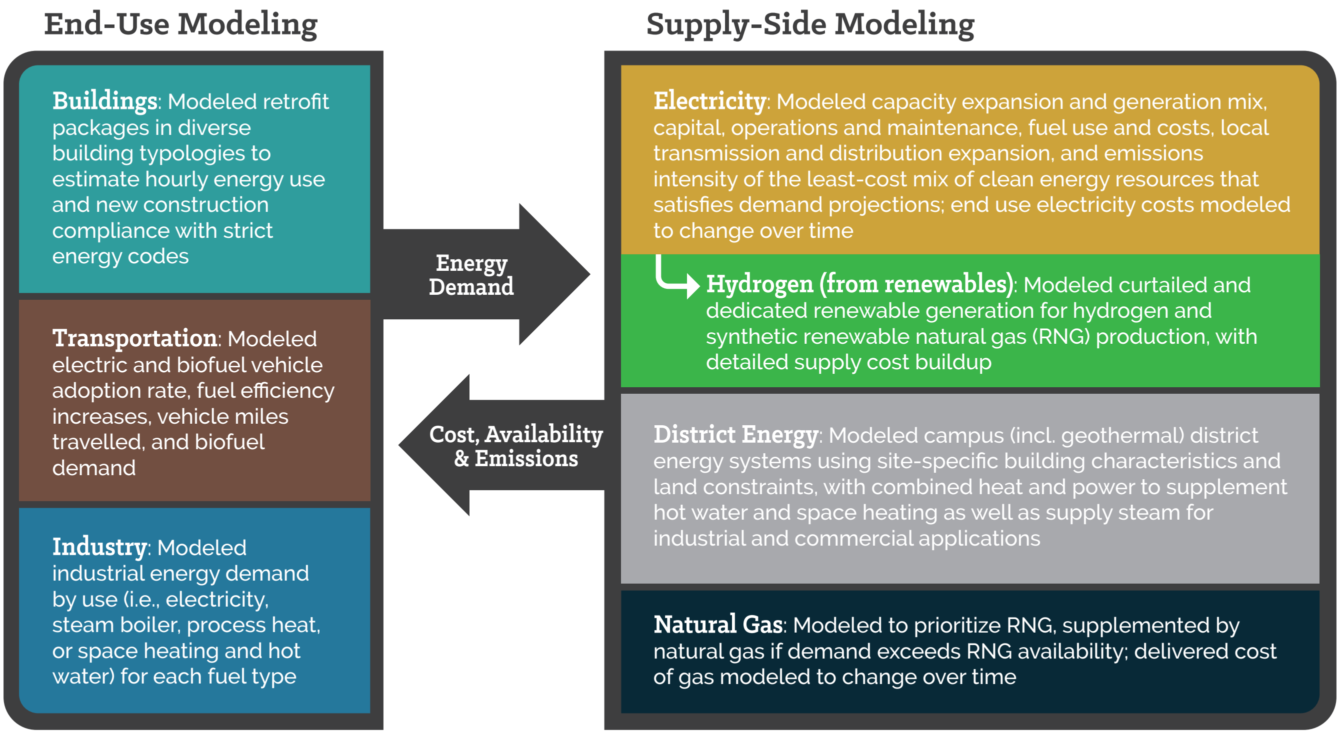
- high global warming potential refrigerant emissions were included in the building sector totals;
- upstream fugitive emissions from transporting fossil gas and RNG were included and allocated to gas end uses rather than enumerated separately; and
- RNG emissions were calculated on a lifecycle basis.[b]

A multi-sectoral integrative modeling platform was used for this study (Figure 2). The platform modeled energy demand by end use for three sectors: buildings, industry, and transportation. Energy demand was used in electricity, district energy, and natural gas sector models to identify cost, energy use, and emissions associated with in-city end uses.

a Analysis for the buildings sector built on the extensive groundwork laid by the Buildings Technical Working Group (TWG) modeling of measures to reduce energy use and emissions from buildings, the city's largest source of GHG emissions. First convened by NYC MOS in 2015, the TWG was comprised of over 50 industry, labor union, academic, and community experts and stakeholders that advised the City on how it can meet its goal of reducing GHG emissions from the buildings sector 80% by 2050. The TWG was responsible for developing and recommending data analysis, metrics and indicators, and potential policy tools to the Mayor's Office in order to implement the City's 80x50 goal. In 2016, the TWG ultimately delivered the *One City Built to Last Technical Working Group Report: Transforming New York City Buildings for a Low Carbon Future*, which was intended to guide City policymaking on building sector decarbonization. Different components of the TWG models were used in this study to develop updated emissions reduction Pathways for the buildings sector.

b To calculate the carbon intensity of blended gas, this analysis used a weighted average of lifecycle emissions for each type of gas used to meet demand.

FIGURE 2: MODELING APPROACH



This analysis used a multi-sectoral modeling approach to estimate energy demand, supply, costs, and emissions through 2050 in four different scenarios: a Policy Reference Case and three Pathways that achieve at least 80% emissions reductions (from a 2005 baseline) by 2050. See discussion on study limitations below.

SECTOR-SPECIFIC ANALYSIS APPROACH

For the **buildings sector**, energy use models simulated hourly energy demand over the course of a year for typical NYC buildings: multifamily, 1-4 family, commercial, and institutional buildings.[c] The modeling included the impact and cost of different packages of energy efficiency measures. To assess energy efficiency impacts, the building simulations conducted for the City's 2016 *Buildings Technical Working Group* (TWG) study were used as a starting point.[22] Measures were combined into new, updated energy efficiency bundles, resulting in retrofit packages used in the buildings sector modeling (Box 3).

To determine how much building stock could potentially be electrified, this study relied on a data-driven, qualitative feasibility assessment and input from subject matter experts that focused on two common typologies, one multifamily and one commercial.[d] This approach helped address the diversity of building stock across NYC. The conclusions and trends from that assessment were then extrapolated to the remaining building stock. This analysis considered policy drivers, market preferences, prudent staging, and stock turnover of existing equipment in modeling building-based measures.[e]

c The building classifications (called "groupings" and "typologies") used in this report are explained in the definitions on page xxi.

d The electrification technical feasibility deep dives were done on the Multifamily, Pre-war, greater than 7 stories typology and the Commercial, Pre-war, greater than 7 stories typology.

e Given the diversity and range of building stock across NYC, it was neither within the scope of this study to conduct a series of detailed engineering analyses, nor was it effective to develop a generalized quantitative approach across typologies to assess feasibility.

Box 3: Retrofit Measures

Two major categories of building retrofits were modeled in this study. The first category was retrofits to existing heating, ventilation, and air conditioning (HVAC) and domestic hot water (DHW) systems through electrification or low carbon fuels. Buildings received only one type of heating and cooling system retrofit.

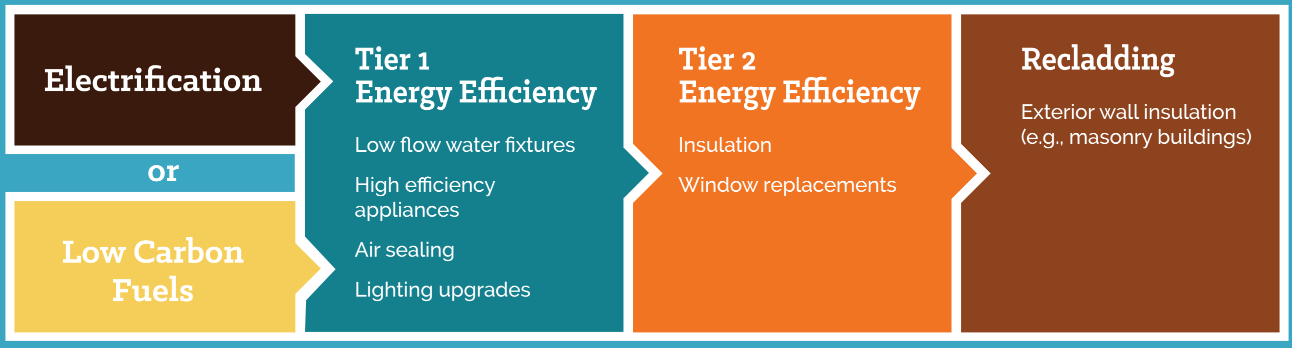
- **Electrification** of these systems involves the replacement of existing equipment with electric equipment. The electrification technologies modeled include air source heat pumps (ASHP) for space heating and heat pump water heaters for DHW. In some typologies, electric instantaneous water heaters or electric boilers were used instead. References to electrification "measures" or "upgrades" signify the electrification of heating and hot water systems.
- Existing heating and DHW equipment could also be replaced with high efficiency gas equipment, like boilers and condensing tankless water heaters, and cooling equipment with currently available high efficiency gas-fired units. These upgrades were modeled as **Low Carbon Fuels** measures.

The second category was retrofits to building interiors and/or exteriors to improve building energy efficiency. Energy efficiency measures are building upgrades that improve building energy performance and reduce energy load and related emissions. This study modeled implementation of three energy efficiency packages, or "tiers," built off of efficiency tiers developed for the 2016 City-sponsored study, *One City Built to Last: Transforming New York City Buildings for a Low-Carbon Future.*[23] The three different tiers generally increased in level of required work and expense. Each tier was adopted in sequence, i.e., all buildings that adopted Tier 2 energy efficiency measures were assumed to have adopted Tier 1 energy efficiency measures. The tiers used in this study are:

- **Tier 1 Energy Efficiency** mostly included less-extensive measures with shorter payback periods. For residential buildings this included low-flow water fixtures, high-efficiency appliances, air sealing, building controls, and lighting upgrades. For larger multifamily and commercial typologies, Tier 1 energy efficiency included more expensive items like elevator and building management and control systems replacement.
- **Tier 2 Energy Efficiency** mostly included envelope retrofits such as insulation and window replacements and was generally more costly than Tier 1 energy efficiency, except for very large buildings.
- **Recladding**, the final energy efficiency tier, included more extensive and costly building envelope upgrades, such as exterior wall insulation of masonry buildings.

These energy efficiency tiers are assumed to be implemented in sequence; for example, every building with Tier 2 energy efficiency upgrades would also have Tier 1 energy efficiency upgrades implemented.

FIGURE 3: BUILDING RETROFIT CATEGORIES



Industrial sector emissions were estimated using utility and federal sales and end-use data,[f] with energy efficiency and electrification of end uses modifying today's levels.

For the **transportation sector**, on-road vehicle [light-duty (LDV), medium-duty (MDV), heavy-duty (HDV), and buses] emissions were modeled, while rail emissions (including subways and commuter rail) were assumed to fall 80% through 2050. The on-road model relied on a stock turnover approach, paired with vehicle miles traveled (VMT) to estimate fuel consumption, cost, and emissions. VMT reduction assumptions from previous modeling conducted as part of the City's 2016 *Roadmap to 80x50* report,[24] which assessed the VMT reductions from different strategies to increase public transit, biking, and walking trips, were used in this study.

This study assessed the role of **district energy systems** and their contribution to shaping energy demand. The analysis evaluated different options to decarbonize the Con Edison steam system,[g] from partial electrification to relying on low carbon fuels, in addition to varying the number and type of buildings that remain on the steam system over time.[h] This study also evaluated how existing campus systems could be expanded or new campus district systems could be built using geothermal heating systems powered by clean electricity and combined heat and power (CHP) fueled by low carbon fuels.

This study then considered what mix of low carbon gas and clean electricity would be needed to meet modeled energy demand and achieve the City's decarbonization goals. Modeling was performed of **low carbon gas** availability focused on biogenic RNG, hydrogen, and synthetic RNG to estimate the availability of biogenic RNG to meet the city's energy requirements. This analysis did not specify the particular facilities from which the RNG was sourced; rather regional feedstocks were considered as a pool of potentially deliverable resources and allocated to the city proportional to its regional share of fossil gas demand. All Pathways leverage excess, or curtailed, renewable electricity for synthetic RNG and hydrogen production. If low carbon gas demand exceeded supply for a Pathway, it was assumed that the residual gas demand was met through continued use of fossil gas, when allowed by existing policies.[i]

Finally, the sectoral models resulted in cumulative hourly electric loads, which were used as inputs to the **electricity sector** models. Both a capacity expansion model and a production cost model[j] were used to identify required generation, grid operational impacts, a subset of the electricity sector capital costs, and resulting grid emissions. The electricity sector models were used to examine deployment of different resource mixes, including the existing resource targets for wind, solar, and storage, and the clean energy requirements as mandated in relevant State and City policies.

Table 1 includes key modeling assumptions applied in the Policy Reference Case and Pathways, most of which are discussed in more detail in the body of the report.

f Federal data sources include the U.S. Energy Information Administration (EIA) Manufacturing Energy Consumption Survey and the National Renewable Energy Laboratory (NREL) Industry Energy Tool.

g The Con Edison steam system generates steam from five central plants and distributes it through underground tunnels and pipes to more than 1,600 buildings in Manhattan.

h Hourly steam demand from buildings was estimated using building energy modeling similar to what was used for electricity and gas demand. The modeled results were adjusted to align with actual steam system use data.

i Low carbon fuels and gas terminology is defined in the definitions on page xxiii.

j Capacity expansion models determine the least-cost deployment of generating assets or energy storage needed to meet demand and comply with model constraints (such as renewable energy targets); production cost models determine the electricity generation mix and the deployment of battery storage as well as the use of transmission infrastructure.

TABLE 1: KEY MODELING ASSUMPTIONS

	Policy Reference Case	Pathways
Buildings and Industry		
Gas-fired boiler efficiency	90% for residential equipment 90-95% for commercial equipment	
Maximum rate of building heating, cooling, and DHW* equipment replacement citywide	6% of gross square foot per year	
Average heat pump heating coefficient of performance	ASHP*: 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)	
Electrification of heating, cooling, and DHW equipment	Not included	Included
LL97* compliance	Not included	Included
New construction EUI* code stringency	Baseline code in place through 2020; 20% EUI reduction code from 2021-22; 40% EUI reduction code in place 2023-2024; 70% EUI reduction code in place 2025-2050	
Transportation		
Fuel efficiency improvements	LDV*: 36 mpg (gasoline) by 2025 MDV*/HDV*/Bus: 9 mpg (diesel) by 2027	LDV: Additional 20% for 2026-2050 MDV/HDV: Additional 15% for 2028-2050
LDV* fleet changes	15% of new LDV sales are ZEV by 2025	80% of new LDV sales are ZEV by 2040
Bus fleet changes	MTA* 100% electric buses by 2040	
Biofuel use	No additional biofuel blends	Higher biofuel blends considered
Light-duty VMT*	+7% VMT by 2050	-17% VMT by 2050
District Energy		
New district geothermal systems	Not Included	Included
Electric steam boilers	Not Included	Included
Con Edison steam system customer base changes	Some small customers leave steam system	Some small and/or large customers leave steam system
Electricity		
New York State Clean Energy Standard**	70% of electricity supply met by renewable sources by 2030	100% of electricity sales met by zero-emission energy by 2040
New York State clean energy mandates	Battery storage: 1,500 MW by 2025; 3,000 by 2030 Offshore wind: 9,000 MW by 2035 Distributed solar: 6,000 MW by 2025	
NYSDEC* Peaker Rule	Affected peaking units retired, replacement capacity based on NYSIO* 2019-2028 Comprehensive Reliability Plan	
Natural Gas		
Hydrogen blend limit	Hydrogen Not Included	15% of pipeline throughput or 5% of energy content
RNG supply sources	RNG Not Included	Anaerobic digestion of animal manure, food waste, water resource recovery facilities, and landfill gas

*__Acronyms__: *ASHP: Air Source Heat Pump; DHW: Domestic Hot Water; EUI: Energy Use Intensity HDV: Heavy-Duty Vehicle; LDV: Light-Duty Vehicle; LL97: Local Law 97 of 2019; MDV: Medium-Duty Vehicle; MTA: Metropolitan Transportation Authority; MW: Megawatt; NYISO: New York Independent System Operator; NYSDEC: New York State Department of Environmental Conservation; VMT: Vehicle Miles Traveled; ZEV: Zero-Emission Vehicle*

***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.*

Note: *This table includes key modeling assumptions applied in the Policy Reference Case and Pathways, most of which are discussed in more detail in the body of the report. Table 3 in Chapter 5 describes the key distinguishing measures between the Pathways.*

ANALYSIS LIMITATIONS

This study was designed to understand the major variables that could affect the City's climate policies and strategies. To achieve this, this study used an approach that relied on necessary simplifications to translate complex and highly dynamic changes into a modeling framework. Any study that attempts to project energy and economic trends three decades into the future is inherently uncertain. For example, predicting the timing and scale of technology deployment and innovation is extremely challenging. Meanwhile, the New York region's energy system is highly complex and dynamic, driven by market forces, regulations, weather and climate, and many other factors.

This study used 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:

- this study did not account for COVID-19 or post-COVID-19 pandemic impacts in the modeling;
- capital, labor, and technology were assumed to be available at the pace and scale needed to achieve deep decarbonization across all sectors;
- except for the transportation and electricity sectors, modeling assumptions were based upon currently available technology performance and incorporate limited assumptions regarding changes in cost and performance over time. For example, heat pump performance was assumed to remain constant over the period of analysis;
- to estimate costs of the Pathways, NYC-specific cost data was used whenever available. When it was not, national values were used and scaled;
- customer behavior was not considered;
- this study did not estimate land costs associated with siting new resources;
- this study did not include a detailed electric, gas and steam rates analysis;
- changes to electricity wholesale market design were not assumed;
- electricity system reliability was not explicitly modeled to account for events such as cold snaps and heat waves, and specific local grid design issues were not assessed;
- electric distribution system expansion costs were estimated based upon historic costs for incremental increases in electric load; depending on the magnitude of expansion projected, such costs may be very different;
- the natural gas delivery system was assumed to be able to accommodate the projected changes in supply modeled in this study;
- NYC Executive Order 52 of 2020 through which the City committed to not support infrastructure that expands the supply of fossil fuels and the 2021 commitment in Mayor de Blasio's State of the City address to move forward with banning new fossil fuel connections in some new construction by 2030 were not included in this analysis as they were established after the modeling began;
- geothermal systems were estimated based on high-level screenings and do not reflect in-depth technical feasibility of sites;

- LL97 was factored in with emissions limits for NYC but was not analyzed for explicit building-level compliance (Box 4);
- for the few industrial sources of emissions in the city, this study looked at emissions from both process loads and end uses and assumed that these facilities could adopt the same electrification and energy efficiency measures as commercial buildings;
- specific strategies to decarbonize landmarked buildings in NYC, which account for ~11% of the city's built floor space, were not assessed, rather they were treated in the same manner as other buildings in the city;
- the transportation sector analysis relied on the VMT assumptions developed for the City's 2016 *Roadmap to 80x50* report;
- this analysis did not model the full societal costs of car ownership nor the cost of building or maintaining public transportation infrastructure such as subways, bus lanes, or bike lanes and may therefore overstate the cost savings associated with reduced VMT;
- the impacts of cold temperatures on battery electric vehicle (BEV) battery performance and range were not assessed;
- the modeling did not include sources of off-road transportation (e.g., aviation and maritime) emissions, which constitute 5% of citywide GHG emissions;
- this study relied on national average emissions factors for vehicle fuels and charging profiles from other large U.S. cities; and
- this study did not model waste sector emissions, which constitute 4% of the City's total; it was assumed that there would be an 80% reduction in emissions from waste by 2050.

Box 4: Modeling Local Law 97 of 2019

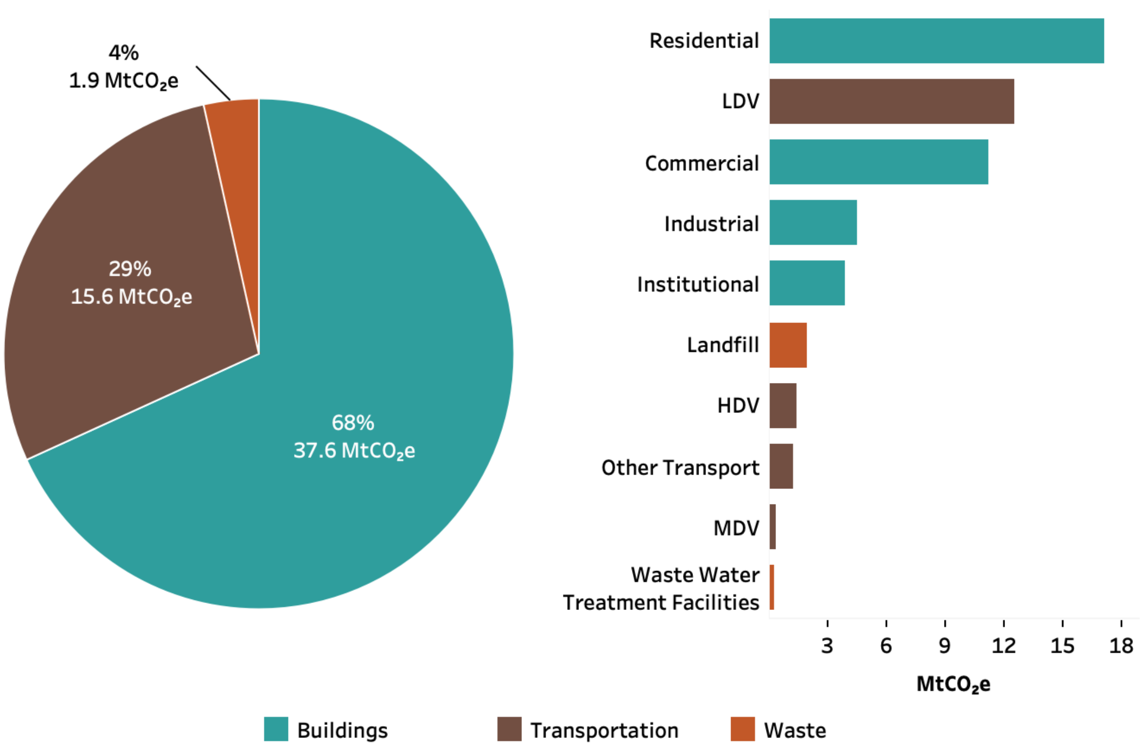
LL97 made history as the first law to set explicit GHG emissions targets for most of NYC's largest buildings. To account for LL97 in the modeling, NYC tax lot data was analyzed to identify buildings subject to LL97 in each typology. For typologies with a large proportion of buildings subject to LL97 (> 50%), the total emissions intensity of all buildings in that typology was compared to the calculated emissions limit per LL97. The energy efficiency and electrification adoption for those typologies was then adjusted to ensure that the total emissions were within 5% of the LL97 emissions limit. The 5% tolerance was assumed to account for alternative compliance options. Therefore, the approach was to assess overall compliance with LL97 at the typology level, not at the individual building level, within tolerance.

NYC's Energy System Today

NYC's energy system provides critical services to millions of people every hour of the day and every day of the year. A system of this size, scope, and complexity presents unique opportunities and challenges for decarbonization. This section provides an overview of NYC's energy system today—the starting point on the city's path to carbon neutrality.

The largest share of NYC's emissions (68%) comes from buildings,[a] which include residential, commercial, industrial, and institutional buildings[b] (Figure 4). Transportation is the next largest source of emissions (29%), the majority of which are from light-duty vehicles (LDV).[c] Waste contributes the smallest share of emissions (4%).

FIGURE 4: NYC EMISSIONS PROFILE, 2019[25]



The buildings sector contributes the vast majority of GHGs in NYC, followed by transportation and then waste.

a Emissions from the buildings sector include both emissions attributable to fuel combusted on-site (e.g., for water heating, space heating, and cooking) as well as emissions attributable to the generation of electricity and steam offsite that is consumed in buildings.

b Building "groupings" and "typologies" are defined on page xxi. Residential buildings include 1-4 family homes and multifamily buildings; Institutional buildings include universities, hospitals, and other large non-commercial and non-multifamily buildings.

c Vehicle classes are defined on page xxii. LDVs are vehicles under 10,000 pounds, such as sedans, pick-up trucks, and minivans.

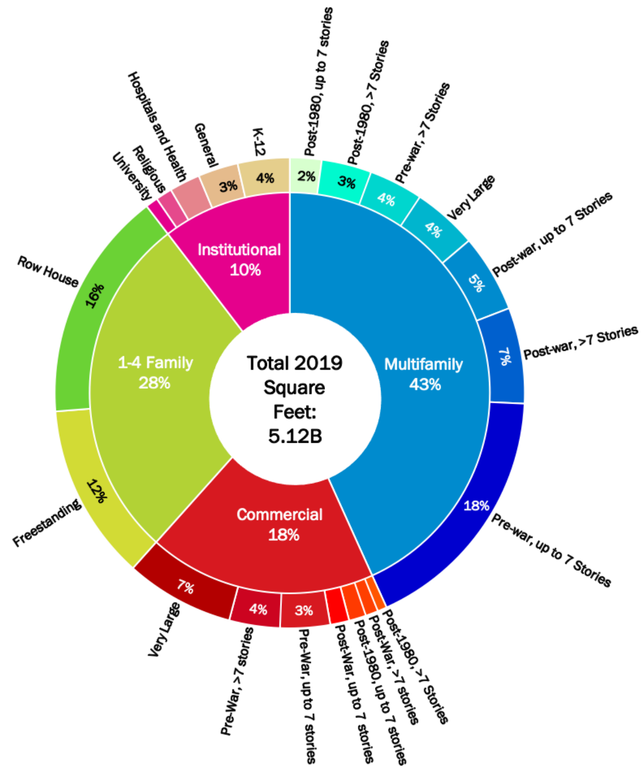
BUILDINGS AND INDUSTRY

NYC's buildings are the commercial engines of the city's economy and the homes of millions of New Yorkers. The buildings and industrial sectors cover large swaths of the city and require significant amounts of electricity and fuel. The nature of the built environment allows for multi-pronged strategies to support decarbonization, even as the specific measures may be different across residential and commercial buildings, and for industrial facilities. One of the greatest challenges to decarbonizing the city's built environment is its sheer size.

Buildings Sector Description

Decarbonizing NYC's buildings is one of the most important elements of reaching carbon neutrality by midcentury. NYC is one of the oldest, largest, and most dense cities in the United States, and its building square footage is expected to grow 8.6% from 2010 levels by 2050.[26] More than two-thirds of the city's GHG emissions are associated with the buildings sector (both emissions from electricity generation and fuels used in buildings). The five boroughs together have over one million buildings[27] and five billion square feet of building space, ranging from single family homes to the tallest building in the Americas (Figure 5). The building types with the most challenging retrofit circumstances include larger multifamily buildings—where many units may have to be vacated during the retrofit and the landlord-tenant costs split blunts financial incentives to improve energy efficiency—and smaller commercial buildings constructed before 1945 with existing steam heating systems and limited space in mechanical rooms.[d]

FIGURE 5: NYC BUILDING STOCK, 2019

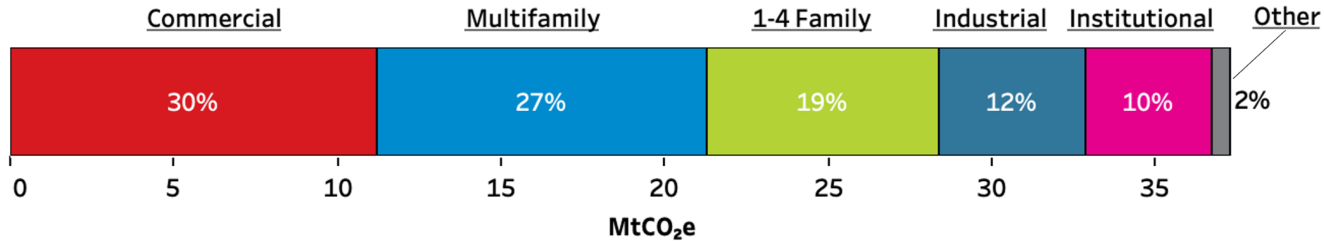


NYC's one million buildings have a range of uses, ages, sizes, and classifications, presenting unique opportunities and challenges for decarbonization.

Among existing buildings, unique building classifications have specific regulations impacting their ability to be retrofitted with energy efficiency or other low carbon measures. For example, the NYC Landmarks Preservation Commission currently requires permits for any work that could affect the facades or interiors of more than 37,000 landmarked properties, which represent 11% of NYC's building stock.[28,29] Separately, 40% of multifamily residential buildings over 50,000 square feet have at least one rent-regulated unit; these buildings face unique regulatory and financial barriers.[30] Landmarked buildings and some rent-regulated buildings are often subject to modified energy regulations.

d "Small" buildings are those up to seven stories, while "large" buildings are those greater than seven stories. "Very large" buildings are those that are greater than 500,000 square feet.

FIGURE 6: NYC BUILDINGS AND INDUSTRIAL SECTOR EMISSIONS BY TYPE, 2019



The largest share of building sector emissions is from commercial buildings (30%), followed closely by multifamily buildings (27%), and 1-4 family rowhouses and standalone homes (19%). The remaining share is from industrial, institutional, and other emitters. **Note:** *"Other" includes fugitive emissions (e.g., unintentional leaks), traffic lights, and streetlights.*

Regardless of age, all buildings require consistent and reliable energy supply. Utilities and other energy providers deliver natural gas, electricity, fuel oil, and steam to buildings across the city. These energy sources enable ventilation, lighting, space heating and cooling, and hot water end uses in commercial and residential buildings. Industrial-zoned buildings also need significant energy input to power heavy-duty equipment and processes, and institutional buildings, like hospitals, are equipped with back-up generation to prepare for lapses of electricity supply.

Legacy building systems reflect the age of the city's built environment and are also very energy intensive. For example, as of 2019, 1.8 billion square feet of multifamily, 700 million square feet of commercial, and 90 million square feet of industrial building area were heated with steam—including both steam generated on-site and from district steam systems. This equates to 80% of multifamily buildings and 75% of commercial buildings (by square feet) that use steam heat, making steam boilers the most common heating system in the city.[31] These boilers in individual buildings, powered by natural gas or fuel oil, transform water into steam that rises to radiators without the need for pumps; however, these systems are also subject to overheating, often have limited controls, require a high temperature for combustion, and can be costly to replace.

Buildings Sector Emissions

Buildings contribute nearly 70% of the city's total emissions, due in part to their large square footage and high energy intensity (Figure 6). Consequently, the sector is a focus of recent energy and climate legislation. Local Law 84 of 2009, as amended by Local Law 133 of 2016, requires that all buildings 25,000 square feet or larger measure and report their energy and water consumption to the City each year;[32] Local Law 33 of 2018 requires energy efficiency scores and grades to be publicly disclosed;[33] and Local Law 97 of 2019 (LL97) requires emissions reductions from the same set of buildings, which comprise nearly 60% of the city's total building square footage, beginning in 2024.[34] These requirements grow more stringent over time to align the buildings sector with the City's overarching emissions reduction goals.[35]

Industrial Sector Description

NYC's numerous industries employed 530,000 people in 2015 for food processing; garment, chemical, materials and furniture manufacturing; e-commerce; construction; and auto repair.[36] The industrial workforce in NYC is largely non-white (62%) and foreign-born (50%), and constitutes 15% of the private sector workforce.[37] Unlike many other areas in the country, NYC has seen industrial and manufacturing employment increase over the past decade, and it anticipates future growth.[38] For example, in 2018, there were nearly 100,000 specialty trade contractors (electricians, pipe fitters, construction workers, etc.) in the city.[39] Specialty trades have experienced above-average growth in NYC since 2010 that is projected to continue through 2026.[40]

The City has designated 21 Industrial Business Zones (IBZs) to protect and promote the growth of industry by providing tax breaks and business support to industries in those zones.[41] There are IBZs in all boroughs except Manhattan, as such, 62% of the employees in the industrial sector worked in the outer boroughs in 2015.[42] According to the City's Buildings Technical Working Group (TWG), buildings used for industrial purposes comprise about 6% of NYC's building footprint. Factories and warehouses make up 65% of industrial space; transportation, garages, and utilities make up the remainder.[43] The industrial real estate market continues to perform well even in the face of the COVID-19 pandemic due to an increase in online purchasing and the continued need for associated warehouse space.[44]

Industrial Sector Emissions

Industrial emissions accounted for 9% of total emissions in 2019. The majority of emissions from the industrial sector (57%) are from electricity consumption and over a third derive from natural gas consumption in industrial buildings. The remainder are related to fuel oil used for process heat as well as steam.[45] Fossil fuels are often used in industrial equipment with high process heat requirements.

TRANSPORTATION

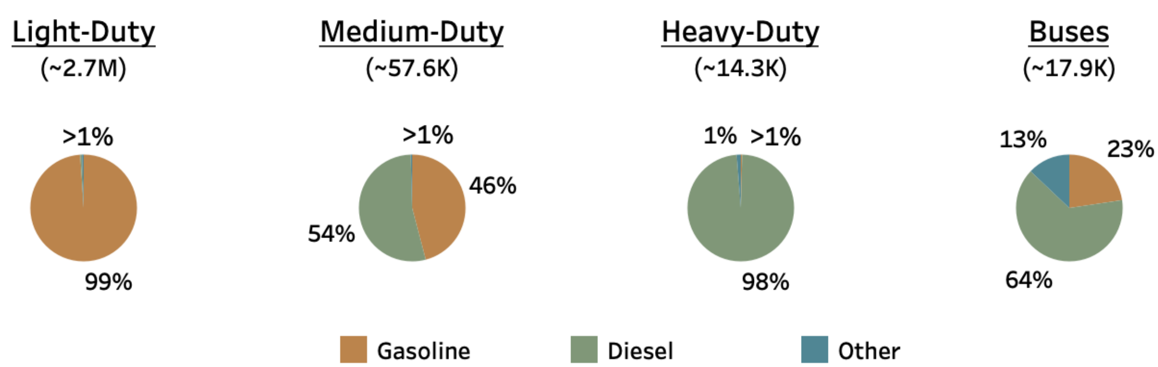
NYC's transportation sector is unique compared to that of most other cities. While New Yorkers rely heavily on the public transit system there were still 2.7 million LDVs registered in NYC in 2019. At the same time, there are thousands of trips each day by cabs, rideshare, and other for-hire vehicles (FHV) that are not actually registered in the city. Decarbonizing the transportation sector requires replacing on-road internal combustion engine vehicles (ICEV) with clean alternatives. Widespread adoption of zero-emission vehicles (ZEV) necessitates significant investments in charging infrastructure as well as charging management.

Transportation Sector Description

New Yorkers walk and rely on public transit more than any other major city in the United States.[46] Over 40% of trips New Yorkers make are on foot, 16% are by subway,[47] and 8% are by bus. The Metropolitan Transportation Authority (MTA) moved an average of 2.2 million New Yorkers by bus per week in 2019, the highest number of bus riders in the country—more than the next three largest bus systems combined.[48] About 30% of trips made are by car in personal vehicles, on rideshare, or licensed taxi FHV.

Nearly all LDVs run on gasoline, while medium-duty vehicles (MDV) and heavy-duty vehicles (HDV) rely heavily on diesel (Figure 7). Buses in the city comprise a small proportion of the total vehicle stock but have the greatest share of electric and natural gas drivetrains. The City has been electrifying its vehicle fleet by managing the largest charging network in New York State with over 1,000 charging ports that serve over 2,200 City-owned ZEVs.[49]

FIGURE 7: NYC VEHICLE STOCK COMPOSITION, 2019



Nearly the entire vehicle stock in NYC is comprised of internal combustion engine vehicles (ICEVs), though 13% of buses have alternative fuel drivetrains. **Note**: *"other" includes compressed natural gas (CNG) vehicles, plug-in hybrid electric vehicles (PHEV), and battery electric vehicles (BEV).*

Half of NYC households own at least one vehicle; however, a citywide survey in 2019 found that about 15% of households reduced the number of vehicles owned in the previous year due to parking and car ownership costs as well as the ease of switching to public transportation.[50] Outside of Manhattan, there is greater reliance on personal vehicles. Eighty-four percent of trips on Staten Island, 48% of trips in the outer neighborhoods of Queens, and 42% in the northern neighborhoods of the Bronx are made in a car.[51]

Vehicle trips in NYC tend to be short. Two-thirds are under five miles, and about a quarter of trips are under a mile.[52] Commute times can be long as travel speeds declined about 30% between 2010 and 2018 due in part to the rapid increase of ride-hailing vehicles. The number of FHVs tripled since 2010, growing from 40,000 to over 120,000 in 2019.[53] Across the city, on-road congestion resulted in more than 113 million "lost hours" of productivity, resulting in a citywide cost of $20 billion per year.[54]

NYC has one of the most complex truck route systems in the country, comprised of nearly 1,000 miles of designated routes.[55] MDVs and HDVs deliver goods to businesses and direct to New Yorkers. As of 2019, about a third of New Yorkers received a delivery and/or had someone come to their home to do work (i.e., maintenance) each day.[56] The City initiated a process of reducing local truck fleet emissions through the Clean Trucks Program, which funded the upgrade or scrappage of over 600 trucks. The trucks were replaced with compressed natural gas (CNG), hybrid electric-diesel, or more efficient diesel trucks.[57] In addition, the City launched a pilot program called the Cargo Bikes Program in late 2019 to promote more bicycles to deliver goods through UPS, Amazon, and DHL.[58] The Cargo Bikes Program helps lower emissions while reducing congestion in lower Manhattan.

Transportation Sector Emissions

The Transportation sector contributed 29% of citywide emissions in 2019, of which 95% were from on-road transportation.[59,e] LDVs make up the vast majority (80%) of transportation sector emissions, followed by HDVs (9%). Emissions from drivers passing through—but not residing in—the city are not counted in aggregate emissions.

ELECTRICITY

The electricity sector powers NYC and is the backbone of the city's economy. It can also be the cornerstone of decarbonization as electrification of end uses can displace outdated, inefficient, carbon-intensive end uses. Because electricity flows into NYC from New York State and neighboring states, statewide and regional coordination is critical.

Electricity Sector Description

The electricity system includes electricity generation, transmission, and distribution infrastructure. In 2019, the city's peak electricity demand was 10,000 megawatts (MW), about a third of New York State's entire peak demand. NYC's annual electricity consumption was 52,000 gigawatt hours (GWh), about double what is currently produced within the city.[f,60] On average, New Yorkers consume about half as much electricity per capita per year as the rest of the country—6,000 kilowatt-hours (kWh) per person compared to 12,000 kWh per person nationally.[61] Even among urban areas where the average electricity consumption is 10,000 kWh per person per year,[62] New Yorkers consume less electricity.

Electricity is delivered to customers via Con Edison's distribution network, which includes nearly 130,000 miles of overhead and underground electricity lines in the city—enough to circle the Earth five times.[63] Con Edison generates very little of the city's electricity itself; its only generation is from the company's steam-electric generating facilities.[64]

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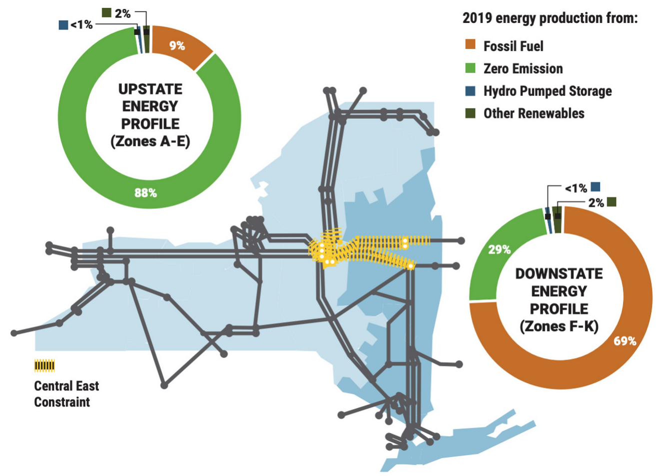
e On-road transportation includes LDVs, MDVs, HDVs, and buses. Off-road transportation emissions sources include rail (including the subway system), marine transport, and aviation and were not evaluated in this analysis.

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.

Electricity generation profiles of upstate and downstate New York are quite distinct. Eighty-eight percent of upstate electricity generation derives from zero-emission sources, while 69% of downstate electricity production derives from fossil fuel sources. In 2019, renewable electricity constituted less than 1% of downstate installed capacity.[65] The New York State regional transmission system consists of more than 11,000 miles of high voltage power lines, enough to reach to Sydney, Australia.[66] Despite this vast infrastructure, congestion on these lines currently hinders transmission of zero-emission electricity generated upstate to the downstate area (Figure 8).

FIGURE 8: NEW YORK STATE TRANSMISSION SYSTEM AND UPSTATE AND DOWNSTATE ENERGY PROFILES[67]



Upstate electricity generation is nearly 90% from zero-emission sources. Transmission and geographic constraints prevent those low-emitting sources from reaching downstate, including NYC, requiring nearly 70% of downstate electricity to be provided by fossil-fueled sources. Source: *Power Trends 2020, published by the New York Independent System Operator.*

The combination of transmission congestion and high electricity demand creates "load pockets," which are areas that rely heavily on local generation due to limited ability to import power. NYC itself is a load pocket within the state, and there are several areas within the city that are themselves load pockets. Electricity demand in these regions is often met by fossil fuel-fired "peaker" generation plants, or plants close to or within the city that only operate during periods of high demand. Peaker plants are now subject to 2019 New York State requirements to not exceed daily nitrogen oxides (NO_x) emission limits by 2023 and 2025, to improve poor air quality around the peaker plants and reduce GHGs.[68]

Electricity Sector Emissions

Most electricity consumed in NYC is generated by fossil fuel power plants, nuclear facilities, and hydroelectric facilities in the region. The retirement of the Indian Point Energy Center in 2021, a nuclear power plant located about 30 miles north of NYC, will increase the fossil share of the downstate grid's energy mix.[69] Forty-three percent of the city's electricity demand was met by in-city generation in 2019, which was nearly entirely from combined cycle power plants and oil- and gas-fired peakers and steam generators.[70]

NATURAL GAS

Natural gas is used across several sectors. Most natural gas is consumed by multifamily buildings (41%), followed by commercial (24%) and 1-4 family buildings (16%). Industrial and institutional end uses make up the remaining consumption (19%). Natural gas is used across sectors—it directly fuels building end uses, such as cooking stoves, appliances, and space and water heating systems; it is burned to generate electricity; and it supplies energy to the city's district energy network.

Natural Gas Sector Description

Millions of customers throughout NYC use natural gas (Box 5). In 2019, Con Edison and National Grid's NYC operating company, the Brooklyn Union Gas Company, were among the country's top 20 companies in terms of natural gas sales volumes; combined, they would place seventh, having moved over 214 billion cubic feet of gas, or slightly less gas than what Connecticut consumes in a year.[71]

Natural gas travels to NYC via transmission pipelines and is delivered to customers through the distribution pipeline network. Con Edison and National Grid respectively manage 4,300 and 4,128 miles of large distribution gas pipelines, as well as service lines connecting those larger lines to homes and businesses.

Box 5: Natural Gas Delivered in NYC Today

In 2020, the gas network in NYC on its peak day delivered 2.23 trillion British thermal units (tBtu) of energy, 1.14 tBtu by National Grid and 1.09 tBtu by Con Edison.[72] For reference, electricity supplied to NYC on the day of the electric peak was 219,000 MWh (0.75 tBtu per day).[73] The gas network in NYC currently delivers approximately three times the amount of energy on its peak day in winter than the electric network delivers on its peak day in summer.

Natural gas demand has increased significantly over time. There are more new customers as new building space is constructed and as approximately 12,400 existing buildings convert to natural gas each year and the City phases out heavier fuel oils. Con Edison has reported 40% growth in peak demand since 2011 for customers receiving continuous gas service,[74] and National Grid has reported a 27% increase since 2010.[75] Constraints on the natural gas system may introduce risks to meeting increased peak demand. This has led utilities to implement temporary moratoria on new gas services and customer conversions in recent years; however, through implementing both supply and demand side measures, the moratoria have since been eliminated.

Natural Gas Sector Emissions

In 2019, natural gas combustion was the single largest source of emissions in the city, responsible for nearly 19 million metric tons of carbon dioxide equivalent ($MtCO_2e$), or 34% of NYC's total emissions.[76,g] Most natural gas combustion is in the buildings sector, with about 10 $MtCO_2e$ from natural gas use in the residential sector, 7 $MtCO_2e$ from use in commercial and institutional gas use, and 2 $MtCO_2e$ from manufacturing and construction gas use. Natural gas combustion in these buildings and industrial end uses emits more GHGs than all fuel combustion in the transportation sector.

DISTRICT ENERGY

District energy systems provide heating and cooling to nearly 2,000 commercial and residential buildings in NYC through a network of water and steam distribution pipes. Steam, hot water, or chilled water is produced at centralized facilities and transported via an underground network to customers. Decarbonizing the steam production process can transform the existing systems into valuable clean energy carriers for many critical needs, including space and water heating, sanitation, and humidity.

District Energy Systems Description

There are 18 district energy systems in NYC, 15 of which also produce electricity using combined heat and power (CHP) plants.[77] These systems are installed at colleges and universities, hospitals, housing cooperatives, commercial clusters, and large business districts in four of the five boroughs.

The largest district energy system by volume in the city—and the country—is the Con Edison steam system. As one of the first district energy systems in the world, it began operations in 1882 and now serves approximately 1,600 buildings in Manhattan, including some of the city's most iconic skyscrapers and museums.[78] The Con Edison system generates steam using predominately natural gas at six facilities and then distributes steam across Manhattan through more than 100 miles of pipe (Figure 9).

The Con Edison steam system has a maximum capacity of 11.4 million pounds of steam per hour, and in 2020, the steam system on its peak day delivered 132,000 million pounds (0.159 tBtu) of steam. On average 60% of the annual steam sendout is produced through cogeneration from two plants: East River Station in Manhattan and the Brooklyn Navy Yard Cogeneration Plant (BNYCP) in downtown Brooklyn. In addition to supplying the Con Edison steam system, BNYCP also provides additional steam for use within its own industrial campus at the Brooklyn Navy Yard. Most pipes deliver steam at roughly 160 pounds per square inch and 370°F. The steam is used for heating, hot water, and cooling.[h,79]

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g This does not include upstream GHG emissions attributable to natural gas.

h Large buildings can cool air with steam using devices called chillers. Chillers remove heat from water, and this "chilled" water is used to cool and dehumidify air. Steam is used to power parts of the chilling process.

FIGURE 9: CON EDISON DISTRICT STEAM SYSTEM[80]

This figure shows the Con Edison steam system service territory. The blue stars indicate the locations of central steam generation plants that are owned and operated by Con Edison. The gray star indicates the cogeneration plant in Brooklyn that is not owned and operated by Con Edison but delivers steam to their steam system in Manhattan according to a contract between both parties.

District Energy Emissions

In 2019, the steam system emitted 920 thousand tons of carbon dioxide (CO_2), or 1.7% of NYC's total emissions.[81] District steam is a relatively efficient way to produce heat. Steam accounted for 2.5% of emissions from buildings in 2019, while providing 3.4% of the energy used by buildings. This can be compared to fuel oil, which is less efficient and provided 7.1% of energy used by buildings but produced 8.5% of building sector emissions.

WASTE

NYC generates 14 million tons of waste per year, spending over $1 billion annually to manage and using 2,000 City-owned and 4,000 private trucks.[82]

Waste Sector Description

Landfills, wastewater treatment, and biological treatment are sources of waste-related emissions in NYC. Landfills hold municipal solid waste (MSW), including food waste, and produce methane—a potent GHG. The transportation, processing, and storage of waste also contribute GHG emissions. Over one million tons of food waste are sent to landfills each year.[83] Organic MSW can also be processed via composting and anaerobic digestion, processes referred to as biological treatment.

More than one billion gallons of wastewater flow through over 6,000 miles of sewer pipe each day to 14 wastewater treatment plants managed by the NYC Department of Environmental Protection (NYCDEP).[84] Wastewater and biological treatment emit methane and nitrous oxide. National Grid has partnered with the NYCDEP on a renewable natural gas (RNG) pilot at Newtown Creek Wastewater Treatment Plant in Brooklyn to collect methane from wastewater treatment, and sludge from food waste from nearby schools.[85] This innovative pilot project is discussed further in Box 14.

Waste Sector Emissions

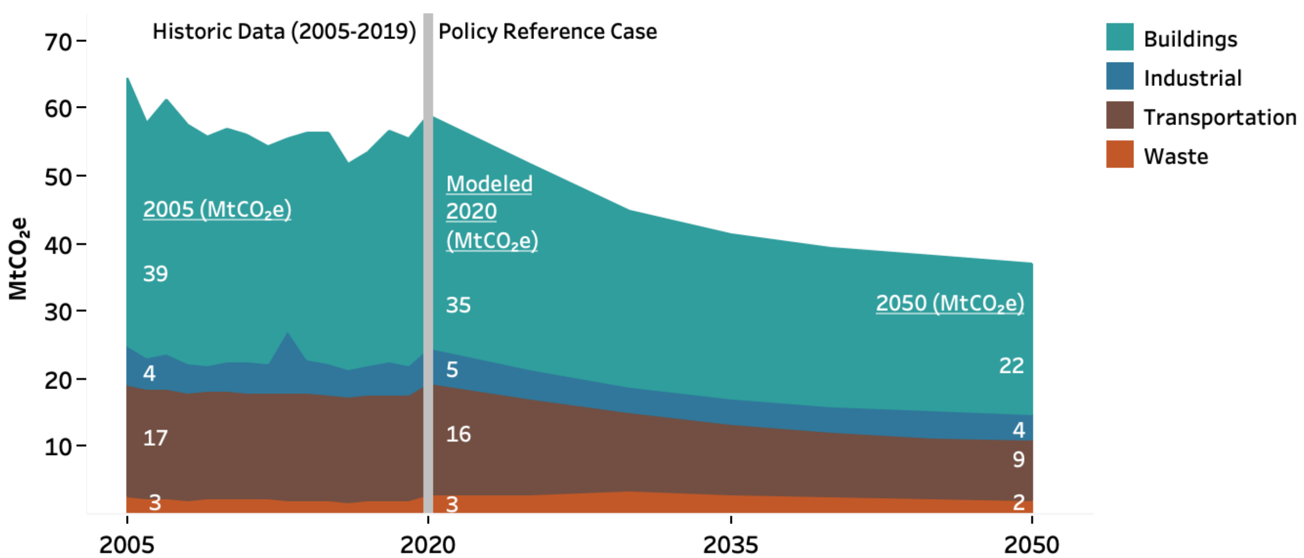
In 2019, the waste sector accounted for approximately 4% of the city's total emissions, or 2 $MtCO_2e$. Over 88% of the emissions from waste came from landfills, 11% from wastewater treatment, and the remaining from biological treatment.[86] Between 2008 and 2019, methane emissions from wastewater facilities decreased 58% and nitrous oxide emissions decreased 13% over that same period. Landfill methane emissions have decreased by 2%. Emissions from biological treatment have nearly quadrupled due to increased composting activity; even with this growth, they are still equivalent to less than 1% of landfill emissions.[87]

Policy Reference Case

The Policy Reference Case establishes a baseline projection of energy supply, demand, emissions, and cost through 2050 based on existing policies that, as of June 2019, had clearly defined requirements at the federal, state, and local levels (Table 2). Economywide and sectoral emissions limits from the NYC Climate Mobilization Act, the midcentury carbon neutrality target in New York State's Climate Leadership and Community Protection Act (CLPCA), and the CLPCA's 100% zero-emission electricity by 2040 target were not included in the Policy Reference Case. These emissions targets are modeled in the three emissions reduction Pathways to better understand compliance options.

NYC's annual greenhouse gas (GHG) emissions fell 14% between 2005 and 2019, from 64 million metric tons of carbon dioxide equivalent ($MtCO_2e$) to 55 $MtCO_2e$.[88] Existing policies support further emissions reductions by midcentury: in the modeled Policy Reference Case, emissions fall 37% from 2020 to 2050, which equates to a 44% reduction by 2050 from the actual 2005 emissions baseline (Figure 10).[a] Policies supporting emissions reductions include the New York State Clean Energy Standard, improved building efficiency standards, and mandates for deploying zero-emission vehicles (ZEV).

FIGURE 10: HISTORIC AND PROJECTED GHG EMISSIONS IN THE POLICY REFERENCE CASE, 2005–2050



Total emissions decrease 37% from nearly 59 $MtCO_2e$ in 2020 to 37 $MtCO_2e$ in 2050 in the Policy Reference Case. There are reductions across all sectors from 2020 to 2050, with transportation sector emissions decreasing 47%, building sector emissions decreasing 36%, industrial emissions decreasing 27%, and waste emissions decreasing 28%. In total, these emissions reductions represent a 43% decline from 2005. The precise trajectory between 2020 and 2050 will depend in part on building space heating and domestic hot water (DHW) adoption rates, the pace at which the electric grid decarbonizes, and other factors.

a This analysis only modeled 2020-2050; however, comparisons of 2050 modeled emissions levels to the actual 2005 emissions levels are given throughout this report to align with the baseline year of the City's GHG emissions reduction target.

TABLE 2: POLICY MODELING FRAMEWORK

Policies Included in the Policy Reference Case	**Federal Policies and Programs** • Conventional and hazardous pollutant rules, including the Cross-State Air Pollution Rule (CSAPR) and the Mercury and Air Toxics Standards (MATS) • Transportation fuel economy standards [Corporate Average Fuel Economy (CAFE)] • Federal Production Tax Credit (PTC) and Investment Tax Credit (ITC) phase out as outlined in 2015 omnibus **Regional Policies and Programs** • Regional Greenhouse Gas Initiative (RGGI) requirements as of June 2019, with New Jersey joining in 2020 with an initial 18 $MtCO_2e$ cap and Virginia joining in 2021 with an initial 28 $MtCO_2e$ cap • Renewable and clean energy standards for states outside of New York State including technology-specific tiers for offshore wind, energy storage, solar, and nuclear energy **New York State Policies and Programs** • Zero Emissions Credit (ZEC) to nuclear through 2029 • Retirement of remaining coal-fired generation by 2020 • Public Service Commission (PSC) New Efficiency: New York targets by 2025, including heat pump targets by utilities • New York State Clean Energy Standard: 70% of retail electricity sales by renewables by 2030 • Battery storage mandate of 1,500 MW by 2025 and 3,000 MW by 2030 • Offshore wind mandate of 9,000 MW by 2035 • Distributed solar mandate of 6,000 MW by 2025 • 10,000 ZEV charging stations by the end of 2021 and 800,000 zero-emission LDVs operating in the state by 2025. • Transmission projects selected by the New York Independent System Operator (NYISO) as part of the Public Policy Transmission Projects process (T027 and T019) • Metropolitan Transportation Authority (MTA) deployment of 500 electric buses; MTA goal of 100% electric buses by 2040 **New York City Policies and Programs** • Local Law 88 of 2009 lighting and submetering requirements by 2025, with Local Law 32 of 2018 energy stretch code for new construction • Incremental impacts of Retrofit/Building Energy Efficiency Program (BEEP) expansion • No. 4 Fuel Oil phase out by 2030 • Biodiesel blend requirements[89] • Local Law 92 of 2019 and Local Law 94 of 2019 requirement of solar deployment on all new building construction • 1,000 MW of distributed solar by 2030 • 500 MW of energy storage by 2025 • 60 dual-port ZEV chargers from Con Edison's curbside ZEV charging pilot program • 20% of new LDV registrations ZEV by 2025
Policies Included in Pathways	All policies included in the Policy Reference Case, plus: **New York State Policies** • 100% of electricity from zero-emission sources by 2040 **New York City Policies** • 80%+ economywide emissions reductions by 2050 • Local Law 97 of 2019 buildings emission limits[b]

b This analysis evaluated compliance with LL97 emission limits based on building typology averages and adjusted energy efficiency and electrification adoption to ensure compliance targets were met (see Box 4). Other compliance options not modeled in this analysis include GHG emissions offsets, renewable energy credits, distributed energy resources, and fines.

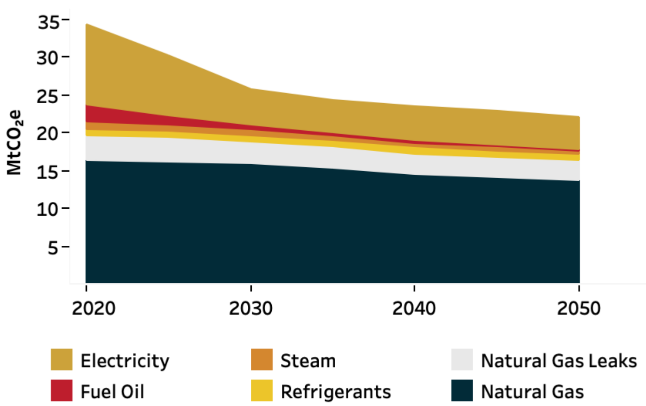
BUILDINGS AND INDUSTRY

The buildings sector experiences the largest overall drop in emissions in the Policy Reference Case compared to other sectors. This is mostly due to the reduced emissions intensity of the electric grid. Energy efficiency measures across the building sector and switching from heavy fuel oil in industrial buildings also reduces emissions and energy use through 2050 in the Policy Reference Case.

Buildings and Industrial Sector Emissions Reductions

In the Policy Reference Case, emissions from the buildings sector decrease 36% by 2050 from 2020 levels (Figure 11). This equates to a 44% reduction from 2005 levels. Reductions in the buildings sector are primarily driven by assumptions regarding clean grid policies—especially the State's requirement of 70% electricity supply met by renewables by 2030—and New York State's energy efficiency mandates for utilities. Emissions reductions are further enhanced by building codes at the city level.

FIGURE 11: BUILDINGS EMISSIONS BY ENERGY USE TYPE IN THE POLICY REFERENCE CASE, 2020-2050



Clean energy and energy efficiency policies lead to a 60% reduction in emissions from buildings sector electricity use between 2020 and 2050. Fuel oil emissions are nearly eliminated in the sector. Fossil natural gas emissions decline approximately 16% during that period. The precise trajectory between 2020 and 2050 will depend in part on space heating and DHW adoption rates.

The Policy Reference Case does not include any measures specific to the industrial sector. Decreasing the emissions intensity of the electricity grid is projected to reduce industrial sector emissions by roughly 25%.

Buildings and Industrial Sector Energy Use

Nearly every building in the city (96% on a square foot basis) is expected to receive Tier 1 energy efficiency[c] improvements before midcentury in the Policy Reference Case. This aligns with the 2020 New York Independent System Operator's (NYISO) *Gold Book* baseline case efficiency forecast that reflects substantial achievement of *New Efficiency: New York* emissions reduction strategies and other energy policies and standards in effect as of April 2020.[90,d]

To address new construction, the analysis assumed that overall energy use of new buildings follows the City's current proposed energy codes strategy through 2020, and then code stringency increases to reduce new construction energy use intensity 20% between 2021 and 2022, 40% between 2023 and 2024, and 70% after 2025.

In large part due to these energy efficiency assumptions for new and existing buildings, total buildings energy use decreases 30% from 2020 levels, falling across every energy source (Figure 12). Energy efficiency measures are responsible for a 23% reduction in electricity use and a 25% reduction in gas use between 2020 and 2050 in the Policy Reference Case, saving 108 thousand British thermal units (tBtu) per year by 2050.

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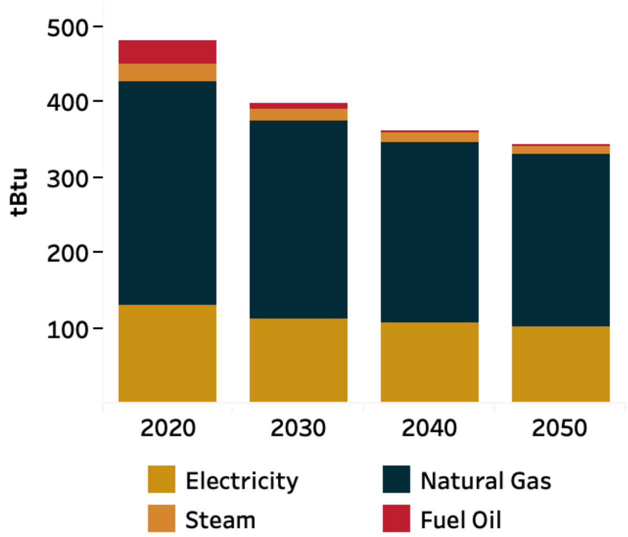
c Energy efficiency tiers and other buildings and industrial sector decarbonization measures are detailed in Box 3 in Chapter 2 and on page xxi-xxii.

d Modeled energy efficiency and equipment retrofit packages were implemented until the NYISO *Gold Book* energy savings reductions were achieved. Between 2016 and 2050, this required a total electricity reduction of 10 Terawatt-hours (TWh), a gas reduction of 77 thousand British thermal units (tBtu), a No. 2 fuel oil reduction of 27 tBtu, and a steam reduction of 14 tBtu. Most buildings implemented high efficiency gas-fired heating and hot water systems and Tier 1 energy efficiency measures, while buildings on district steam implemented Tier 1 and Tier 2 energy efficiency measures. No heating or hot water systems were electrified.

FIGURE 12: BUILDINGS ENERGY USE IN THE POLICY REFERENCE CASE, SELECT YEARS



On-site energy use in buildings is projected to fall through 2050 in the Policy Reference Case, with considerable cuts in fuel oil and natural gas. From 2020 to 2050, fuel oil energy use falls 97%, from 31 tBtu to 1 tBtu. This drop in energy use is equivalent to a reduction of over five million barrels of oil used annually by 2050. Natural gas use dips after 2020, falling 70 tBtu by 2050.

Any growth in industrial sector energy demand is assumed to be offset by energy efficiency improvements in industrial buildings and processes. Therefore, there is no net change in industrial sector energy consumption between 2020 and 2050 in the Policy Reference Case.

TRANSPORTATION

There are significant transportation sector emissions reductions in the Policy Reference Case due to modest adoption of ZEVs and improved vehicle efficiency.

Transportation Sector Emissions Reductions

Emissions from the transportation sector fall 47% from 2020 to 2050 in the Policy Reference Case, driven by fuel efficiency improvements and the uptake of ZEVs. Fuel economy improvements are assumed to continue through 2025 for light-duty vehicles (LDV) and 2027 for medium- and heavy-duty vehicles (MDV and HDV) and halt thereafter, consistent with the final year of the federal Corporate Average Fuel Economy (CAFE) standard requirements. Emissions related to LDVs fall over 40% while emissions related to HDVs fall just 3%.

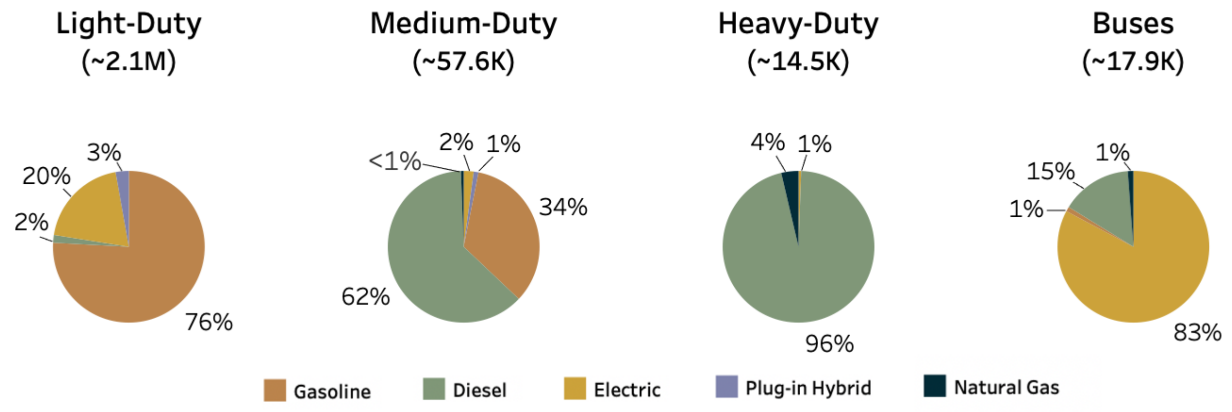
Transportation Sector Energy Use

The Policy Reference Case assumes that there will be 850,000 ZEVs statewide by 2025 and that 15% of new LDV sales in NYC will be electric by 2025. ZEVs include battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), which still have tailpipe emissions but can operate fully electric for short distances.[91] By 2050, 22% of LDVs are ZEVs, 88% of which are BEVs and the remainder of which are PHEVs (Figure 13). Gasoline use in 2050 falls 42% relative to 2020 in the Policy Reference Case, while electricity consumption for the transportation sector increases 84%. The decline in gasoline use is slightly offset by increased vehicle miles. In the Policy Reference Case, the total vehicle fleet grows, and as a result, vehicle miles traveled (VMT) increase 12% across all vehicle classes through 2050.

The proportion of diesel vehicles remains relatively unchanged through 2050.[e] Only 3% and 1% of MDVs and HDVs are electrified by 2050, respectively. Diesel consumption is relatively unchanged, falling 2% between 2020 and 2050. The Policy Reference Case assumes that the Metropolitan Transportation Authority (MTA) reaches its target of an all-electric bus fleet by 2040, and that all new bus sales in the city are electric by 2040. Ultimately, over 80% of buses are electric by 2050.

e To estimate vehicle stock turnover in the modeling, the LDV and MDV populations were assumed to have a constant age distribution based on vehicle registration data for NYC in 2019. The lifespans of vehicles were fixed and did not change whether the new vehicle was an internal combustion engine vehicle (ICEV) or ZEV. The HDV lifespan was determined using the VISION model developed by Argonne National Laboratory.

FIGURE 13: VEHICLE COMPOSITION IN THE POLICY REFERENCE CASE, 2050



ZEV sales increase modestly in the Policy Reference Case and by 2050, diesel and gasoline powered engines still comprise a majority of the vehicle stock.

ELECTRICITY

New York State's target to deliver 70% of electricity from renewable sources to retail customers by 2030 drives significant changes in grid capacity, generation mix, and emissions throughout the region in the Policy Reference Case (Figure 14). The Policy Reference Case modeled its electricity load assumptions using NYISO's 2020 *Gold Book* Baseline Case, which is inclusive of policies like *New Efficiency: New York*.[f]

Electricity Sector Emissions Reductions

In the Policy Reference Case, natural gas use declines as renewables are added to the grid. To meet 2030 targets, 4.5 gigawatts (GW) of offshore wind and less than 1 GW of incremental solar is added by 2030 along with 500 MW of battery storage. While natural gas continues to provide the majority of electric capacity in the city, most of the generation comes from offshore wind by 2030. Overall, electricity emissions in the city fall by more than half by 2030 and remain low through 2050.

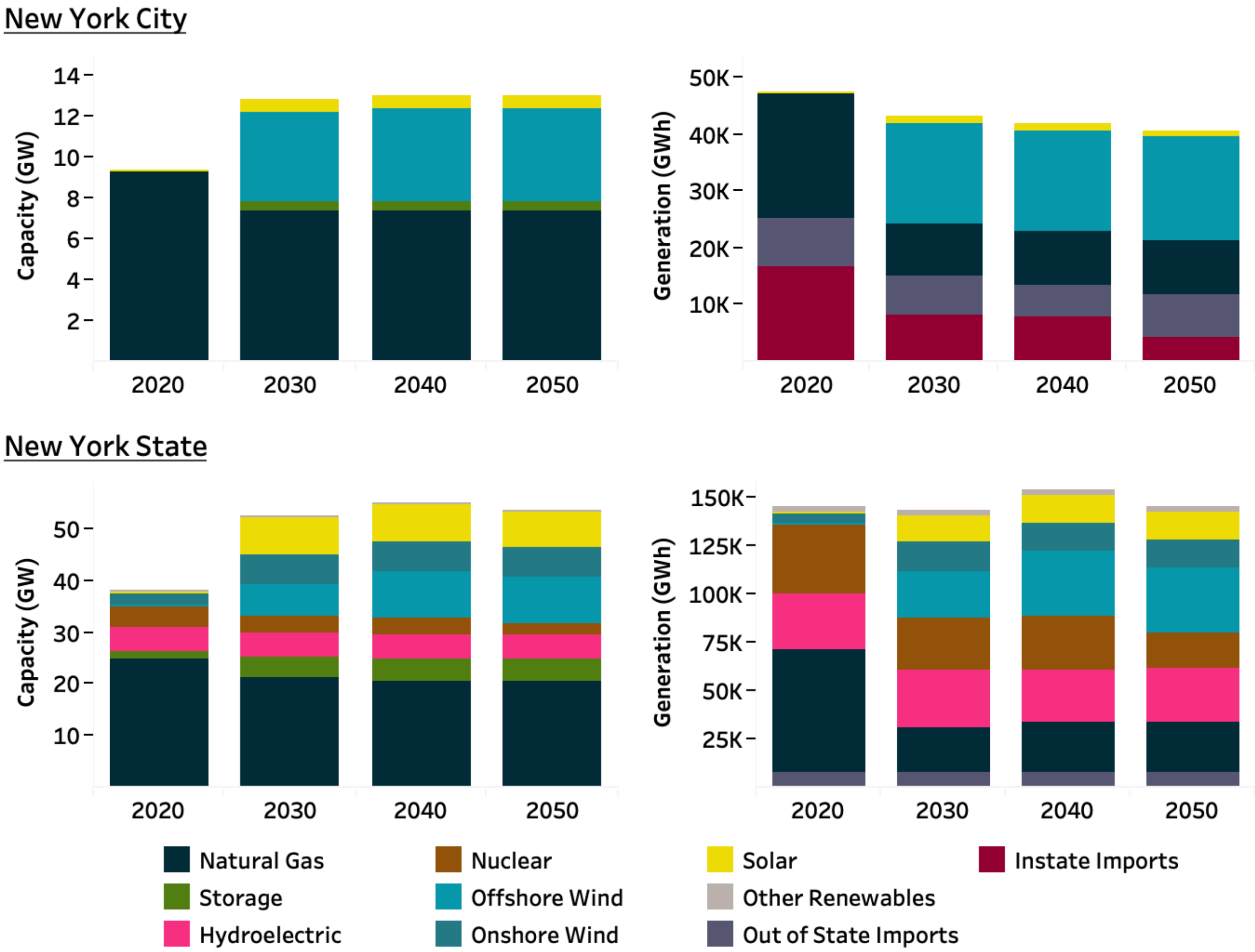
Electricity Sector Resources

State policy drives most of the changes in generating capacity by 2030 in the Policy Reference Case.[92] Substantial additions of renewable generation capacity were assumed to be added throughout the state to meet the CLCPA's goals. The Policy Reference Case integrated new renewable resources including 14.7 GW of wind (5.7 GW onshore, 9 GW offshore—4.5 GW of which is included in NYC's grid) and 7.3 GW of solar—with less than 1 GW of incremental solar included in NYC's grid. Indian Point Energy Center Units 2 and 3 were assumed to retire in 2020 and 2021, respectively, decreasing nuclear capacity,[g] and over 4 GW of battery storage were assumed to be added statewide—0.5 GW of which were included in NYC's grid. Natural gas-fired generation declines as renewables increase; fossil-fuel generation falls by half from 2020 to 2050. Offshore wind provides a quarter of the state's total generation by 2050, and solar and onshore wind each contribute 9% of annual in-state generation.

f The Policy Reference Case assumed 6,000 MW of behind-the-meter solar is installed statewide by 2025. Over 200 MW of non-solar behind-the-meter distributed generation was also assumed to be installed.

g The existing New York State nuclear capacity is based on 60- or 80-year lifetimes. Nuclear plants were assumed to qualify for the Zero-Emission Credit (ZEC) until 2029. Nuclear imports from Ontario were also considered, including their scheduled outage for refurbishments and projected end-of-service.

FIGURE 14: NEW YORK CITY AND STATE ELECTRICITY CAPACITY AND GENERATION IN THE POLICY REFERENCE CASE, SELECT YEARS



The city's electricity generation capacity is almost entirely made up of natural gas in 2020, comprising 34% of total capacity in the Policy Reference Case. Natural gas generation and electricity imports are significantly displaced by offshore wind generation by 2030, and by 2050, offshore wind makes up 44% of the city's total electricity generation. The state has a more diverse fuel mix by 2050 and continues to rely heavily on hydroelectric generation (~20%) and nuclear generation (~22%). **Note:** *Solar capacity shown above represents distributed solar additions required to meet NYC's 1 GW distributed solar target by 2030.*

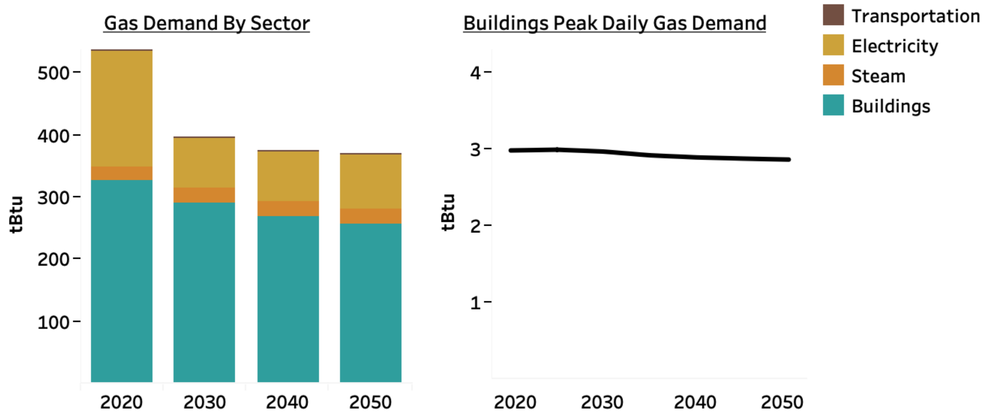
NATURAL GAS

Natural gas demand falls by more than one-third by 2050 in the Policy Reference Case, as gas consumption falls across every end-use sector and most significantly in the electricity sector. Low carbon gases were not assumed to be available in the Policy Reference Case. Emissions from natural gas are counted in the end-use sectors that consume natural gas: buildings, transportation, electricity, and steam.

Natural Gas Demand

In the Policy Reference Case, natural gas demand declines across every sector through 2050, ultimately falling 32% from 2020 levels (Figure 15). The electricity sector experiences the steepest declines in natural gas consumption over the next decade, driven by changes in the electricity generation mix due to the State's requirement that 70% of retail electricity sales are from renewables by 2030. All building heating equipment installed in new and existing buildings was assumed to be gas-fired in the Policy Reference Case. Substantial energy efficiency reduces buildings' gas demand nonetheless, and peak daily gas demand in buildings falls 4% between 2020 and 2050.

FIGURE 15: PROJECTED NATURAL GAS ANNUAL CONSUMPTION AND BUILDINGS PEAK DEMAND IN THE POLICY REFERENCE CASE, SELECT YEARS



Total natural gas demand declines between 2020 and 2050, with the most significant demand reductions from electricity generation due to the State's requirement that 70% of retail electricity sales are from renewables by 2030. While buildings' average annual gas demand also decreases due to energy efficiency investments, peak daily gas demand for buildings decreases only slightly.

The Policy Reference Case assumptions about gas demand differ from utilities' gas demand forecasts. The Policy Reference Case assumed an unprecedented step change in energy efficiency over and above existing policies such as *New Efficiency: New York*. This immediate demand reduction was assumed in the Policy Reference Case without a determination of how that level of demand reduction could be achieved, so that the focus of this study could be on policy choices that differentiate the Pathways. This approach provides a high-level trajectory for natural gas demand over the next three decades to 2050, rather than a reliable estimate of year-by-year demand changes.

This approach differs from utilities' gas demand forecasts that inform energy infrastructure planning needs. Utilities conduct robust natural gas demand forecasts that use actual customer demand data, service territory-specific economic projections, and a detailed analysis of current and anticipated energy efficiency program achievements. The utilities have presented and explained their long-term natural gas demand forecasts in Case 20-G-0131 before the New York Public Service Commission (PSC) in the *Proceeding on Motion of the Commission in Regard to Gas Planning Procedures*. These utility-specific forecasts will continue to account for the likely incremental change in demand as policies and programs to achieve State and City goals are put in place. These forecasts do not mirror the trajectory in the Policy Reference case as the programs, policies, and their subsequent results will continue to develop over time and at a pace that may be different than projected in the Policy Reference Case.

DISTRICT ENERGY

In the Policy Reference Case, district steam demand falls significantly by midcentury. This decline is due to more efficient buildings and buildings leaving the steam system to generate on-site steam.

District Energy Systems Demand and Emissions Reductions

Like the natural gas sector, the emissions associated with generating steam are attributed to the end-use sectors that buy and consume steam—namely, the buildings and industrial sectors. The Policy Reference Case assumed that some customers using the Con Edison steam system leave to generate on-site steam. Substantial energy efficiency improvements for the buildings that remain on the Con Edison steam system also cause steam demand to fall. Overall, district steam use declines 44% between 2020 and 2050. The Policy Reference Case assumed all industrial customers on the Brooklyn Navy Yard steam system maintain service, while non-industrial customers leave the system by 2040. Other, smaller district energy systems were not included in these estimates. The emissions factor for steam is unchanged between 2020 and 2050 in the Policy Reference Case, so steam system emissions fall proportional to demand.

NYC Energy Infrastructure Pathways

Existing policies provide a strong foundation for climate progress—reducing emissions 44% by 2050 in the Policy Reference Case. Three emissions reductions Pathways provide strategies for NYC to reach 80% direct emissions reductions by 2050 in support of the City's carbon neutrality goal.

Three emissions reductions Pathways that achieve at least 80% direct emissions reductions by 2050 were developed to examine options for NYC to deeply decarbonize by midcentury. This study assessed the main drivers of emissions reductions, aggregate and sector-based costs, key findings by sector, and the associated opportunities and challenges. 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, with additional measures added to increase emissions reductions.[a]

The 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% of electricity from zero-emission sources by 2040, and adoption of light-duty zero emission vehicles (ZEV) 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. The first two Pathways were designed to explore the extent to which a plausible amount of electrification or low carbon gases could contribute to reaching 80% or greater emissions reductions. The third Pathway evaluates what might be achievable if the key elements from the first two Pathways are pursued simultaneously (Table 3).

The **Electrification Pathway** assumes high rates of electrification across buildings and all on-road transportation to examine the implications of increasing reliance on electric infrastructure and the end-use implications of transitioning away from the current level of natural gas use in buildings and petroleum in vehicles. In the buildings sector, most existing heating, ventilation, and air conditioning (HVAC) systems are replaced by electric air source heat pumps (ASHP). Substantial vehicle electrification occurs across all vehicle classes. The industrial sector also experiences electrification of key end uses. The Con Edison steam system transitions in part to electric boilers. Low carbon gas from biogenic renewable natural gas (RNG), synthetic RNG, and hydrogen is available to the electricity sector to help meet the high peak demands resulting from electrification.

The **Low Carbon Fuels Pathway** assumes a larger supply of biogenic RNG is available for direct use in buildings and to supply the Con Edison steam system, and biofuels displace fossil fuels for medium-duty vehicles (MDV) and heavy-duty vehicles (HDV). Most existing building heating systems upgrade to high efficiency gas boilers that burn a blend of fossil and low carbon gases. Half as many buildings electrify in this Pathway as in the Electrification Pathway. As with the Electrification Pathway, light-duty vehicles (LDVs) and buses rapidly electrify. End uses in the industrial sector remain largely gas-fired, with low carbon gases almost entirely displacing fossil gas by 2050.

The **Diversified Pathway** was designed to estimate the emissions reduction potential and cost of simultaneously pursuing high rates of building and vehicle electrification, energy efficiency, and low carbon gases. For transportation, this Pathway assumes the same modeling assumptions as the Electrification Pathway.[b]

All Pathways include reduced vehicle miles traveled (VMT), significant energy efficiency measures, geothermal heat pump adoption for district energy systems, and hydrogen and synthetic RNG produced from otherwise curtailed renewable electricity generation in New York State.

a Key modeling assumptions that differ between the Policy Reference Case and the Pathways are shown in Table 1 in Chapter 2.

b Terminology associated with buildings, transportation, gas and fuel, and district energy is defined on page xxi-xxiii.

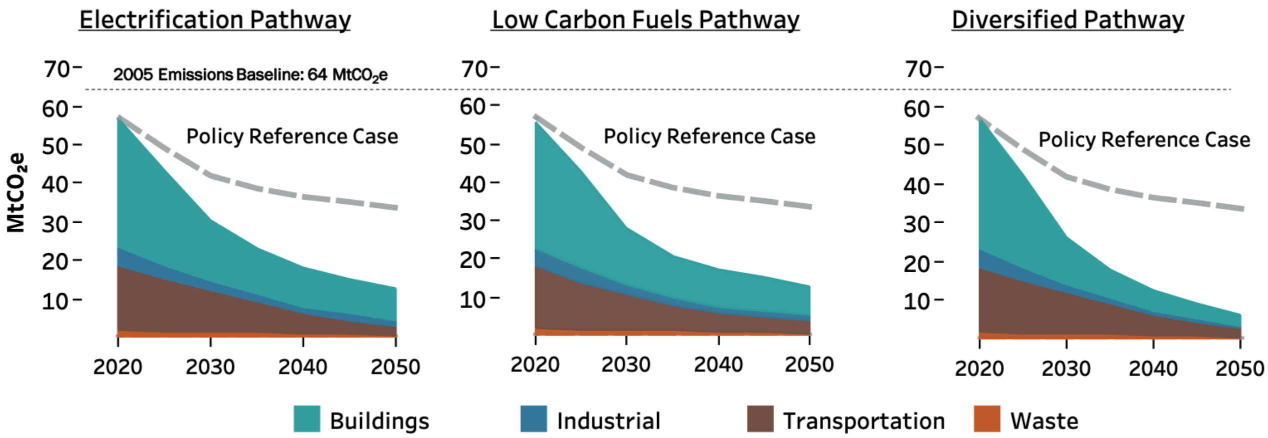
TABLE 3: ASSUMED PATHWAY MEASURES

	Electrification	Low Carbon Fuels	Diversified
Buildings and Industry			
Energy Efficiency Retrofits*	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%
Dual Fuel Heating Systems*	6%	0%	6%
Gas Heat Pumps*	2.5%	4.5%	2.5%
Industrial Space Heating, Energy Uses, and Process Heat	Partially Electrified	Mostly Gas or other Fuels	Partially Electrified
Transportation			
Light-Duty Vehicle Sales	68% Battery Electric Vehicles (BEV), 12% Plug-In Hybrid Electric Vehicles, 20% Internal Combustion Electric Vehicles by 2040		
Medium and Heavy-Duty Vehicle Sales	100% BEV by 2050	Biofuels used to decarbonize**	100% BEV by 2050
Bus Sales	100% BEV by 2040		
Light Duty Vehicle Miles Traveled	-17% by 2050		
District Energy			
Con Edison Steam System Customer Defection	Most small buildings (<14 million lb/year) leave steam system	Fewer small buildings leave steam system, all large buildings (>14 million lb/year) remain	Most smaller buildings (<14 million lb/year) leave steam system
Con Edison Steam System Electric Boilers	Yes	-	Yes
New Combined Heat and Power	-	Yes	-
New District Geothermal Systems	Yes		
Electricity			
New York State Clean Energy Standard	100% of electricity sales met by zero-emission sources by 2040		
Renewable Natural Gas (RNG) Allowed for Electricity Generation	Yes	Only Con Edison East River Cogeneration Facility	
Natural Gas			
Biogenic RNG Supply in 2050	26 tBtu	61 tBtu	61 tBtu
Hydrogen and Synthetic RNG Supply	Curtailed Generation and Dedicated Solar	Curtailed Generation	Curtailed Generation
Low Carbon Gas Allocation Priority (includes biogenic RNG, synthetic RNG, and hydrogen)	1 Steam 2 Electricity 3 Buildings/Industry	1 Steam 2 Transportation 3 Buildings/Industry	1 Steam 2 Buildings/Industry 3 Electricity

** As measured by total adoption across all buildings on a gross square footage basis in 2050; energy efficiency tiers are defined in Box 3 in Chapter 2.*

***Biofuels include 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.*

FIGURE 16: GHG EMISSIONS REDUCTIONS BY SECTOR IN THE PATHWAYS, 2020-2050



By 2050, citywide emissions fall 81% in the Electrification and Low Carbon Fuels Pathways from the 2005 baseline, or 78% from the modeled 2020 year; the Diversified Pathway reaches a 90% reduction from the 2005 baseline, or an 88% reduction from the modeled 2020 year. These citywide reductions reflect rapid progress across every sector. The precise trajectory between 2020 and 2050 will depend in part on space heating and domestic hot water (DHW) adoption rates.

Primary Drivers of Emissions Reductions in the Pathways

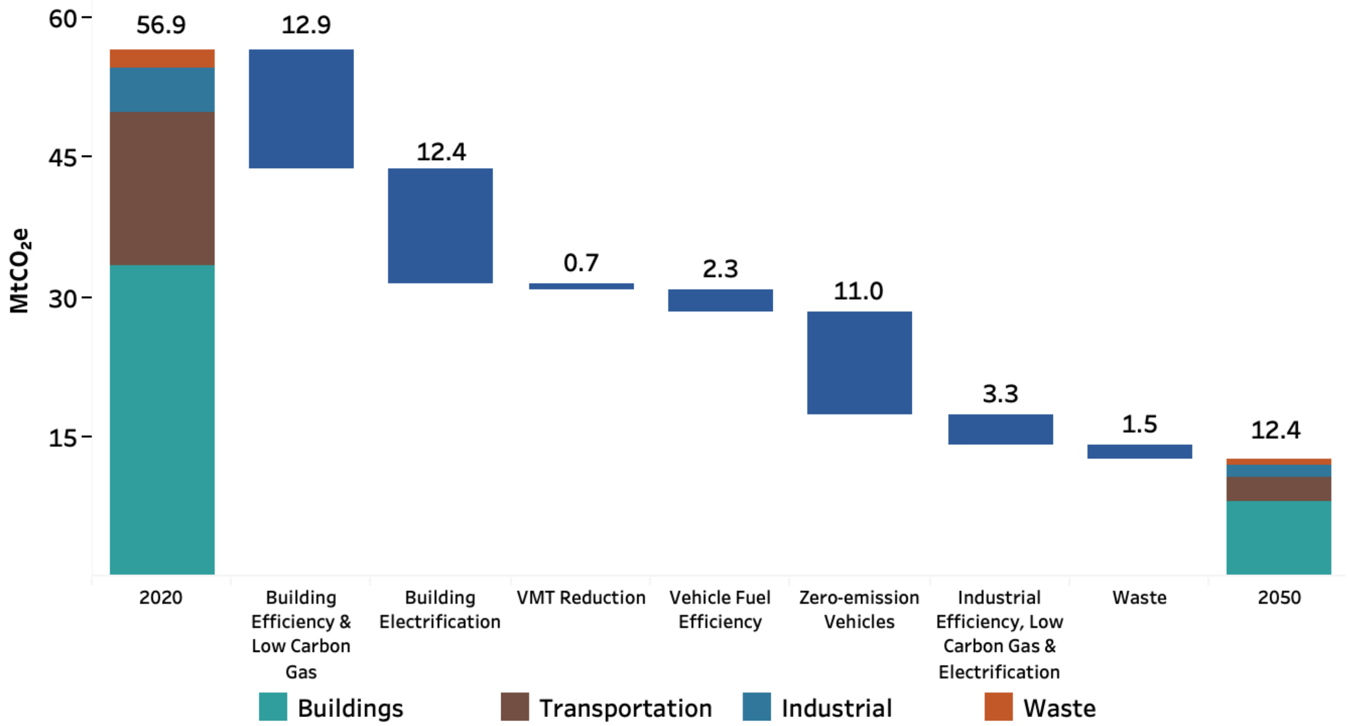
All three Pathways achieve the statutory, citywide goal of reducing GHG emissions 80% by 2050 (relative to 2005). The Electrification and Low Carbon Fuels Pathways both reduce emissions by 81%, while the Diversified Pathway has a 90% reduction, bringing NYC closest to carbon neutrality. In all Pathways, emissions reductions are mostly driven by the buildings sector, followed by transportation, industry, and waste (Figure 16).

The key measures contributing to emissions reductions across the Pathways are discussed below. While each measure in Figures 17-19 is shown separately, many components of the system must work in concert to successfully abate over 80% of the city's emissions. The key measures rely on enabling technologies, such as non-emitting electricity generation and low carbon gas. Without the availability of low carbon gas and low carbon electricity, more emissions would remain.

Emissions reductions in the **Electrification Pathway** are driven by building energy efficiency, cleaner fuels, building electrification, and ZEV adoption (Figure 17). Nearly 60% of buildings (on a square foot basis) electrify heating and hot water systems, and ZEVs make up 75% of all vehicles by 2050. As a result, building electrification and vehicle electrification account for 23.3 $MtCO_2e$, or 53% of annual emissions reductions from 2020 to 2050. Electrifying without investing in renewable energy, low carbon fuels, and other zero-carbon generation capacity, however, will not yield the same emissions benefits.[c]

c To attribute emission reductions to either building energy efficiency or building electrification measures, energy use was modeled in buildings with both energy efficiency retrofits and electrified heating and compared to a second simulation for buildings with energy efficiency retrofits alone. Emission factors by fuel type in each Pathway were used to convert the change in energy use by electrification to estimate emission reduction.

FIGURE 17: EMISSIONS REDUCTIONS BY MEASURE IN THE ELECTRIFICATION PATHWAY



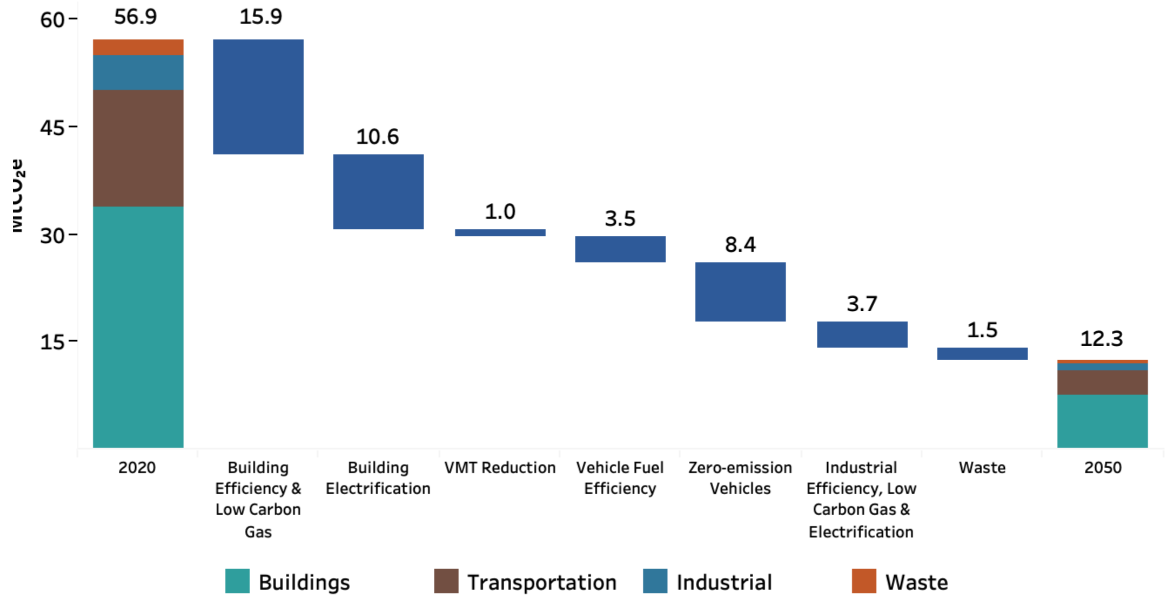
The Electrification Pathway relies heavily on electrifying building heating systems and all vehicle classes. For this Pathway, building and vehicle electrification provide the largest reductions in annual emissions by the year 2050, avoiding 12.4 $MtCO_2e$ and 11 $MtCO_2e$ per year, respectively. Building energy efficiency and low carbon gas use also contribute significantly to annual emissions reductions in this Pathway.

The largest emissions reduction measure in the **Low Carbon Fuels Pathway** is the use of energy efficiency and cleaner fuels in buildings (Figure 18). Fewer buildings electrify in this Pathway than in the others (31% on a square foot basis), and low carbon gas displaces fossil natural gas in non-electrified buildings and industrial end uses. By 2050, energy efficiency and use of low carbon gas and cleaner electricity in buildings reduce annual emissions by 15.9 $MtCO_2e$, or 35% of the total economywide emissions reductions between 2020 and 2050.

In the transportation sector, just as many LDVs are electrified as in the Electrification Pathway; however, the Low Carbon Fuels Pathway uses low carbon fuels to abate emissions from MDVs and HDVs. Together these measures reduce transportation sector emissions 8.4 $MtCO_2e$ between 2020 and 2050, or 24% fewer annual emissions reduced than in the Electrification Pathway.

The key measures rely on enabling technologies, such as non-emitting electricity generation and low carbon gas. Without the availability of low carbon gas and low carbon electricity, more emissions would remain.

FIGURE 18: EMISSIONS REDUCTIONS BY MEASURE IN THE LOW CARBON FUELS PATHWAY

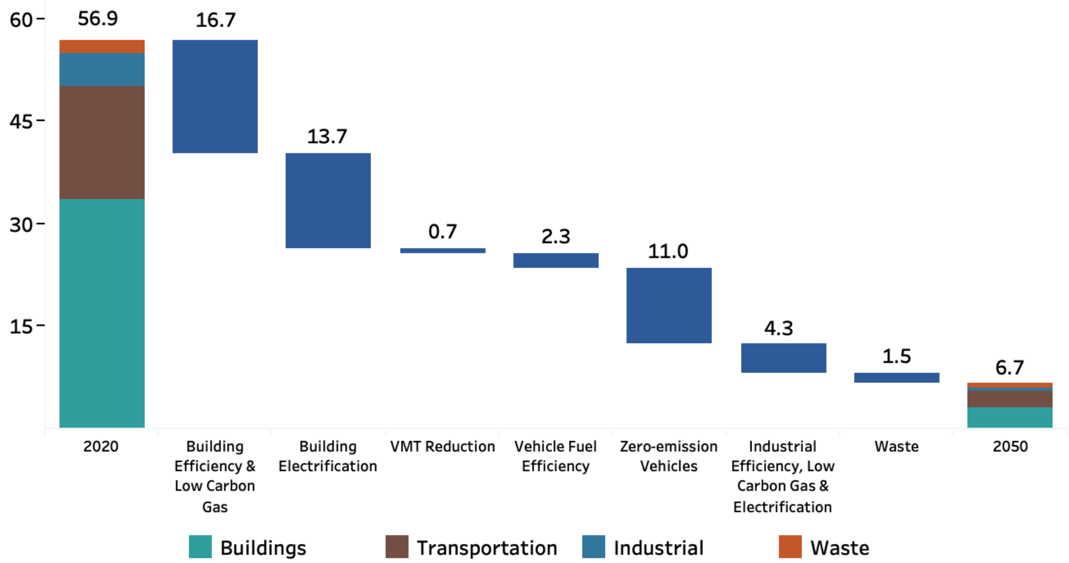


The Low Carbon Fuels Pathway relies heavily on fuel switching to low carbon gases for building heating and renewable fuel alternatives for heavy-duty transportation. For this Pathway, building energy efficiency and low carbon fuel use provides the largest reduction in annual emissions by 2050, avoiding 15.9 $MtCO_2e$ per year in 2050. The electrification of building heating systems and vehicles assumed in this Pathway is more limited compared to the other Pathways but still reduces annual emissions substantially.

The **Diversified Pathway** employs both an aggressive electrification strategy and large amounts of low carbon gases. The combined emissions reductions from building electrification, building energy efficiency, and low carbon fuel use in buildings is 30.4 $MtCO_2e$ in 2050 relative to 2020.

Compared to the Low Carbon Fuels Pathway, the Diversified Pathway has greater availability of low carbon gas, which was used in part by the buildings sector. The remaining emissions in 2050 are the lowest in this Pathway due to the combination of strategies across all sectors (Figure 19).

FIGURE 19: EMISSIONS REDUCTIONS BY MEASURE IN THE DIVERSIFIED PATHWAY



The Diversified Pathway relies on both electrifying building heating systems and using low carbon gas for remaining gas use in buildings. As a result, building energy efficiency and low carbon gas use reduce annual emissions 19 $MtCO_2e$ per year by 2050. Building energy efficiency and low carbon gas use also contribute significantly to annual emissions reductions in this Pathway.

While each Pathway incorporates a distinct set of emissions reduction approaches, three common measures play an outsized role. First, building energy efficiency and use of lower emitting fuels in buildings avoid between 12.9 and 16.7 $MtCO_2e$ per year by 2050. This requires nearly every building in NYC to receive some level of energy efficiency improvement and at least a third of building space to undergo extensive retrofits. Second, building electrification—paired with a cleaner electric grid—avoids emissions at a similar scale, between 10.6 and 13.7 $MtCO_2e$ per year by 2050. These emissions benefits are predicated on increasingly clean electricity delivery and require careful deployment of peak demand management options and new grid infrastructure. Finally, vehicle electrification—also paired with a cleaner grid—avoids between 8.4 and 11 $MtCO_2e$ of on-road emissions per year by 2050. Hundreds of thousands of new vehicle chargers would be required to support this level of ZEV deployment. These three measures—building efficiency and lower emitting fuels, building electrification, and vehicle electrification—account for at least 78% of total emissions reductions between 2020 to 2050 in every Pathway.

Achieving deep decarbonization by 2050 will also rely on additional emissions reductions measures. These include reducing VMT by replacing private car trips with biking, walking, public transport, or shared transport; improving vehicle efficiency; using cleaner fuels more efficiently in the industrial sector; targeting waste sector emissions; and providing low carbon gas to steam generation.

Costs of Emissions Reduction Pathways

Cumulative Pathway costs are shown in Figure 20 and cumulative Policy Reference Case costs are shown in Figure 21. Costs across the three Pathways are expressed as a single estimate because total costs differ little between the Pathways when considering the range of uncertainties in the assumptions. From today's vantage point and with currently available technology, the modeling suggests the Low Carbon Fuel Pathway to be modestly lower cost than the other Pathways.

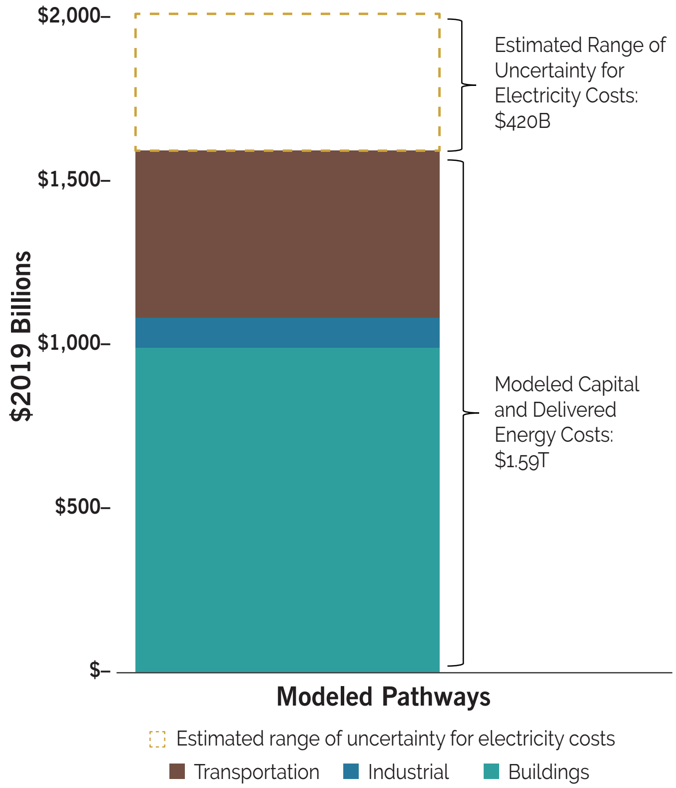
Many of the costs modeled in this analysis are not wholly incremental to today's spending. For example, New Yorkers already pay for energy to power, heat, and cool the buildings they live and work in and to fuel their vehicles. Similarly, building owners regularly replace heating and cooling equipment at the end of its useful life and invest in energy efficiency to comply with the latest energy codes, improve occupant comfort, and save on energy bills. Additionally, vehicles are regularly replaced at the end of their useful lives. Figure 20 and Figure 21 do not subtract out these regular, ongoing costs from the cumulative cost estimates.

Modeled capital and total delivered costs are an estimate of expenditures that could be needed to implement the measures modeled in the Pathways. For the buildings sector this includes energy costs; equipment and labor for energy efficiency and HVAC equipment retrofits; new construction; and, to a limited extent, the cost of new district energy systems.[d] Transportation sector costs include new ZEV charging infrastructure, new vehicles, vehicle maintenance costs, and fuel costs. Electricity sector costs include the cost of new electric generation capacity within or directly connected to the city and grid capacity needed to meet the projected peak demand growth. Electricity sector capital costs are proportionally allocated across the end-use sectors.[e]

d Energy cost accounts for building electricity, natural gas, fuel oil, and steam consumption multiplied by each energy source's unit delivered cost. Retrofit costs account for the purchase and implementation of energy efficiency measures, space heating equipment and DHW equipment. Retrofit costs for the Policy Reference Case and the Pathways are estimated as replacement costs based on ranges of average equipment lifetimes and turnover rates as well as the cost of new energy efficiency measures. New construction cost includes baseline construction cost, such as labor and steel and cement material costs, and additional costs to meet required energy savings targets.

e Industrial costs do not include capital costs for equipment retrofits. These costs were not included because there is limited data available on industrial equipment stock, particularly relative to the stock information available for other sectors.

FIGURE 20: MODELED CAPITAL AND DELIVERED ENERGY COSTS TO ACHIEVE THE PATHWAYS, 2020-2050



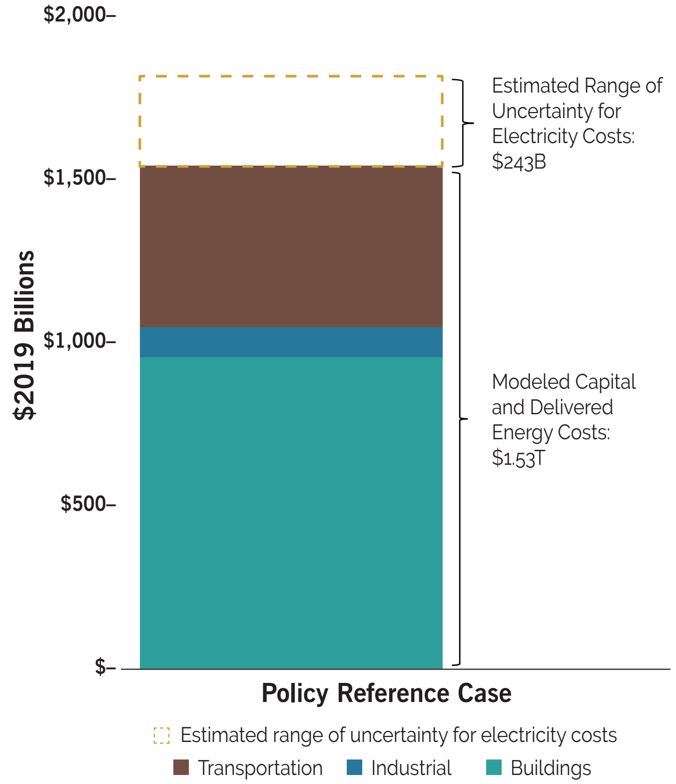
This figure shows the modeled costs for the measures in the Pathways. The sectoral bars represent modeled capital and delivered energy costs for the lowest cost Pathway modeled. The dashed box represents an estimated range of uncertainty for electricity costs for the Pathways.

Investments needed to maintain a reliable and safe energy system, such as planned resiliency, non-wires solutions (NWS) investments, enhanced customer experience, and information technology needs were not included in the modeling and may not be fully captured in retail rates today. In addition, some costs associated with generation, such as upstate electric generation investments potentially required to meet statewide end-use emissions reduction goals, were also not included in the modeling.

This estimated range of uncertainty for electricity costs reflects an approximation for on-going investments needed to maintain safety, reliability, resiliency, and grid capabilities. To develop the estimated range of uncertainty, a simple escalation factor was applied to electricity infrastructure costs based on historic rate increases.

The Policy Reference Case (Figure 21) projects significant expenditures in the buildings and transportation sectors due to anticipated equipment turnover in the next 30 years, aggressive energy efficiency assumptions, and that 70% of electricity sales are met by renewable sources by 2030. The different set of investments in the Pathways, therefore, represent efforts and expenditures beyond the already significant expenditures in the Policy Reference Case for measures that maximize emissions reductions, especially with the realization of 100% of electricity from zero-emission sources by 2040 and the introduction of low carbon fuels.

FIGURE 21: 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.

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 reality, costs for many technologies, such as solar and battery storage, have declined substantially as markets matured. Given the inherent uncertainty of projecting 30 years in the future during a time of unprecedented energy system transformation, further cost analysis will be required as more information becomes available. In addition, this study did not consider the cost of climate inaction, which NYC has acutely felt through events such as Hurricane Sandy.

The Pathways assume all building electrification occurs at the same time as substantial building energy efficiency upgrades to reduce electricity use required for heating and cooling. While this represents the most cost-efficient practice, directly reducing the cost of building electrification and its impact on peak electricity demand is highly optimistic. Timing more substantial building efficiency upgrades such as insulation, window replacement, and recladding to occur prior to or at the time of electric heating conversion faces many practical challenges, including equipment turnover cycles not lining up with building renovation cycles, complex logistics, and building owner capital constraints. Without substantial intervention and support, these challenges can lead to higher heating electrification costs and higher peak electricity demand. Furthermore, 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.

The following sections discuss the key insights from the three Pathways by sector, highlighting overarching findings, major distinctions between Pathways, and implications for deeply decarbonizing NYC by 2050.

BUILDINGS AND INDUSTRY

The buildings sector contributes about two-thirds of the city's emissions. In all Pathways, energy efficiency upgrades and electrification of heating systems across the city's varied building stock reduce the sector's emissions by 76-91% between 2020 and 2050. Implementing these measures at scale will require workforce and business development efforts, financing mechanisms, and alignment of tenant and building owner incentives.

Once installed, these upgrades would not only contribute significantly to City and State climate goals but can also provide important non-energy benefits like better air quality and more equitable access to heat in the wintertime and air conditioning in the summertime. The industrial sector also realizes significant emissions benefits from better-performing equipment, higher percentages of low carbon gases in the gas supply, and decarbonization of the electricity sector.

TABLE 4: KEY BUILDINGS AND INDUSTRIAL SECTOR FINDINGS FROM THE PATHWAYS MODELING

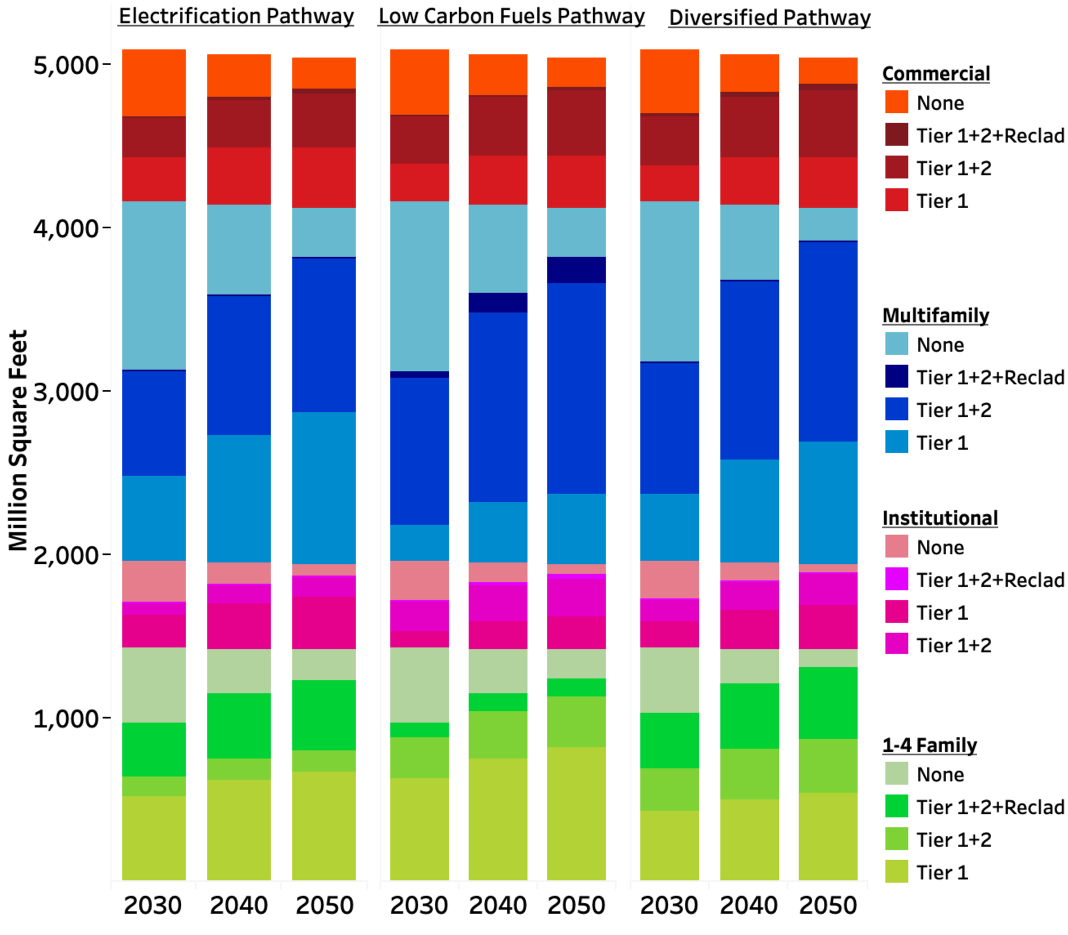
	Electrification	Low Carbon Fuels	Diversified
The scale and pace of energy efficiency and electrification retrofits is high.			
Proportion of buildings electrifying space heating and hot water systems by 2050 (percentage of gross square footage)	59%	31%	62%
Average number of buildings electrifying each year (2020-2050)	18,700	10,700	19,800
Number of buildings electrifying by 2050	607,000	340,000	642,000
Percentage of buildings adopting at least Tier 1 energy efficiency upgrades by 2050	87%	88%	92%
Average number of buildings implementing only Tier 1 energy efficiency upgrades each year (2020-2050)	11,700	16,200	10,500
Average number of buildings implementing Tier 1 + more significant energy efficiency upgrades each year (2020-2050)	27,500	27,400	28,900
Number of buildings implementing energy efficiency measures by 2050	909,000	910,000	958,000
Building energy efficiency significantly reduces sector energy use by 2050.			
Total building energy consumption in 2050 [relative to 480 trillion British thermal units (tBtu) in 2020 model results]	242 tBtu	275 tBtu	227 tBtu
Total building energy savings from energy efficiency measures by 2050 (relative to 2020 model results)	207 tBtu	211 tBtu	223 tBtu
Electricity savings from energy efficiency measures by 2050	33 tBtu	38 tBtu	35 tBtu
Gas savings from energy efficiency measures by 2050	123 tBtu	131 tBtu	134 tBtu
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 (ASHP) provides key building emissions benefits relative to adopting high-efficiency natural gas boilers. This does not account for any low carbon gas that could be used for heating in the future.			
Building retrofits are capital intensive but they help manage rising delivered energy costs.			
Energy efficiency measures and updated heating and DHW systems are critical to reducing energy consumption and managing both equipment and fuel costs in the buildings sector through 2050.			
Technologies that can help manage peak electricity demand in the winter can have vital roles in a future with higher rates of electrification.			
Implementing dual fuel heating systems in place of ASHPs in 6% of buildings in the Electrification Pathway could result in peak demand savings of 7% (from 15.5 to 14.5 GW) in 2050.			
Use of low carbon gases in the buildings and industrial sector could provide emissions benefits today as well as valuable system benefits.			
Industrial sector emissions reductions between 2020-2050	70%	77%	90%
Energy efficiency and heating system retrofits provide substantial non-energy benefits.			
Upgrades can limit allergens and provide better temperature control in apartments. Electrification of building systems specifically helps to improve on-site outdoor air quality.			
The rented building stock faces specific implementation challenges in planning, financing, and managing misaligned incentives between tenants and landlords.			
Two-thirds of the housing stock and most commercial stock is rented; this stock faces unique challenges in planning, financing, impacts on housing affordability, and managing misaligned incentives between tenants and landlords.			
Energy efficiency can be a large driver of inclusive economic opportunity.			
Energy efficiency at this scale is unprecedented and create create a large number of job and business opportunities that require specialized skills and training.			

The scale and pace of energy efficiency and electrification retrofits is high.

In all three of the Pathways, nearly every existing building requires energy efficiency upgrades, ranging from lightbulb replacement to roof insulation, and a significant subset of those buildings electrify heating and domestic hot water (DHW) systems. Box 6 describes the modeling approach used to estimate the pace and extent of building energy efficiency and electrification measures.

Up to 92% of the building stock implements Tier 1 energy efficiency improvements by 2050 (Figure 22). On average across the three Pathways, 28,000 buildings implement Tier 1 energy efficiency upgrades per year per year from 2020 to 2050 for a total of more than 900,000 buildings.[f] Of those, about 15,000 per year also implement more significant Tier 2 energy efficiency or recladding upgrades. On average across the Pathways, a total of 500,000 buildings complete a Tier 2 energy efficiency retrofit by 2050. Achieving deep decarbonization without significant amounts of energy efficiency would be much more challenging.

FIGURE 22: CUMULATIVE DEPLOYMENT OF ENERGY EFFICIENCY RETROFIT PACKAGES, SELECT YEARS



In 2050, more than 900,000 buildings implement Tier 1 energy efficiency improvements, representing up to 92% of the building stock. Approximately half of all buildings implement more significant Tier 2 or recladding measures. **Note**: *the above graphic shows energy efficiency deployment in the building stock existing at the beginning of the study period only and not in new construction. Some buildings existing in 2030 are demolished by 2050, so the building square footage decreases slightly over time.*

f There are small differences between the average number of buildings per Pathway implementing Tier 1 energy efficiency measures (27,500 in the Electrification Pathway; 27,400 in the Low Carbon Fuels Pathway; and 28,900 in the Diversified Pathway).

Box 6: Projecting Electrification and Energy Efficiency Adoption Rates in Multifamily and Commercial Building Typologies

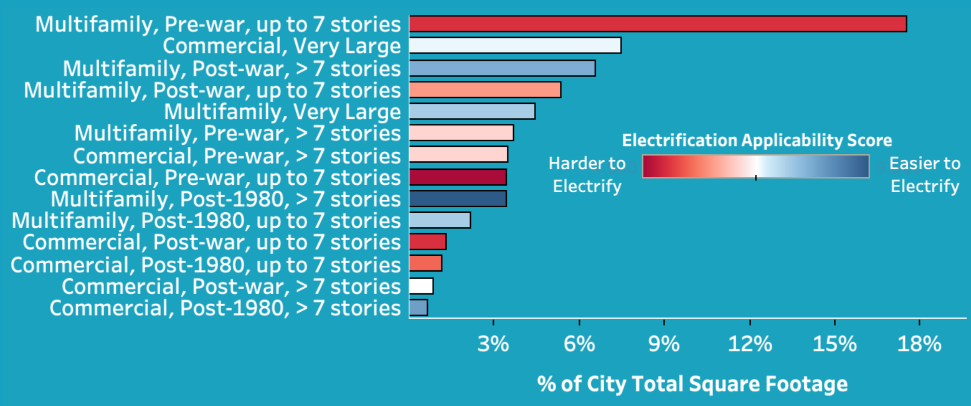
Methodologies were developed to project adoption rates for electric heating technologies and energy efficiency upgrades. The electrification methodology includes two principal components: assessing the feasibility of electrification and determining stock turnover.

Electric Heating Technology Adoption

Assessing feasibility of electrification

To identify the technical feasibility of replacing existing heating, cooling, and DHW systems with electrified systems in NYC's heterogeneous building stock, electrification applicability scores were calculated for multifamily and commercial building typologies. These scores rolled up the relative costs and technical feasibility of various electrification technologies, based on data and input from NYC technical experts. Electrification applicability scores range from 0 to 10, with 10 reflecting the highest potential for electrification. Figure 23 shows the results of this scoring exercise compared to square footage of the analyzed commercial and multifamily typologies.

FIGURE 23: ELECTRIFICATION APPLICABILITY SCORE BY COMMERCIAL AND MULTIFAMILY TYPOLOGY



Multifamily and commercial buildings greater than seven stories built after 1980 and post-war multifamily buildings greater than seven stories had the highest electrification applicability scores, indicating the highest potential for electrification. Two additional typologies that scored well include very large commercial buildings and multifamily buildings built after 1980 with up to seven stories.

These higher scores result in part because buildings greater than 25,000 square feet are subject to Local Law 97 of 2019 (LL97), providing a potential emissions incentive to electrify end uses. Additionally, newer buildings (i.e., those built post-1980) have characteristics, such as more advanced building systems, less reliance on steam, and higher-efficiency windows, that are more conducive to electrification. Finally, very large commercial buildings typically have existing mechanical floors and staff engineers, which increase technical feasibility of electrification; however, commercial buildings are typically more complex than multifamily buildings and have larger open spaces that require more energy for heating and cooling.

This exercise highlighted a major gap—some building types with the largest shares of square footage in the city, such as pre-war, multifamily buildings less than seven stories, have significant cost and technical barriers to electrification. Energy efficiency and electrification retrofits in these buildings can trigger code compliance for tangential building systems or attributes, adding to overall project costs and disincentivizing building modernization. Other barriers to electrification found across typologies include a lack of mechanical room space in small commercial and large multifamily, commercial, and institutional buildings currently using district steam systems, as well as a lack of dedicated mechanical building staff. These issues present challenges in installing and maintaining centralized heat pump systems.

Determining stock turnover

A stock turnover model was developed for each building commercial and multifamily typology to account for existing heating and DHW system replacement at end of useful life. This was determined based on equipment service life estimates, introduction years for each heating technology, maximum annual equipment stock turnover rates, and available Local Law 87 of 2009 energy audit data.

Evaluation of the city's current heating equipment stock suggests that a high percentage of existing heating systems are past their useful life; consequently, a high replacement rate could be feasible in the coming decade. A range of stock turnover rates were examined, including looking at two scenarios, one where stock turnover was capped at 3% and a second scenario where it was capped at 6% annually to align with the historic boiler replacement rate (6.7% per year between 2012 and 2018) and to account for longer-than-average equipment lifetimes observed in the city. To project electric heating adoption rates annually and cumulatively, a Bass diffusion curve[*] was applied.

Energy Efficiency Adoption

Energy efficiency measures were assumed to be implemented at the time of heating and DHW systems replacement. This best practice ensures that new heating and DHW systems are right-sized while minimally disrupting residents and businesses. For example, lighting upgrades and air sealing done as part of a Tier 1 energy efficiency upgrade impact both heating and cooling loads, reducing the required size of an HVAC system. Installing electrified heating and DHW systems without energy efficiency measures would result in higher winter electric peaks, which could then require additional investments in electric supply infrastructure.

In the Electrification Pathway, 80% of buildings within each typology were assumed to implement the energy efficiency upgrades with the highest net present value (i.e., most cost-effective), and the remaining 20% were assumed to implement the second most cost-effective upgrades. The Low Carbon Fuels Pathway generally follows the same net present value heuristic for upgrade implementation. The Diversified Pathway assumes slightly more energy efficiency, driven by a slightly higher percentage of buildings implementing the most cost-effective energy efficiency packages. For all Pathways, the model targeted higher levels of energy efficiency measure adoption in the largest building typologies to ensure that these buildings meet LL97 requirements.

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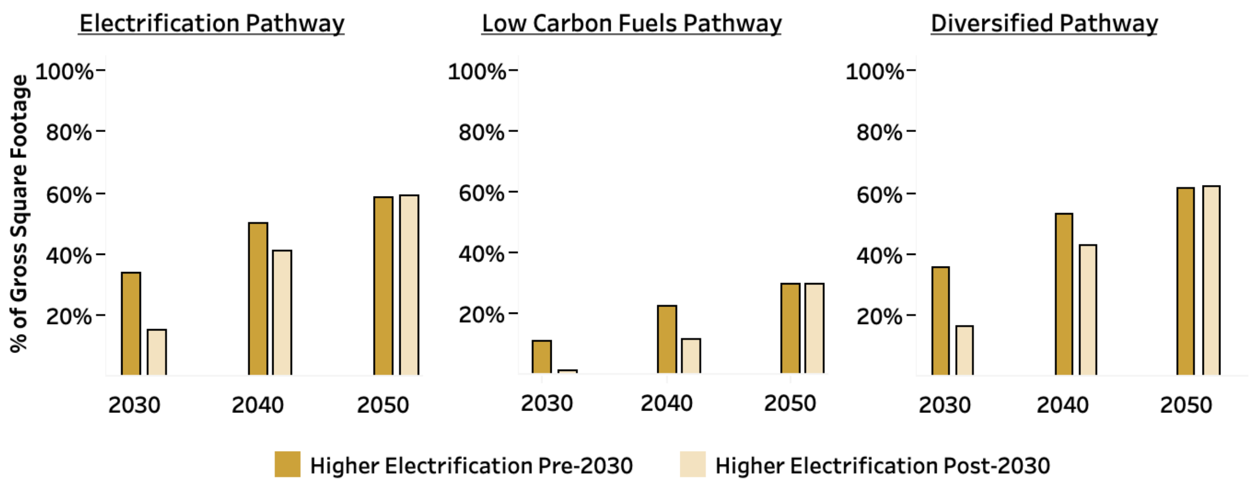
[*] A Bass diffusion curve is a differential equation that describes how new products are adopted in a population. Two Bass diffusion curve parameters are the "coefficient of innovation," which characterizes the behavior of early adopters of a new technology, and the "coefficient of imitation," which characterizes the uptake of lagging market segments. Higher values of each parameter result in faster adoption.

In the Electrification and Diversified Pathways, at least 600,000 buildings, or 60% of building square footage in NYC, fully electrify heating and DHW systems by 2050. While the Low Carbon Fuels Pathway anticipates greater reliance on low carbon gas for end uses in buildings, more than 340,000 buildings, or 30% of buildings, still electrify. On average about 20,000 buildings electrify each year under the Electrification and Diversified Pathways, while about 10,700 per year electrify under the Low Carbon Fuels Pathway. New construction in the Electrification and Diversified Pathways was assumed to be all-electric, while the fuel mix of new construction in the Low Carbon Fuels Pathway was assumed to match that of the existing city building stock, excluding fuel oil.

The distribution of electric heating and DHW system adoption through 2050 will be influenced by a variety of highly uncertain factors (Box 7). To illustrate possible electrification trajectories through 2050, this study modeled two building electrification adoption scenarios (Figure 24). The first scenario assumed the fastest rates of building electrification pre-2030, while the second scenario assumed the fastest electrification rates between 2030 and 2050. In the Electrification and Diversified Pathways, pushing more electrification to later decades increases the building square footage electrifying between 2030 and 2050 by 30%. In the Low Carbon Fuels Pathway, faster electrification later increases adoption between 2030 and 2050 by 33%. The scenarios electrify the same percentage of building square footage by 2050. Implementation of the first scenario would require rapid coordination in early years; in the second, policymakers would need to prepare for more retrofits as 2050 approaches. A scenario with the faster rates of building electrification pre-2030 was used in the Pathways modeling.

FIGURE 24: CUMULATIVE SPACE HEATING AND DOMESTIC HOT WATER ELECTRIFICATION ADOPTION SCENARIOS



This figure shows the percent of 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 as described in Box 7. Both achieve the same amount of 2050 electrification. The "Higher Electrification Pre-2030" scenario was used in the Pathways modeling.

Box 7: Factors Impacting Energy Efficiency and Electrification Adoption Rates

The trajectory of energy efficiency and electrification adoption will ultimately be influenced by a variety of highly uncertain factors. Two electrification adoption scenarios were modeled to illustrate the uncertainty that these factors introduce in forecasting future adoption rates (Figure 24). While some of the following factors were explicitly modeled, others were not, underscoring the fact that the pace and scale of retrofits in NYC could look quite different than the results presented in this study.

- **Stock turnover:** As modeled, over the next 15 years, building equipment will reach end of life and many buildings will need to replace HVAC systems. This could prompt faster replacement in those years, though other factors can dictate whether replacement options are electric or efficient, gas-fired units.
- **Economics:** Upfront capital outlays, financing terms, and operating costs are uncertain. It is generally expected that technology costs, especially for newer technologies, will decline over time. Absent other factors, cost dynamics could make more adoption possible later in the study period. The near-term impacts of the COVID-19 pandemic on the economy and financing could also impact investment timelines.
- **Split incentives:** Two-thirds of the housing stock and most commercial building stock is rented. Overcoming misaligned incentives between landlords and tenants could have a significant impact on retrofit timing. For example, if a tenant pays the utility bills, the landlord cannot use energy savings to recoup the cost of efficiency measures and may be reluctant to make the investment.
- **Implementation considerations:** Efforts should be made to proactively plan for retrofits, rather than waiting until equipment breaks so that building owners can ensure essential services like heating and cooling are available. Building staff or homeowners must also be available to manage work. Buildings may try to wait to see if a clean grid materializes before implementing new measures.
- **Technology availability:** Currently, the market for efficient cold climate heat pumps is still evolving. As time progresses, there may be more options, both in terms of efficiency and design approaches, that could better align with existing conditions within buildings. The technology could also become more efficient over time, which would further reduce costs but would imply later adoption.
- **Low carbon gas availability:** The evolution and availability of low carbon gases in the gas distribution system, and of heating technologies that efficiently use low carbon gases, may impact electrification adoption rates. The costs and benefits of electrified space heating systems as compared to those powered by low carbon gas against the factors mentioned above may also change over time as both classes of technologies evolve. This may drive shifts in electrification adoption rates.
- **User preference:** Installation rates of electrified heating and DHW equipment do not necessarily guarantee use of electric equipment. New Yorkers who still have access to alternative heating elements may choose to use those non-electric devices during the winter. Broader behavioral and cultural shifts could help shape adoption.
- **Policy mandates:** Policies like LL97, which impact a subset of buildings, may drive earlier adoption due to financial disincentives.
- **Energy efficiency/electrification business and workforce readiness:** The ability of projects and crews to operationalize and deploy energy efficiency and electrification measures will need to increase to deploy projects at the assumed pace.

No matter the adoption trajectory, the significant implementation of electrification and energy efficiency measures modeled in this analysis is unprecedented in NYC. Implementation of these upgrades necessitates bold and innovative workforce development strategies, policy, and coordination with building stakeholders. Behavioral and financial incentives are also needed to simultaneously facilitate proactive energy efficiency and heating system upgrades, especially in smaller buildings not covered by LL97.

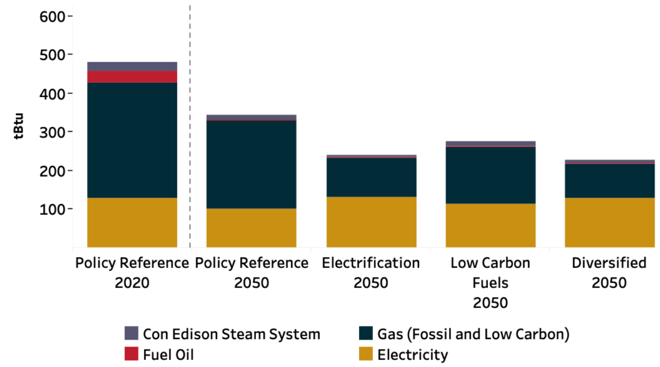
A base of policy and program support for retrofits exists today. Large building owners could meet, or work toward, LL97 requirements by upgrading existing heating and DHW systems and/or implementing energy efficiency measures. The State has energy efficiency targets in place,[g] and utilities already incentivize customers across building typologies to make efficiency upgrades.[93] Technologies commonly targeted by such efficiency programs today, like lighting and appliances, are often relatively inexpensive and have 10- to 15-year lifespans; many can be replaced in the near-term at low cost and with minimal disruption to homeowners, tenants, and building owners.

Citywide, larger-scale retrofits may disrupt New Yorkers where they live and work. While each Pathway anticipates similar disruption from energy efficiency implementation at the city level, impacts to building owners and tenants can vary depending on building type and the extent of retrofit. For example, in multifamily housing and the commercial building stock, Tier 2 energy efficiency projects can impact multiple dwellings or office spaces at once, whereas air sealing in a single-family home will likely cause limited disruption. Installation of electric heating and DHW systems is generally more disruptive than gas-fired equipment installation. High-efficiency gas-fired equipment generally replaces existing equipment but leaves legacy distribution systems in place; electrified equipment installation is more likely to require in-unit work to update distribution systems. Therefore, Pathways with less electrification are expected to be slightly less disruptive than those with more electrification. At the individual building level, impacts to owners and tenants can also vary depending on building legacy and planned replacement systems.

Building energy efficiency significantly reduces sector energy use by 2050.

Energy efficiency is a key enabler of building energy savings across all Pathways. Whether building systems electrify or use gas, limiting energy waste from inefficient appliances, outdated lighting fixtures, and poorly insulated walls and windows can reduce energy demand and related emissions. Energy efficiency measures specifically account for 207-223 tBtu of energy use savings in the Pathways, about half of total building sector energy use in 2020. These upgrades drive 42-52% of energy use declines in the Pathways between 2020 and 2050, making them the most significant driver of total building sector energy use reductions (Figure 25).

FIGURE 25: BUILDING ENERGY USE ACROSS PATHWAYS, 2020 AND 2050



The Policy Reference Case and all Pathways experience significant energy use reductions through aggressive energy efficiency measures.

Electrifying heating and domestic hot water systems has the potential to provide immediate emissions benefits in efficient buildings.

Applying the average 2019 NYC grid emission factor to energy efficient buildings shows that the installation of highly efficient ASHPs provides key building emissions benefits relative to adopting high-efficiency fossil natural gas boilers today, even with a majority fossil-fueled generation electric grid. This outcome does not account for any low carbon gas that could be used for heating in the future.

This analysis used an average emissions factor, which is the quantity of emissions produced over the course of one year divided by the amount of energy produced over the same period. Other studies may instead use

g *New Efficiency: New York* energy efficiency requirements, including a 185 tBtu end-use energy savings target for buildings and industrial facilities.

a marginal emissions factor, which refers to the rate at which emissions change in response to a small shift in electricity load. A marginal emissions factor is particularly valuable when the power plant responding to those shifts in electricity load is significantly less or more emitting than the average generation mix, and in estimating avoided or reduced emissions from discrete measures. An average emissions factor is useful when large-scale changes to energy systems lead to uncertainty about how exactly the electricity system would operate in response to those changes. Use of the average emissions factor also aligns with existing City carbon accounting approaches for LL97 and the Greenhouse Gas Inventory. Given the tradeoffs between these two approaches and the scale of building sector transformation evaluated in this study, additional analysis is required to more explicitly quantify the benefits of electrification as the generation mix changes over time.

Building retrofits are capital intensive but they help manage rising delivered energy costs.

Building sector costs, which include retrofit cost, new construction cost, and delivered energy cost, comprise the most significant portion of costs in the Pathways analysis. Retrofit cost includes the purchase and implementation of energy efficiency measures, and electric and gas-powered heating and DHW equipment. New construction cost includes baseline construction cost and cost to meet energy savings targets required by code. Delivered energy cost includes building electricity, natural gas, fuel oil, and steam consumption multiplied by each fuel's delivered unit cost.

Retrofit costs in particular can vary significantly depending on the specific retrofits being implemented. For example, electrified heating equipment like ASHPs are generally more expensive than their gas-fired boiler counterparts; therefore, in most cases, buildings implementing electrified space and water heating end uses are slightly more expensive to retrofit per square foot. Installing electrified heating systems in a 1-4 family home with Tier 1 energy efficiency retrofits could cost 1.5 times more per square foot than installing a gas boiler.[h] In a multifamily post-war building greater than seven stories also adopting Tier 1 energy efficiency retrofits, it could cost 2.5 times more per square foot to electrify.

Building typology and specific building characteristics also impact capital retrofit costs. Because commercial buildings have more complex systems and larger area, on average, it costs seven times more per square foot to upgrade heating, cooling, and DHW systems and implementing Tier 1, Tier 2, and recladding energy efficiency packages compared to a 1-4 family home implementing the same retrofits. The average multifamily building is more likely than the average commercial building to have existing through-wall or packaged terminal air conditioning systems,[i] a feature that can make electrification of building systems less costly and less technically demanding. Additionally, buildings with higher window density spend more on major energy efficiency upgrades than buildings with fewer windows per square foot.

Thoughtful timing of energy efficiency upgrades and building heating system replacement can help manage capital costs. In this study, energy efficiency was implemented simultaneously with the replacement of heating systems. This reduces the overall capacity necessary for the new system, thereby reducing equipment and related costs. Savings on electric space and water heating equipment were projected to exceed 50%[j] in residential homes that adopt Tier 2 energy efficiency and recladding compared to one with only Tier 1 energy efficiency. Including Tier 2 energy efficiency measures in the multifamily, pre-war, up to seven stories typology can reduce heat pump equipment costs by 15% because smaller capacity equipment can be used.[k]

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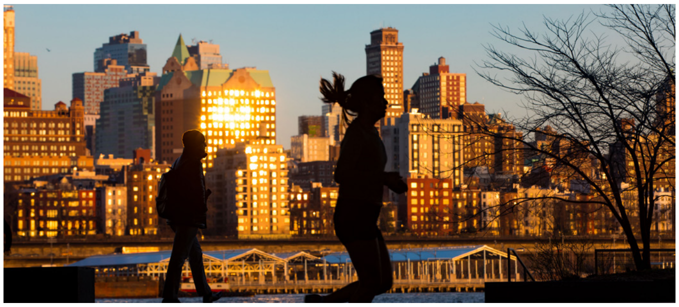
h A gas boiler in a 1-4 family home with Tier 1 energy efficiency retrofits costs $8.45 per square foot versus $5.75 per square foot for electrified heating in the same home.

i Through-wall air conditioners appear similar to window-mounted air conditioners but are installed in a space cut into an exterior wall. Packaged terminal air conditioners are self-contained systems that often look similar to an enclosed radiator with a vent. These systems typically vent to the outdoors via a cutout below a window, which is often covered with a metal grill.

j Installing a heat pump and electric water heater for a small, free-standing residential home was projected to cost $20,034 for a home with Tier 1 energy efficiency measures but only $9,275 for a home with Tier 1 energy efficiency, Tier 2 energy efficiency, and recladding. Tier 1 energy efficiency measures were projected to cost $5,300, Tier 2 energy efficiency measures to cost $33,700, and recladding to cost $5,400.

k An ASHP system with mini-splits is assumed to cost $215,000 to purchase and install in a building with Tier 1 energy efficiency measures and $150,000 to purchase and install in a building with Tier 1 and Tier 2 energy efficiency measures.



In the Pathways, delivered energy costs are anticipated to 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.

Careful attention must be paid to managing energy costs, especially for low-income New Yorkers who already face significant energy cost burden. In 2017, 19% of New Yorkers were living in poverty, 43% were at or below 150% of the poverty level,[94] and nearly 610,000 families (18% of all NYC families) were burdened with energy expenditures in excess of 6% of household income.[95] The COVID-19 pandemic has undoubtedly exacerbated household financial challenges. Ensuring equitable access to cost-saving energy efficiency retrofits for all New Yorkers is a cornerstone of a just energy transition (Box 8).

Careful attention must be paid to managing energy costs, especially for low-income New Yorkers who already face significant energy cost burden.

Box 8: NYCHA Retrofit Demonstration Project

In January 2020, the NYC Housing Authority (NYCHA) announced a request for proposal for a first-of-its-kind deep energy retrofit demonstration project as part of the State's RetrofitNY program.[96]

The demonstration project must meet the following requirements:

- achieve GHG targets as required by LL97;
- approach or achieve net-zero energy performance;
- exclude the use of fossil fuels on-site;
- be standardized, scalable, and significantly compress costs at scale;
- improve resident comfort and quality of life, as well as the building aesthetic;
- be installed with minimal resident disturbance and on-site construction period; and
- deploy an offsite manufactured panelized envelope treatment.

This project will serve as a prototype for NYCHA's housing portfolio of more than 2,500 buildings and for all NYC multifamily buildings, demonstrating emissions reduction and non-energy retrofit benefits. Best practices and lessons learned for engineers and building operators will emerge from the selection of building system equipment, energy efficiency upgrades, and other building materials. Construction crews and project planners may uncover opportunities to reduce disruption. The promise of future retrofit efforts will push companies to develop innovative, scalable, and cost-effective building systems and treatments.

Technologies that can help manage peak electricity demand in the winter can have vital roles in a future with higher rates of electrification.

Electrification across all Pathways can increase winter electric peaks on the coldest days when heating is most critical. Absent management, winter electric peak loads in the Electrification Pathway more than double in 2050, triggering upgrades and expansions of the electric grid. Implementation of technologies and policies that can help manage winter peak demand will therefore be indispensable as more building systems electrify. Demand management, demand response, and distributed energy resources (DER) will be needed to actively manage peaks and minimize associated system costs and related electricity cost increases. Such measures could include:

- **tariff design:** widening various types of dynamic pricing, such as peak and off-peak pricing, critical peak pricing, and real time pricing;
- **DERs:** deploying distributed energy resources such as solar photovoltaics (PV) combined with battery storage, standalone building scale battery storage, thermal storage, vehicle-to-grid (V2G) systems, and combined heat and power (CHP);
- **gas heat pumps:** using gas-fired systems in a fraction of the building stock;
- **dual fuel heating systems:** maintaining gas-fired heating systems in buildings that retrofit with electric systems. These buildings would operate with electric heating systems but use the gas-fired systems during electric peak load hours; and
- **managed vehicle charging:** encouraging vehicle charging at times when electricity demand is otherwise low.

While the above list provides many examples of ways to reduce the peak, managed vehicle charging, dual fuel heating systems, and gas heat pumps were explicitly modeled within the Electrification Pathway and the Diversified Pathway as a proxy to show what could be achieved through targeted peak demand management measures (see Figures 35-37).

Dual fuel heating systems use efficient electric heat pumps for most hours of the heating season but during the coldest hours, the system switches over to a fuel-fired heating source. The model assumed that the switchover to a fuel-fired heating source would occur at below 10˚F. Dual fuel heating systems can often keep existing fuel-fired equipment and systems in place, using controls to switch from electric to fuel systems.

This study assessed impacts to peak demand if dual fuel heating systems replaced ASHPs in 6% of the city's building stock. Fuel switching from electricity to gas during very cold weather reduces peak winter electric demand by 7% (from 15.5 to 14.5 GW) in the Electrification Pathway. This winter peak reduction is equivalent to the contribution of one of the Indian Point Energy Center's nuclear generating units.[97] This would translate directly into lower build-out and generation costs for the electricity sector and less reliance on peaking generation resources such as renewable natural gas (RNG) and battery storage.

Gas heat pumps use gas-fired engines rather than electric motors to operate, while the vapor compression technology is the same as that used in electric heat pumps. These heat pumps use little to no electricity, relying on gas to meet both heating and cooling needs. The gas heat pump systems modeled in this study are generally more efficient for heating than high-efficiency natural gas boilers. In the Electrification and Diversified Pathways, 2.5% of the building stock adopts gas heat pumps, while 4.5% of the building stock does so in the Low Carbon Fuels Pathway. This implementation option could further reduce electric heat pump contribution to winter peak demand.

While not incorporated into the modeling, the impact of other peak reduction measures was also quantified. For example, if half of the electric resistance hot water heaters in use in 2050 in the Electrification Pathway (~1.6 million heaters) were made controllable (i.e., had the ability to shift the heating of water to off-peak hours), peak winter electric demand could decrease by roughly 450 MW in 2050.

These examples represent only a handful of possible peak load management options available and showcase potential peak reductions from measures that are considered feasible in the near term. Box 9 discusses existing demand management programs in NYC. More sophisticated and responsive new measures will likely materialize in the coming decades from ongoing equipment and control systems innovation. Going forward, a more systematic assessment of these and other options will be needed, including more granular geographic and time-dependent analysis of demand management opportunities, as well as an evaluation of how a portfolio approach that includes a variety of technologies, policies, and pricing approaches could mitigate peak demand while minimizing costs.

Box 9: Current Con Edison and National Grid Demand Management Programs

Both Con Edison and National Grid have established an energy efficiency program portfolio for their electric and gas customers with a focus on the commercial, multifamily, and 1-4 family segments. Programs include incentives across the supply chain to customers, retailers, developers, and contractors; energy audits; and educational materials about energy efficient products and services. The utilities collaborate with New York State Energy Research and Development Authority (NYSERDA) on energy efficiency to ensure that their programs and services are well coordinated, and each organization's efforts effectively encourage the adoption of energy efficiency measures.

In addition to energy efficiency, both National Grid and Con Edison continue to expand demand management efforts. Demand management projects enable customers to receive the energy services they need while deferring or avoiding large capital expenditures on additional wires or pipelines. Con Edison has developed an assessment tool to determine which combination of energy efficiency, demand response, customer-sited generation, and/or energy storage measures are right for given customer segments.[98] Combined portfolios of these types of projects coordinated by the companies are known as "non-wires solutions" (NWS) and "non-pipeline solutions" (NPS) for electricity and natural gas, respectively.

National Grid has implemented a portfolio of gas demand response programs that are designed to meet customer energy needs in lieu of traditional gas supply infrastructure projects. The portfolio of gas demand response programs was developed to achieve a combination of daily and hourly gas reductions. Programs range from those geared towards eight-hour gas reductions from large commercial and industrial customers to shorter duration events for residential customers.

Distributed energy resources have already been used in the city to mitigate peak capacity constraints in the first NWS portfolio, known as the Brooklyn Queens Demand Management Program. Con Edison has invested nearly $120 million to date to defer the peak capacity constraints of three networks, utilizing customer-sited solutions in the form of battery storage (4.3 MW), fuel cells (6.5 MW), CHP (2.8 MW), and solar (400 kW) facilities, deferring the need to invest $1.2 billion in the development of a substation and traditional grid infrastructure upgrades. This process has been expanded to two other areas of the city through the Water Street and Newtown NWS portfolios.

Use of low carbon gases in the buildings and industrial sector could provide emissions benefits today as well as valuable system benefits.

In the industrial sector, adoption of electrified end uses is not as prevalent as in other building types. Energy use requirements remain high to power industrial processes. Total sector energy use across the Pathways decreases less than 10% between 2020 and 2050. However, the industrial sector realizes significant emissions benefits from the replacement of natural gas with low carbon gases for energy-intensive processes, as well as through high-efficiency heating, cooling, and process equipment installation.

In the Electrification Pathway, replacing existing space heating equipment with electric heat pumps, installing all-electric steam boilers and machine drives, and electrifying direct-fired process heating equipment greatly improves operational efficiency when compared to existing equipment. Electricity sector decarbonization and increased electrification of end uses in the Electrification Pathway decreases industrial emissions by 70% between 2020 and 2050.

In the Low Carbon Fuels Pathway, natural gas use in the industrial sector is almost entirely displaced by low carbon gases by 2050. Nearly all direct process heating, steam boilers, and machine drives are powered by low carbon gases in 2050, and gas heat pumps provide all space heating. These measures also lead to significant emissions benefits; by 2050, emissions fall by 77% compared to 2020.

The industrial sector in the Diversified Pathway benefits from both electricity sector decarbonization via electrified end uses and low carbon gas displacement of fossil gas. Most process equipment and boilers are powered by low carbon gases in 2050; about a quarter of space heating end uses electrify and the rest adopt heat pumps that can leverage low carbon gas. Fuel oil end uses also electrify. Efficiency gains from electrified equipment, displacement of oil end uses, and increased adoption of gas-fired end uses—in combination with increased shares of low carbon gases in the fuel supply and a cleaner electricity supply—reduces emissions in the industrial sector by nearly 90% from 2020 to 2050.

Energy efficiency and heating system retrofits provide substantial non-energy benefits.

Building upgrades provide benefits beyond emissions and energy use reductions. Energy efficiency retrofits can weatherize buildings, which, in addition to saving energy and regulating temperatures, offer other health and household-related benefits. These changes can reduce risk of damage and increase property values. They also reduce the risk of mold growth, allergens, and development of other asthmatic triggers, as well as decrease potential for carbon monoxide poisoning.[99]

Electrification of building end uses can improve local air quality since heating would no longer depend on combustion. Electrifying heating systems can also provide an opportunity to improve the resiliency of the structure. For example, when transitioning from boiler systems, which are often located in building basements, to heat pump systems with outdoor compressors, designers should analyze the placement of this critical infrastructure to reduce vulnerability to flood damage.

The benefits of building heating system upgrades are enhanced when replacing older whole-building, centralized steam or hot water systems, which are common in large multifamily buildings. These older systems make individual apartment temperatures difficult to control. Nearly 70% of NYC tenants in buildings with centralized heating systems report chronic overheating in the winter.[100] To moderate apartment temperatures, even on the coldest days, 63% of those tenants reported opening their windows. In the same buildings, other tenants report chronic underheating. These system imbalances and related energy waste account for 7% of citywide building emissions.[101]

Replacing older systems with unitary, mini-split ASHP systems in these multifamily buildings would allow tenants more control over heating in the wintertime and cooling in the summertime.[102] Such systems can be installed in buildings that lack space for a large, centralized system, and would eliminate the need for separate air conditioning.

The rented building stock faces specific implementation challenges in planning, financing, and managing misaligned incentives between tenants and landlords.

About two-thirds of the housing stock in NYC is rented, as is most of the commercial stock. Buildings with rented units face specific challenges as energy efficiency and electrification efforts progress.

In many cases, renter and tenant incentives to install energy-saving systems do not align. 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. NYC faces some of the highest rental prices in the country. Shifting energy costs from the landlord to the tenant without a commensurate reduction in rent may cause displacement or endanger tenants' health if they cannot afford to heat their home in winter or cool it in summer.

Currently, building owners must also finance upfront costs of energy efficiency and electrification upgrades. In most cases, they could take out a loan or use another financing mechanism to pay off energy-saving equipment costs over time. Owners can socialize these costs across tenants through rent increases. However, in rent-regulated residential apartments and buildings, there are limits to how much rent can be raised. Therefore, it may not be possible for the building owner to recover enough of the upfront cost through rent increases in rent-regulated buildings. Rent regulation is a key mechanism by which affordable housing stock for New Yorkers is maintained, therefore, financing retrofits in these units requires special consideration to ensure housing affordability.

Finally, in-apartment renovation coordination can be logistically complicated. Landlords are required to give sufficient notice to enter an apartment and must work with tenants to determine access dates and times for each residence. Depending on the scope of in-apartment work, the building owner must also coordinate tenant schedules with installation team, construction crew, and technician availability. If some tenants refuse to grant access to their apartments or otherwise push back on upgrades, measures may not deliver projected emissions and energy savings benefits, and project timelines may extend.

Energy efficiency can be a large driver of inclusive economic opportunity.

A significant retrofit effort is not possible without a skilled workforce. Ensuring there is a small business and worker base to implement high quality electrification, establish supply chains, and conduct retrofit work at scale requires new business models and new skills. This retrofit effort can also present new pathways for wealth generation and business development for communities that have faced barriers to economic development.

Analysis from the American Council for an Energy-Efficient Economy and the Federal Reserve Bank of San Francisco estimated the net number of jobs created by investments into energy efficiency (including direct, indirect, and induced jobs) relative to the economywide average created by an equivalent investment. The analysis found energy efficiency creates an average of 20 jobs per million dollars of investment in a year.[103] Today, 61,000 people are employed in the energy efficiency industry across all five boroughs, which accounts for most energy employment in the city (43%).[l,104] HVAC mechanics, laborers, electricians, and other trades receive a wage premium when working in clean energy or energy efficiency compared to other fields. This premium is particularly high for entry-level roles.

l Nearly 37,000 people work in transmission, distribution, and energy storage; almost 20,000 work in electric power generation; and over 19,000 work in the motor vehicle industry. Smaller numbers are employed in the solar industry (4,075) but this is more than twice the number of New Yorkers employed in the wind industry (1,800) and almost twice the number employed in the natural gas electric power generation industry (2,783) in 2019.

Of all energy-related employers in New York State, however, those in energy efficiency reported the greatest difficulty in hiring new employees. In the 2020 U.S. Energy and Employment Report, 26% of energy efficiency employers reported that it was "very difficult" to hire new workers, while 59% found it "somewhat difficult."[105] The top three reasons cited were: 1) lack of experience, training, or technical skills; 2) competition or a small applicant pool; and 3) difficulty finding industry-specific knowledge, skills, and interest.[106] Energy efficiency at the scale modeled in the Pathways analysis is unprecedented and can create a number of job opportunities that require specialized skills and training.

The City has estimated that by 2030 there will not be enough HVAC workers to service the residential ASHP market, a gap of over 5,000 NYC workers.[107] To support a skilled workforce, NYSERDA has committed to invest $100 million in grant funding through 2025 in energy efficiency workforce training and development.[108] This investment enables employers in the clean energy space to train current or new employees. The grants will fund new training courses for current buildings and operations workers, on-the-job training for new clean energy workers, and internships for students. The City has also engaged researchers to identify strategies to support Minority and Women-Owned Business Enterprises and worker-owned business participation in the growing energy efficiency market.

Moreover, the money saved from reduced energy use can be redirected to other sectors of the economy.[109] As the city, state, and nation recover from the economic recession of the COVID-19 pandemic, an increased focus on workforce training in clean energy jobs is another important opportunity to further a just, clean transition to a carbon-neutral economy. With concerted policy efforts and programmatic support, the growing clean energy and energy efficiency economy can open doors to good paying, permanent jobs with strong benefits and safety standards, as well as to business ownership and wealth generation for New Yorkers. Workforce and business development efforts could specifically include communities disproportionately impacted by the pandemic.

As the city, state, and nation recover from the economic recession of the COVID-19 pandemic, an increased focus on workforce training in clean energy jobs is another important opportunity to further a just, clean transition to a carbon-neutral economy.

TRANSPORTATION

New Yorkers already rely on low-carbon options for much of their transportation: walking, biking, and public transportation made up 68% of all trips in 2019.[110] However, decarbonizing on-road transportation, which accounts for 26% of the city's emissions, is a challenge that requires electrifying the vehicle stock and adding new vehicle charging infrastructure. The Pathways assessed decarbonization options for on-road vehicles (including cars, trucks, and buses) and did not address rail transit. Additionally, this study drew upon the reduction in vehicle miles traveled (VMT) from usage of public transit, biking, and walking developed for the City's 2016 *Roadmap to 80x50* report.[111] Across the Pathways, transportation sector emissions decline by 80% or more between 2020 and 2050 as the population of zero-emission vehicles (ZEV) ramps up for all light-duty vehicles (LDV), the city's bus fleet becomes all-electric, and heavy-duty transportation either adopts low carbon fuels or electrifies.

Changing the vehicle fleet at this scale presents logistical challenges. By 2050, three out of four vehicles on the road would be electric. This level of ZEV penetration requires nearly one million vehicle chargers to be deployed across the city, setting up challenges for siting and integration while expanding opportunities to build a smart and responsive electric grid.

TABLE 5: KEY TRANSPORTATION SECTOR FINDINGS FROM THE PATHWAYS MODELING

<table>
<tr><th></th><th>Electrification</th><th>Low Carbon Fuels</th><th>Diversified</th></tr>
<tr><td colspan="4">Personal vehicles, predominately located in outer boroughs, need to be rapidly replaced by ZEVs.</td></tr>
<tr><td>Personal battery electric vehicles owned by New Yorkers in 2050 (compared to 19,000 in 2020 model results)</td><td colspan="3">1,300,000</td></tr>
<tr><td>Personal plug-in hybrid electric vehicles owned by New Yorkers in 2050 (compared to 6,800 in 2020 model results)</td><td colspan="3">230,000</td></tr>
<tr><td colspan="4">Reducing private vehicle usage and replacing gasoline vehicles with more than 1.5 million battery electric vehicles and some plug-in hybrid electric vehicles would reduce 2020 transportation emissions approximately 80% by 2050 and lower costs for vehicle owners.</td></tr>
<tr><td>Annual transportation sector emissions reduced by 2050, compared to 2020</td><td>85%</td><td>79%</td><td>85%</td></tr>
<tr><td>Annual fuel and maintenance costs reduced by 2050, compared to 2020*</td><td>18-37%</td><td>12-25%</td><td>18-37%</td></tr>
<tr><td colspan="4">Cutting GHG emissions from medium-duty vehicles (MDV) and heavy-duty vehicles (HDV) can depend on either electrifying or increasing low carbon fuel availability.</td></tr>
<tr><td>Electric MDV and HDV population by 2050 (compared to 1,500 in 2020 model results)</td><td>101,000</td><td>19,000</td><td>101,000</td></tr>
<tr><td>Renewable diesel and biodiesel consumption in 2050 (in gallons of gas equivalents)</td><td>1 million</td><td>110 million</td><td>1 million</td></tr>
<tr><td colspan="4">Improved vehicle efficiency and active transportation alternatives play an important role in reducing on-road emissions.</td></tr>
<tr><td>Average internal combustion engine vehicle (ICEV) efficiency by 2025 (compared to 28 mpg in 2020 model assumption)</td><td colspan="3">36 mpg</td></tr>
<tr><td>Light-duty VMT reduced due to expanding public transit (compared to 23 billion miles traveled per year in 2020 model results)</td><td colspan="3">2 billion</td></tr>
<tr><td>Light-duty VMT reduced due to expanding biking and walking (compared to 23 billion miles traveled per year in 2020 model results)</td><td colspan="3">300 million</td></tr>
<tr><td colspan="4">Deployment and management of vehicle charging infrastructure is critical for making electrified transportation possible at scale.</td></tr>
<tr><td>Residential Level-2 ZEV chargers in 2050 (compared to 1,052 in 2019)</td><td colspan="3">780,000</td></tr>
<tr><td>Direct current fast charging (DCFC) stations in 2050 (compared to 92 in 2019)</td><td>60,000</td><td>11,000</td><td>60,000</td></tr>
<tr><td>Gigawatt-hours (GWh) consumed by electric LDVs, MDVs, and HDVs in 2050 (compared to 88 GWh in 2020 modeling results)</td><td>6,100 GWh</td><td>3,900 GWh</td><td>6,100 GWh</td></tr>
</table>

** The range in cost savings reflects the range in potential electricity prices; the lower end uses the high bound of electricity costs, assuming a 3% growth per year, while the higher end uses the low range of electricity costs based on the Pathways modeling.*

Personal vehicles, predominately located in outer boroughs, need to be rapidly replaced by ZEVs.

There are high rates of ZEV sales assumed in every Pathway: 80% of new LDV sales are electric by 2040, 85% of which are battery electric vehicles (BEV) and 15% are plug-in hybrid electric vehicles (PHEV) (Figure 26) (Box 10).[m]

Box 10: PHEVs and BEVs Can Both Lower Emissions and Reduce Costs

Battery electric vehicles (BEV) have a fully electric drivetrain and plug-in hybrid electric vehicles (PHEV) use both a battery and another fuel (e.g., gasoline or diesel).[112] Both are commercially available options for the LDV fleet. As of 2019, there were 880,000 BEVs and 570,000 PHEVs in the United States.[113] BEVs may be attractive to individuals who commute short distances and have access to vehicle charging at home and/or their destination. PHEVs, which are generally less expensive, may be favorable to drivers who are averse to BEVs due to concerns of range limits and charging station availability. In nearly all cases, a BEV has lower emissions than a PHEV over the life of the car given the remaining fossil fuel use in PHEVs and given the anticipated greening of the grid.

In the Pathways, the adoption of ZEVs was assumed to ramp up between 2020 and 2040; by 2040, 80% of all new LDV sales are ZEVs. Of the light-duty ZEV sales, 85% are BEVs and 15% are PHEVs. By 2050, 63% of all LDVs are fully electric and 11% are hybrid electric. To understand the impacts of deploying a greater number of PHEVs, a high PHEV scenario separate from the Pathways was modeled that flipped the proportion of BEVs and PHEVs sold. The high PHEV scenario assumed 20% of light-duty ZEV sales are BEVs and 80% are PHEVs, resulting in 60% PHEVs in the total NYC vehicle population in 2050. Up to 80% of miles driven with PHEVs were assumed to be electric powered by 2030 with the remaining 20% supplied by gasoline. Achieving this level of electric miles traveled with PHEVs necessitates a rapid expansion of public and private charging infrastructure, similar to the expansion needed for fully BEVs.

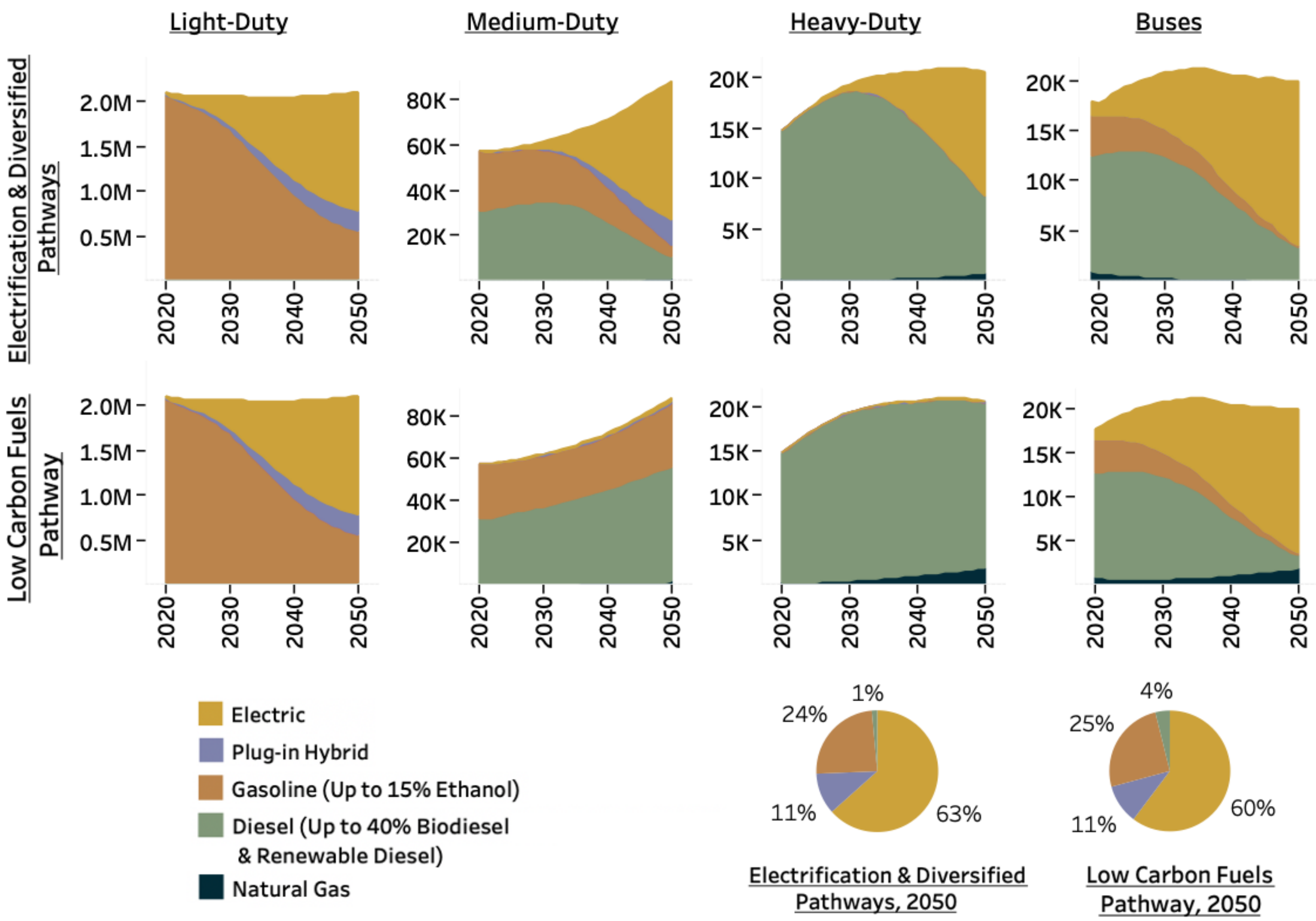
The high PHEV scenario reduces LDV emissions over 80% compared to 2020. Compared to the Electrification Pathway, which has the same number of ZEVs but a different composition of PHEVs and BEVs, the high PHEV scenario has 34% more emissions in 2050. While PHEVs have higher emissions due to gasoline use, both PHEVs and BEVs can be used to meet emissions targets. In addition to the emissions benefit broadly, the benefits of PHEVs to the consumer can be significant. Compared to traditional ICEVs, PHEVs can reduce maintenance costs by a sixth and cut fuel costs by half.[114] Compared to BEVs, PHEVs tend to cost less up front, although this can be affected by the availability of tax credits.[115]

While Manhattan residents mostly rely on the subway and walking, 90% of vehicles registered in NYC are to households in the outer boroughs[116] that use cars at higher rates to get around town and back home.[117] The case for converting these vehicles to electric is strong: most vehicle trips are under five miles and the outer boroughs have greater availabilities of garage and driveway parking where chargers can be integrated.[118]

Access to vehicle charging infrastructure for households that adopt ZEVs requires rapid deployment and thoughtful placement of chargers. For those living in older buildings, the process of installing a ZEV charger is more expensive if the building electrical system is out of date and needs to be brought up to code. This cost could be more prohibitive than the cost of the ZEV, while a ZEV owner in multifamily housing may have limited influence to install a charger. Multifamily housing is also space-constrained and there is frequently no or very limited on-site parking available for residents. The City has ZEV readiness legislation that mandates that 20% of parking spots in most new parking facilities should have the conduit and electrical capacity to support charging, as per Local Law 130 of 2013.

m A zero-emission vehicle (ZEV) is a vehicle which is eligible for New York State's Zero Emission Vehicle Credit, which includes BEVs, PHEVs, fuel cells, and other vehicle types with very low emissions.

FIGURE 26: VEHICLE FLEET COMPOSITION, 2020-2050



ZEVs are rapidly deployed in all Pathways. MDVs and HDVs 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.

The switch to electric cars must be nearly as rapid as the transportation transformations of the 20th century. Over the 30-year span between 1900 and 1930, gasoline-powered vehicles went from a rarity to the dominant form of personal transportation in the United States. Over the next 30-year span from 2020 to 2050, NYC can meet its emissions reduction targets by reducing the number of passenger vehicles using gasoline from 110 to 30 per thousand people and increasing BEVs from 0.3 to 70 per thousand people. A century ago, BEVs were more prominent than cars running on gasoline. Similar to today, BEVs were preferable for those in the city who only needed cars for a short range; they operated with less noise, less pollution, and less maintenance. While internal combustion engine vehicle (ICEV) technology eventually displaced BEVs, the revival of electric transportation shares the same promise of the past: a cleaner way to get around.[119]

As the vehicle fleet transforms, there are significant opportunities to improve public health and local air quality if ZEVs are deployed widely. In particular, vehicle electrification would reduce emissions of fine particulate matter ($PM_{2.5}$), a harmful pollutant responsible for asthma, cardiovascular disease, and respiratory complications. The effects of roadway pollution, especially asthma rates, tend to affect communities of color at higher rates.[120] $PM_{2.5}$ and other pollutants can compound negative health effects, especially for communities burdened by other environmental stressors. A reduction in $PM_{2.5}$ could avert hundreds of premature deaths and hospital visits due to asthma and cardiovascular issues. In this analysis, the Pathways with the highest rates of vehicle electrification have the greatest reduction in $PM_{2.5}$ (Box 11).

Box 11: Air Quality and Public Health Benefits of the Clean Energy Transition

Climate change threatens to exacerbate structural inequities of cost, access, environmental degradation, and air quality pervasive in the modern energy system. Fortunately, the policies aimed at addressing GHG emissions and their impacts on frontline communities can improve the quality of life of all New Yorkers.

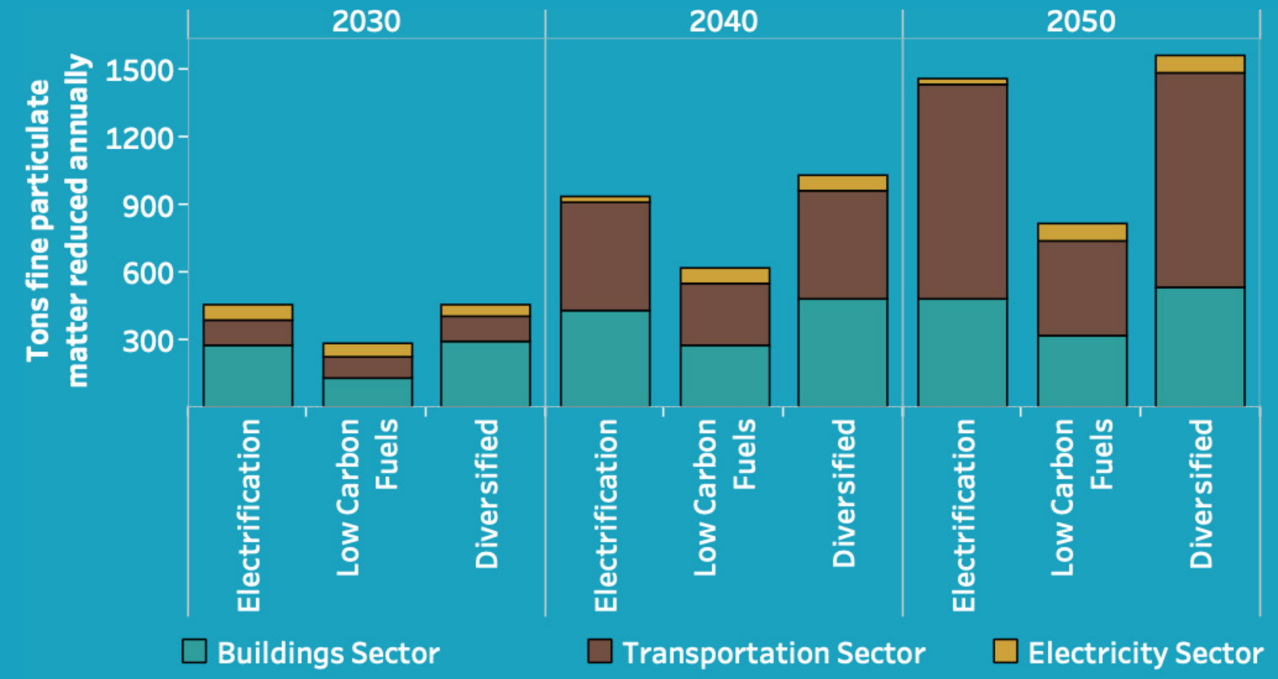
Poor air quality attributable to the combustion of fossil fuels for transportation and power generation is a public health imperative that disproportionately affects communities of color and low-income communities in NYC.[121,122] Tailpipe emissions, especially those from heavy-duty diesel vehicles traveling on commercial routes located in and around low-income communities, cause asthma and respiratory illnesses and exacerbate existing heart and lung conditions.[123] The City has a number of programs to reduce such emissions. The Hunts Point Clean Truck Program has incentivized replacing or upgrading more than 622 older diesel trucks[124] and has expanded to cover more Industrial Business Zones with high truck pollution.[125] The City has also adopted commercial waste zoning for high-quality, low-cost waste management that will cut truck traffic for commercial waste transfer by over 50% as well as support zero waste and transportation efficiency.[126]

Power plants using fossil fuels also present local air quality issues in low-income communities of color such as Queens, the South Bronx, and Sunset Park. Energy efficiency, new transmission lines to connect out-of-city generation, battery electric storage, and other strategies can reduce emissions and reduce the use of fossil-powered plants in NYC.[127] The NYS Department of Environmental Conservation's (NYSDEC) Peaker rule, which sets nitrogen oxides (NO_x) emission caps for peaking plants (i.e., power plants that operate intermittently to provide power during peak electricity demand), effective in 2023 and 2025, will reduce the impacts of in-city peakers in the near term.[128]

Assessing the Health Benefits of Reducing Air Pollution

The NYC Department of Health and Mental Hygiene quantified the health benefits of reductions in fine particles ejected into the air from fuel combusted in power plants, buildings, and vehicles, as well as vehicle tire and brake dust. In all Pathways, emissions of $PM_{2.5}$ decline relative to the Policy Reference Case (Figure 27). The benefits are greatest in the Electrification and Diversified Pathways in which most MDVs and HDVs are electrified rather than reliant on low carbon fuels. A reduction in $PM_{2.5}$ is just one of many health and environmental benefits of a low-carbon energy transition—other local air pollutants will also decline but were not modeled.

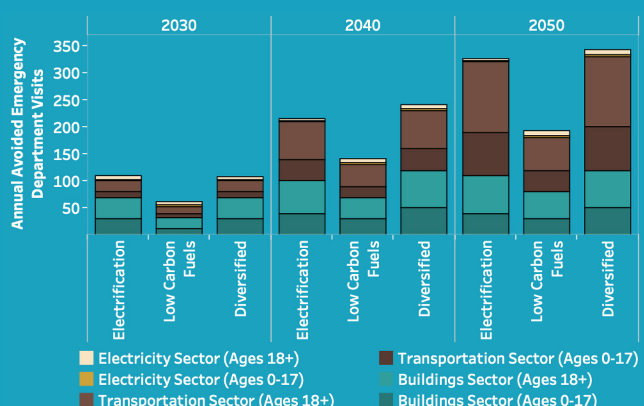
FIGURE 27: ANNUAL REDUCTIONS IN $PM_{2.5}$ EMISSIONS IN THE PATHWAYS, SELECT YEARS



The measures to reduce GHG emissions in the Pathways also reduce $PM_{2.5}$ emissions. This figure shows the $PM_{2.5}$ emissions reductions in the Pathways relative to the Policy Reference Case. Reductions are greatest in the Electrification and Diversified Pathways in which most MDVs and HDVs are electrified rather than reliant on low carbon fuels.

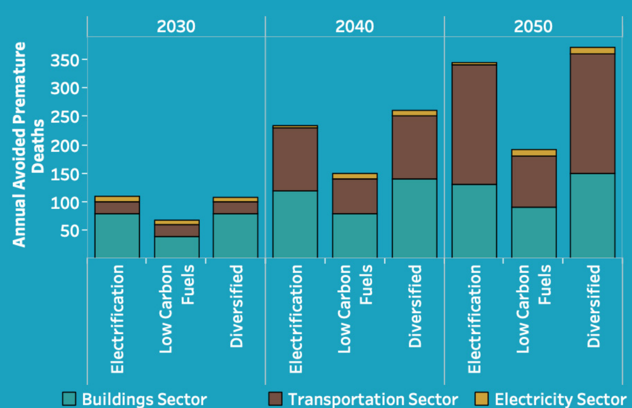
$PM_{2.5}$ emissions reductions were estimated to reduce asthma-related emergency department visits among adults and children by as many as 350 annually (Figure 28). The improved air quality could also avert premature deaths across the city, ranging from roughly 200 to 350 annually by 2050 (Figure 29).

FIGURE 28: ANNUAL AVOIDED ASTHMA EMERGENCY DEPARTMENT VISITS, SELECT YEARS



Relative to the Policy Reference Case, the Pathways could reduce asthma-related emergency department visits in NYC by more than 300 per year by 2050, with the largest contribution stemming from reduced $PM_{2.5}$ emissions from the transportation sector.

FIGURE 29: ANNUAL AVOIDED PREMATURE DEATHS BY ADULTS (25+), SELECT YEARS



Relative to the Policy Reference Case, more than 350 premature deaths annually could be avoided by 2050 in the Pathways with the highest rates of vehicle and buildings electrification.

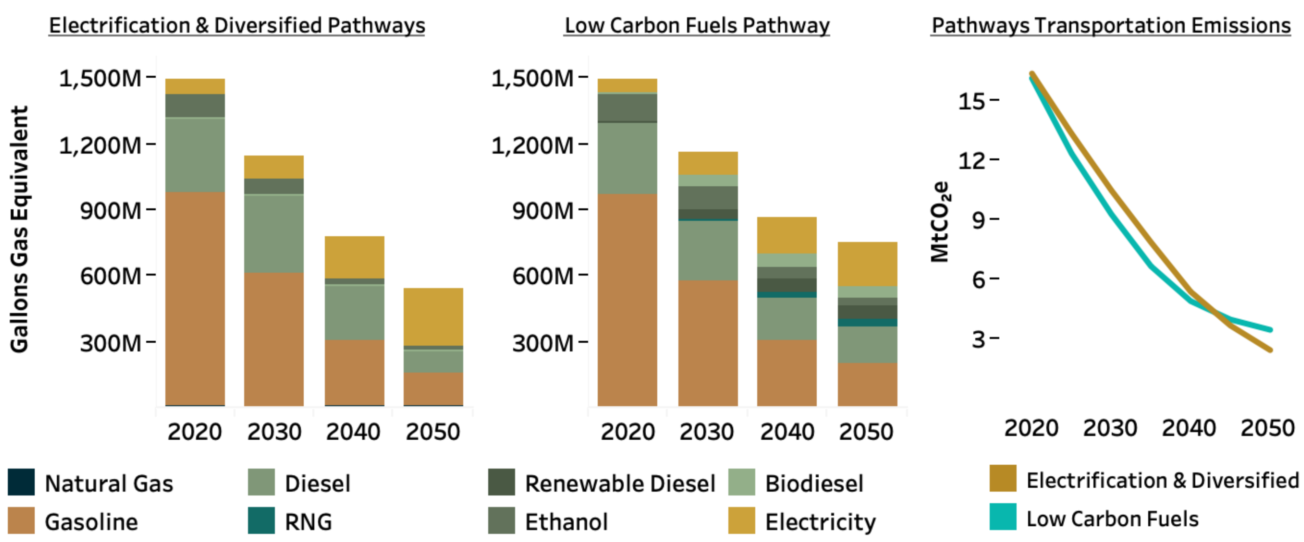
Reducing private vehicle usage and replacing gasoline vehicles with more than 1.5 million battery electric vehicles and some plug-in hybrid electric vehicles would reduce 2020 transportation emissions approximately 80% by 2050 and lower costs for vehicle owners.

While vehicles electrify, the investments made to decarbonize the grid reduce the emissions intensity of the average kilowatt-hour (kWh) of electricity. As a result, emissions decrease for the transportation sector. The annual on-road emissions are reduced 85% by 2050 compared to 2020 emissions in the Electrification Pathway and Diversified Pathways. The annual emissions are slightly higher in the Low Carbon Fuels Pathway, with a 79% reduction in emissions compared to 2020 (Figure 30).

ZEVs use energy more efficiently than ICEVs and require less maintenance.[129] In 2019, a new BEV had an equivalent fuel efficiency of 96 miles per gallon, compared to a new ICEV that had 28 miles per gallon. As the vehicle fleet transforms to become predominantly electric and VMT from LDVs decreases by 17%, total energy use falls rapidly. Overall, in the Electrification and Diversified Pathways, energy use falls over 60% for all cars, trucks, and buses. The Low Carbon Fuels Pathway, which electrifies MDVs and HDVs at a lower rate, has 7% higher total energy use.

As a result of lower energy use per mile, ZEVs typically have lower fuel costs compared to traditional ICEVs,[n] as well as lower maintenance costs because of simpler drivetrains. Accordingly, ZEVs have lower lifetime costs than traditional ICEVs, despite having higher upfront costs.[130]

FIGURE 30: TRANSPORTATION FUEL CONSUMPTION AND EMISSIONS, 2020-2050



Transportation fuel consumption falls across all Pathways, driven by improved fuel efficiency of all vehicle types, the higher intrinsic energy efficiency of ZEVs, and 17% reductions in VMT. Emissions fall at roughly the same rate in all Pathways.

n The relative fuel prices for ZEVs depends on local gas prices, electricity prices, and the fuel economy of the ICEV being compared. These factors are all subject to change considerably over the course of the next thirty years.

Cutting GHG emissions from MDVs and HDVs can depend on either electrifying or increasing low carbon fuel availability.

There are two main avenues for reducing GHG emissions from MDVs and HDVs: electrify or use low carbon fuels. Both avenues have hurdles to widespread commercialization, so both options were included in the Pathways. Electrification relies on technology that is not yet deployed at scale for large drivetrains. Some low carbon fuels, such as high blends of biodiesel (over 20%), require adapted distribution infrastructure and fueling station renovations.

In the Electrification Pathway, 80% of MDVs and over 60% of HDVs are electric as of 2050. The rest are assumed to use non-renewable fuels. In the Low Carbon Fuels Pathway, diesel supply is assumed to be blended with 20% biodiesel and 20% renewable diesel by 2035, yielding diesel supply that is 40% low carbon fuel.[o] Additionally, gasoline is blended with 15% ethanol by 2025 but this is used predominately in LDVs. Also in the Low Carbon Fuels Pathway, the small number of natural-gas-powered vehicles were included and fully supplied by biogenic RNG.

The availability of technology affects the pace of emissions reductions across the Pathways. Emissions decline faster for MDVs and HDVs in the Low Carbon Fuels Pathway, which uses biofuels, as compared to the Electrification Pathway which instead relies on higher rates of electric MDVs and HDVs.[p] Emissions for MDVs and HDVs fall over 30% in the Low Carbon Fuels Pathway by 2035, whereas they only fall by 10% by 2035 in the Electrification Pathway. By 2050, as medium- and heavy-duty ZEVs penetrate the market, emissions for MDVs and HDVs are lower in the Electrification Pathway than the Low Carbon Fuels Pathway.

The public health benefits from electrifying vehicles are greatest when medium- and heavy-duty transportation are electrified. In 2017, transportation accounted for 14% of total citywide $PM_{2.5}$ emissions. Of that, emissions from HDVs accounted for 34% of transportation emissions, while LDVs contributed 12%. About half of transportation sector $PM_{2.5}$ emissions come from brake and tire dust, which is created by ICEV and ZEV alike.[q,131] For reference, MDVs and HDVs make up about 2% of all vehicles and about 10% of all VMT. In the Electrification and Diversified Pathways, $PM_{2.5}$ emissions in the transportation sector fall 50%. The Low Carbon Fuels Pathway reduces $PM_{2.5}$ emissions in the transportation sector 17%. All Pathways reduce negative health outcomes associated with $PM_{2.5}$, including avoiding unnecessary deaths.

The placement of charging stations and the charging patterns of MDVs and HDVs present separate challenges. Managed charging needs to accommodate the use patterns of MDVs, HDVs, and buses, no matter whether it is providing local delivery, running a tightly scheduled bus route, or transporting city waste. Balancing the need of local vehicle use patterns and grid charging capabilities will be an ongoing practice in logistical coordination.

In addition to the technological and logistical constraints, electric MDVs and HDVs will also depend on regional infrastructure to connect supply chains outside of NYC. Efforts to expand the availability of charging infrastructure for medium- and heavy-duty transport can help solve the perennial "chicken and egg" problem faced by ZEVs. However, even with advances in ZEV technology, some types of MDVs and HDVs are especially difficult to decarbonize due to long duty cycles and heavy payloads. In these cases, low carbon fuels are currently the only technically feasible option to reduce GHG emissions.

Although they were not modeled in the Pathways, emissions from off-road vehicles, including marine and aviation transportation, were assumed to fall 80%. While these emissions were just 5% of the city's total transportation emissions in 2019, the opportunities to decarbonize remain uncertain.[r] The subway system is already electrified and will benefit from a cleaner grid. Electrification of aviation and marine transportation rely on technology still in the research and development phase, and biofuels for off-

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o Biodiesel is a fatty acid methyl ester that can be synthesized from vegetable oils, waste oils, fats, and grease. Biodiesel is generally used in low-level blends. Renewable diesel can be produced from the same biomass used to make biodiesel or other sustainable biomass feedstocks but via different production approach that creates fuel that meets the specification requirements of fossil petroleum diesel.

p Biodiesel and renewable diesel are assumed to have a small fraction of the carbon intensity of regular diesel. Only operating emissions of methane and nitrous oxide are counted for in these alternative fuels, which are less than 1% of the GHGs from combustion.

q Transportation sector $PM_{2.5}$ emissions do not include construction activities, off-road transportation, maritime transportation, or industrial vehicles.

r The Greenhouse Gas Inventory for New York City does not include emissions related to aviation and it does not account for indirect emissions, such as the emissions of vehicles that pass through the city but are not registered in NYC.

road transportation do not cut carbon emissions to the same extent as electrifying. Opportunities to decarbonize off-road transportation for the context of NYC deserve further examination.

Improved vehicle efficiency and active transportation alternatives play an important role in reducing on-road emissions.

Current federal standards for LDV efficiency expire at the end of 2025. By then, the efficiency of ICEVs was assumed to improve approximately 27% compared to 2019. The Pathways assumed efficiency improvements continue after federal standards expire, increasing fuel economy 52% relative to 2019 by 2050. In 2050, a new light-duty ICEV in the Policy Reference Case has a fuel economy of 36 miles per gallon, which avoids approximately 35% of on-road emissions relative to a vehicle purchased in 2019. In the Pathways, an efficient light-duty ICEV has a fuel economy of 43 miles per gallon. However, even the most efficient vehicles emit far more than ZEVs as the electricity grid becomes cleaner.

In addition to improved efficiency, vehicle use is reduced in the Pathways in favor of more sustainable modes of transportation. In each Pathway, total VMT[s] for LDVs are assumed to fall 16% by 2050 relative to 2020, while the Policy Reference Case has a 7% increase in light-duty VMT. The reduction in VMT assumes New Yorkers rely more heavily on public transit, walking, biking, and shared mobility. Based on the modeling performed in the City's 2016 *Roadmap to 80x50* report,[132] the Pathways reduce light-duty VMT 17% by2050 compared to 2020. Expansion of and improved access to public transit account for 40% of light-duty VMT reduced, or about two billion miles per year; expanded walking and biking account for 6% of light-duty VMT reduced, or approximately 300 million miles per year. Other policies, such as congestion pricing and shared transportation, further reduce VMT. Many policies and programs could support cleaner transportation options, such as low-cost active mobility options. Large-scale infrastructure investments could also include expanding transit service.

VMT reduction plays an important role for public health as well. In addition to lower tailpipe emissions, reducing VMT can also lower $PM_{2.5}$ emissions from brake and tire dust, which are still produced by ZEVs. In 2017, road dust made up nearly half (47%) of $PM_{2.5}$ emissions in the transportation sector in the city.[133] Active modes of transportation, including

> Active modes of transportation, including biking and walking, provide numerous environmental, health, and lifestyle benefits. Switching from car travel to active transportation has the benefit of encouraging healthy lifestyles and is linked with lower rates of obesity and diabetes.

s Total VMT are a function of the total number of vehicles on the road and the average number of miles driven. For example, if there are 5% more cars and no change in driving behavior, VMT increase 5%.

biking and walking, provide numerous environmental, health, and lifestyle benefits. Switching from car travel to active transportation has the benefit of encouraging healthy lifestyles and is linked with lower rates of obesity and diabetes.[134]

Switching the "last mile" of delivery services from vans and trucks to bicycles can also help reduce VMT in the city. The City launched the Cargo Bike Program in conjunction with UPS, Amazon, and DHL to increase the number of deliveries made by bike. On a typical day, there are over a million freight trips passing through the city and over two million deliveries made.[135] Integrating cargo bikes into the supply chain can reduce emissions, decrease traffic congestion, and improve local air quality.

Deployment and management of vehicle charging infrastructure is critical for making electrified transportation possible at scale.

Deployment of vehicle charging stations will be an infrastructure and logistics challenge. Over 900,000 charging stations—both public and private—are needed to support 1.5 million ZEVs in the city by 2050. About 800,000 of those stations are needed for public and private LDV charging. In the Electrification Pathway, where medium- and heavy-duty transport is electrified, there are about 60,000 chargers needed. MDVs and HDVs rely on direct-current fast chargers (DCFC) that are much more expensive than chargers typically used for LDVs. LDVs also use DCFC chargers but predominately rely on Level 1 and Level 2 chargers. As of 2019, there are over 1,000 Level 2 chargers and 92 DCFC chargers in the city.[136] Level 1 chargers, which were not analyzed in the Pathways, rely on a standard 120 Volt outlet, while Level 2 chargers use a higher voltage and therefore have higher installation costs. A Level 2 residential ZEV charger costs about $1,200 to install. Based on NYC Department of Transportation bids for DCFC infrastructure across four locations conducted in 2019, a DCFC charging station can cost up to $250,000 to install.

Taxis and for-hire vehicles (FHV) present separate challenges for charging infrastructure due to their recent growth and importance to New Yorkers' mobility. The number of FHVs on the road has tripled between 2010 and 2019, and taxis and FHVs combined make up 30% of traffic during peak hours of travel.[137] The decentralized nature of FHVs requires more on-road charging stations, as drivers need fast, on-the-go charging. Box 12 discusses ZEV charging programs currently underway in NYC.

Box 12: NYC Electric Vehicle Charging Programs

NYC has committed to investing $20 million in charging infrastructure citywide, with $10 million allocated to charging the City's fleet—the largest municipal fleet in the nation— and plans to install at least 50 direct-current fast chargers (DCFC) for public use.[138] The commitment will help fulfill Governor Cuomo's "ZEV Make Ready" initiative to build 50,000 new charging stations.[139]

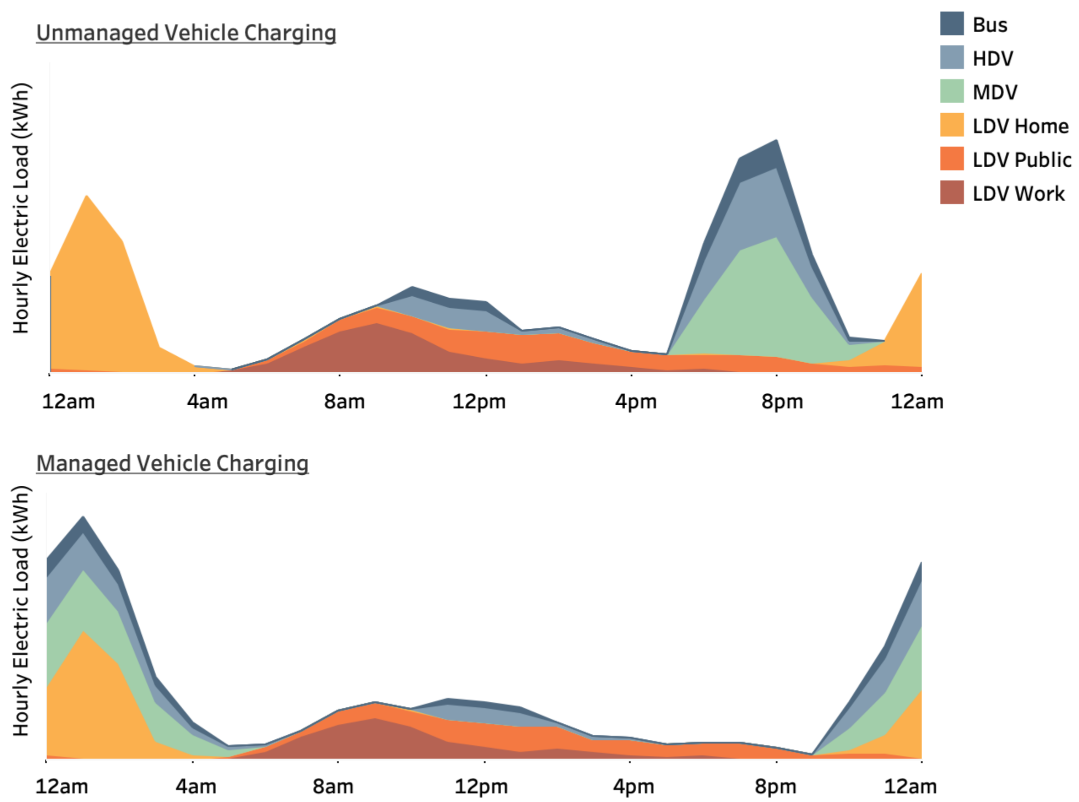
In early 2020, Con Edison formally announced a partnership with the NYC Department of Transportation (NYCDOT) and ZEV charging infrastructure developer AddEnergie to launch a curbside ZEV charging pilot that includes 60 Level 2 dual-unit charging stations in order to assess opportunities and challenges for curbside charging business models and advance the market for ZEV charging. This pilot is a part of the State's Reforming the Energy Vision (REV) Demonstration Projects and will allow up to 120 vehicles to charge at curbside locations across the five boroughs of NYC, including 20 plugs dedicated to serve the City's fleet.[140,141,142]

The timing and throughput of vehicle charging will become an increasingly important issue for utilities to manage. Coincident charging of thousands of vehicles in the late afternoon would burden both the available generation for the city and the transmission and distribution infrastructure to deliver power to each vehicle. Figure 31 shows modeled ZEV electricity demand for managed and unmanaged charging of a diverse fleet of ZEVs. In every Pathway, ZEV charging was shifted from evenings, when citywide peak power demand typically occurs, to overnight. As a result, the impact of higher vehicle electrification on peak demand is lower. Managed vehicle charging resulted in shaving approximately 2 gigawatts (GW) off the winter peak in 2050 in the Electrification and Diversified Pathways. While projections of the peak demand buildup in a decarbonized NYC are uncertain, managing charging of vehicles is an important component.

Several tools are available to help manage time of charging. Direct time-managed charging, time-of-use pricing, third-party charge management services, and vehicle-to-grid (V2G) implementation can all help lower system costs associated with adding new vehicle loads to the grid. Beyond reducing costs, these grid balancing options support the integration of renewables into the grid, enabling consumers to charge when renewable generation is abundant and later draw on energy stored in vehicles connected to the grid.

Managed charging, while an effective way to manage peak demand, may have separate challenges when implemented for vehicle fleets that have all-day operational requirements. ZEV owners who do not have charging available at home and rely on workplace or public chargers would have limited options to participate in managed charging programs. Compared to managed charging of personal vehicles, managed charging of fleet vehicles involves supply chain logistics and long-term planning but fewer decisionmakers. For example, van and truck fleets must follow designated routes and connect businesses and consumers with out-of-city supply chains. Managing charging for these consumers may require well-designed incentives to influence behavior.

FIGURE 31: MANAGED VEHICLE CHARGING SHIFTS LOADS TO OFF-PEAK TIMES



Unmanaged vehicle charging leads to peak ZEV electricity demand from 6-8pm when residential energy demand also peaks (top figure). Managed charging that shifts vehicle demand to overnight hours could help manage the operation of the grid (bottom figure).

ELECTRICITY

In all three Pathways, the electricity sector transforms as over half of the grid-scale, fossil-fueled power plants in the city retire by 2040 and are replaced with renewable resources and batteries. At the same time, peak power demand increases by up to a third and the system becomes winter peaking in Pathways with high buildings electrification.

The availability of low carbon gas for the electricity sector depends on its prioritization relative to other end uses across the city. In the Low Carbon Fuels Pathway, low carbon gas was prioritized to buildings over the electricity sector and as a result, no low carbon gas is available to operate gas-powered power plants. In the Electrification Pathway, low carbon gas was prioritized to the electricity sector over the buildings sector.

TABLE 6: KEY ELECTRICITY SECTOR FINDINGS FROM THE PATHWAYS MODELING

	Electrification	Low Carbon Fuels	Diversified
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 some low carbon gas.			
Proportion of NYC electricity generation using wind, solar, and hydro by 2050 (compared to 10% in 2020 model results)	82%	90%	90%
Retirement of gas-fired generating capacity in NYC by 2040 (compared to 9.3 GW of total capacity in 2020 model results)	5.4 GW*	8.8 GW	8.9 GW
Battery storage and low carbon gas-fired generation are sources of dispatchable capacity that could provide reliability for a decarbonized grid.			
NYC gas-fired capacity using low carbon gas in 2040	4 GW*	0.4 GW	0.3 GW
Battery storage capacity in 2050	7 GW	6 GW	10 GW
Peak demand increases in scenarios with high electrification rates, driven by higher demand in winter months, underscoring the need for aggressive efficiency and demand management measures.			
Peak winter electricity demand in 2050 (compared to 7.8 GW in the winter of 2017-2018)[143]	14.5 GW	9.3 GW	14.4 GW
Peak summer electricity demand in 2050 (compared to historic summer peak, 11.5 GW in 20132014)[144]	13 GW	11.3 GW	13 GW
Annual electricity sales in 2050 (from 52,000 GWh in 2019)	58,000 GWh	49,000 GWh	57,000 GWh
Proportion of building square footage with electrified heating in 2050 (from 7% today)	59%	31%	62%

**Low carbon gases are used more in the electricity sector in the Electrification Pathway than in the Low Carbon Fuels Pathway due to the prioritized allocation of low carbon gas. The Low Carbon Fuels Pathway prioritizes the building sector before the electricity sector, while the Electrification Pathway prioritizes the electricity sector before the building sector (see Table 9).*

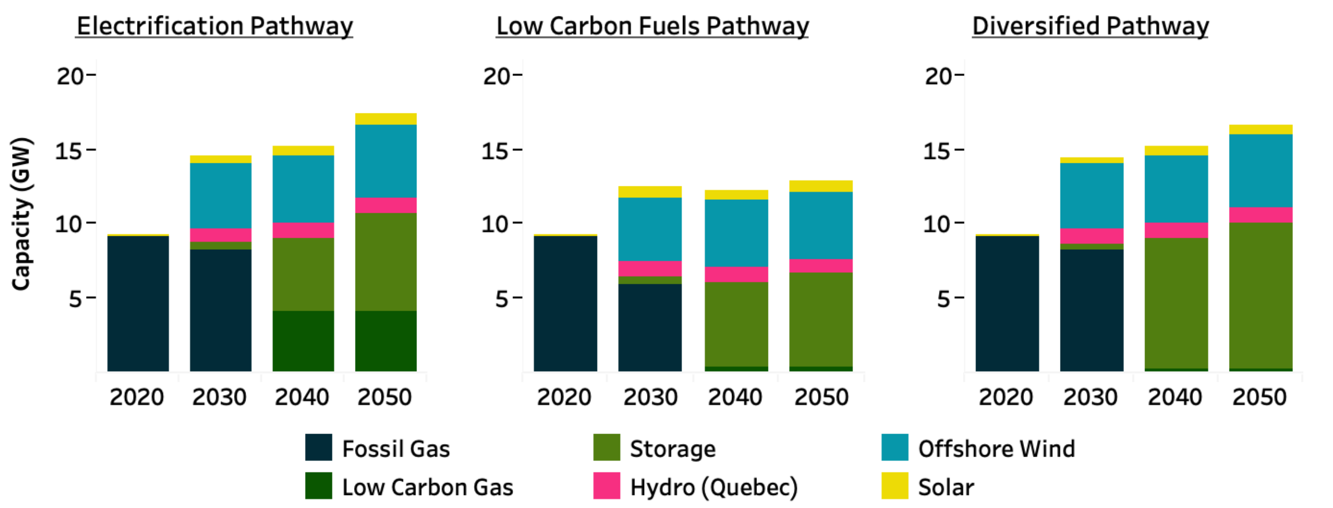
Electricity generation in the city is reimagined in order to meet City and State targets; renewables accompanied by storage play a lead role, most existing power plants retire by 2040, and fossil gas at remaining plants is replaced by some low carbon gas.

The emissions reductions of the electricity sector—driven by the State targets of 70% renewable electricity by 2030 and 100% zero-emission electricity by 2040—are a key driver of emissions reductions across buildings, industrial, and transportation sectors. These emissions reductions require a transformation of the electricity generation profile in the city. During the clean energy transition, it is important to ensure that the electric system remains resilient and reliable as existing fossil units are phased out.

By 2040, the proportion of NYC's electricity demand met by fossil fuels falls to 0% from 60% today, driven by new wind, solar, and hydropower resources. Electricity generation in NYC is almost entirely reliant on fossil fuels, with roughly 9 GW of natural gas capacity and 250 megawatts (MW) of distributed solar. In the Low Carbon Fuels and Diversified Pathways, all fossil-fueled power plants in the city retire by 2040 except for 300-400 MW that are a part of the East River cogeneration plant; in the Electrification Pathway, over 5 GW of power plants retire. In all Pathways, any gas-fired generation remaining past 2040 exclusively uses low carbon gases. While low carbon gas reduces those plants' carbon emissions, local air pollutants persist; synthetic and biogenic RNG combustion generates local pollution at the same rate as fossil gas. However, synthetic and biogenic RNG emit far less harmful pollutants compared to heavy fuel oils, and hydrogen does not generate pollution if produced using renewable resources.

Across the Pathways, roughly 5 GW of offshore wind, 1 GW of incremental solar (including distributed solar power, Box 13), and 6-10 GW of battery electric storage capacity are added to the city's grid (Figure 32). All Pathways also assume 1 GW of hydropower is directly imported into the city from Canada starting in 2025. Imports from upstate and out-of-state continue to supply power to NYC in all Pathways as well. The Diversified Pathway builds the most wind and battery capacity—a result of high electrification and low carbon gas supply being directed to the building sector instead of the electricity sector.

FIGURE 32: NYC ELECTRICITY GENERATION CAPACITY, SELECT YEARS



Within NYC, fossil gas is replaced with a combination of low carbon gas capacity and battery electric storage across all three Pathways. The Electrification Pathway results in about 4 GW more total capacity in 2050 than the Low Carbon Fuels Pathway because of the significant need for dispatchable power during peak periods. **Note**: *low carbon gas-fired electric capacity in the Low Carbon Fuels and Diversified Pathways in 2040 and 2050 represents a cogeneration facility that is used to produce steam and power. Solar capacity additions in all Pathways include distributed solar additions required to meet NYC's 1 GW distributed solar target by 2030. Electrification and Diversified Pathways add small amounts (~200 MW) of utility-scale solar by 2030.*

Box 13: Distributed Solar in NYC

NYC is already one quarter of the way to its 1,000 MW solar goal by 2030. To accelerate progress towards this goal, the City has enacted policies to encourage wider adoption of on-site solar generation. As of November 2019, new buildings and buildings undergoing major roof renovations are required to install solar or green roofs, where feasible, under Local Laws 92 and 94 of 2019.[145] New affordable housing properties are also required to install solar where it is cost effective, reducing operating costs for affordable housing.

Over 25,000 NYC property owners have chosen to install solar as of February 2021, a majority of which are small residential installations. This distributed generation is beneficial for reducing consumption of grid energy and can help shift consumption away from peak periods, especially when paired with energy storage.

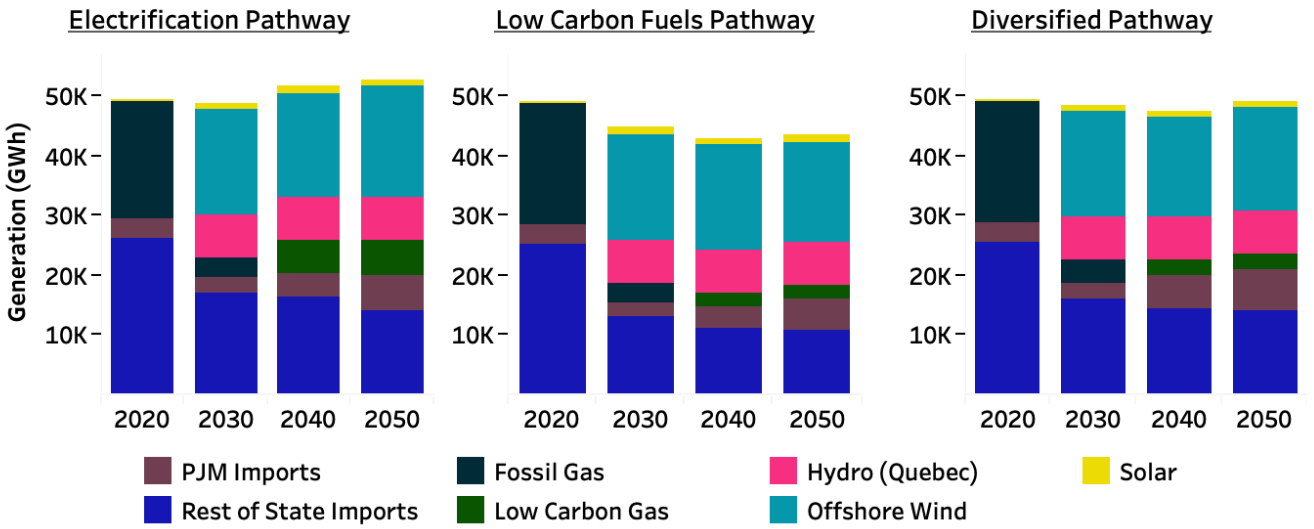
Distributed solar can also help New Yorkers save on their electricity bills, even for renters and residents of buildings that cannot host a system on-site. Community solar, where customers subscribe to a share of a solar array anywhere in the city, allows subscribers to purchase locally produced clean energy and reduce their energy bills. New York City Housing Authority (NYCHA) and NYC Economic Development Corporation have made their roofs available to community solar developers who provide utility bill discounts to low-income communities in NYC.

Between 2020 and 2050, both capacity and total generation increase within the City as annual electricity demand increases up to 15% (Figure 33). The increase in capacity is led by offshore wind, which provides 30% of the generation by 2030. As NYC increasingly receives more electricity from offshore wind, imports of electricity from the rest of New York State decline. In 2020, it was estimated that NYC generated about half of the electricity that it consumed; however, in the Electrification Pathway and Low Carbon Fuels Pathway, this increases to more than 60% by 2050. The Diversified Pathway imports slightly more electricity as a share of its total annual consumption, roughly 43% by 2050. Fully decarbonizing NYC depends on regional coordination with other states to reduce emissions in their electricity supply.[t]

The retirement of old gas-powered plants presents a unique opportunity to substantially reduce emissions in neighboring communities that have been affected by decades of environmental injustice. Families who are also affected by job loss after a plant closure may require support and resources. Guiding the just transition is critical to ensure support from a broad coalition of stakeholders.

t The clean energy standard applies to electricity sold in-state and does not exclude the possibility of out-of-state electricity imports. The Pathways met electric load in-state from resources that are considered clean but imports are assumed to include fossil generation in the energy mix.

FIGURE 33: NYC ELECTRICITY GENERATION AND IMPORTS, SELECT YEARS



By 2030, offshore wind contributes the largest share of any generation source across all Pathways, followed by a mix of imports, hydro, low carbon gas, and solar. Demand increases by 2050 relative to 2020 in the Electrification and Diversified Pathways, while it steadily decreases in the Low Carbon Fuels Pathway. This is due to the lower buildings electrification rate in the Low Carbon Fuels Pathway. Out-of-state imports, which are permitted under clean energy standards, include fossil generation after 2040.

Battery storage and low carbon gas-fired generation are sources of dispatchable capacity that could provide reliability for a decarbonized grid.

Both low carbon gas and battery storage can supply dispatchable electricity to the grid. However, both technologies are untested at the scale required to deeply decarbonize the city. Batteries are limited by the amount of energy that they can store and how fast that energy can be discharged. Batteries also require capital to build and space to occupy. At the same time, low carbon gas availability is uncertain, and there is no policy framework to develop these resources at scale. While maintaining gas-fired electricity generation assets can avoid new capital expenditures, sources of RNG would need to be connected to the existing pipeline gas transmission and distribution system, requiring investments. Additionally, RNG combustion still generates air pollutant emissions, which must be considered. Navigating the tradeoffs between technologies requires an assessment of the costs and benefits for each, especially as there is potential opportunity to reduce pollution near environmental justice communities. The Pathways modeling does not fully explore the tradeoffs between RNG and battery capacity and requires further study.

Low carbon gas-fired generation can mitigate capital cost requirements for scenarios with high electrification rates that lead to greater peaks and larger capacity requirements. The Diversified Pathway, which has similar levels of electrification as the Electrification Pathway, has higher capital costs for electricity generation because it relies primarily on battery storage to provide dispatchable capacity. In the Low Carbon Fuels and Diversified Pathways, RNG-fired capacity is all but eliminated. The only RNG capacity that remains in either Pathway is a single cogeneration facility that produces steam for the Con Edison steam system and cogenerates electricity. In contrast, the Electrification Pathway prioritizes RNG to the electricity sector over the building sector, which allows this Pathway to mitigate costs associated with a higher peak demand.

The cost of operating gas-fired units could increase, however, when RNG is used in place of fossil gas. In 2030, the average commodity cost of biogenic RNG is between five to seven times greater than average commodity cost of fossil gas, based on the assumptions for sources and availability of RNG. That cost differential is projected to remain through 2050.

Battery electric storage meets or exceeds gas capacity in all three Pathways once the grid decarbonizes by 2040. Across the Pathways, between 6-10 GW of new battery capacity is added.[u] While the Pathways replace gas-fired capacity with varying amounts of low carbon gas and battery electric storage capacity, an explicit study of electricity reliability was not performed. Meeting electricity demand during a heat wave or cold snap is more difficult with less dispatchable capacity and this dynamic requires further study.

While siting new generation and grid resources can be difficult anywhere, the challenges are magnified in a dense urban environment. Batteries could pose a particular challenge in NYC, where battery safety concerns have led to a stringent regulatory and siting regime in the city. The battery storage used in the Pathways could require roughly 200–320 acres of land to site.[v] This space is approximately equivalent to the current size of the Astoria Energy Complex, a privately-owned multi-owner site in Queens that currently hosts almost 40% of the City's electric generating capacity today. All battery projects must be approved by the NYC Fire Department and the NYC Department of Buildings to ensure fire safety. This approval can add time to the battery permitting process. The City's Fire Code and Zoning Resolution also have several site-based limitations for batteries, which further constrain where they can be placed and can limit the potential pace of adoption.[146] Streamlining permitting processes while upholding safety standards could result in a reduction in soft costs for battery systems, which currently account for up to 20% of total installed costs.[147]

One opportunity to ease siting challenges is to take advantage of the zoning and grid infrastructure at fossil-fueled power plants that are set to retire. For example, Con Edison and a business partner, 174 Power Global, have an agreement that will place the largest battery storage project in New York State on an industrial site in Astoria, Queens. The batteries will be able to discharge 100 MW of electricity.[148] There is also interest in using old power generation sites for data centers, commercial land, and public parks. Given disparate interests, how these spaces are prioritized for re-use requires thoughtful consideration and stakeholder engagement.

Peak demand increases in scenarios with high electrification rates, driven by higher demand in winter months, underscoring the need for aggressive efficiency and demand management measures.

New loads from electrified building end uses, ZEVs, and possibly steam generation can change the electricity demand profile, creating challenges for managing costs, designing electricity transmission and distribution, and ensuring reliability on a more dynamic grid.

The aggregate electricity system peak demand grows modestly in the Pathways considering the scale of transformation in the city. This is due in part to the aggressive energy efficiency measures that were assumed. The Electrification and Diversified Pathways transition to a winter peaking system and peak demand overall increases by 30% between 2020 and 2050 (Figure 34).[w] Without aggressive energy efficiency and peak demand management strategies, ZEV charging and heating electrification could push peak demand even higher.

Meanwhile, the Low Carbon Fuels Pathway sees a slight reduction in peak demand relative to 2020. Peak demand for this Pathway continues to occur in the summer. Due to building energy efficiency measures and the installation of more efficient cooling systems, all Pathways see a similar peak demand reduction in the summer between 2025 and 2035. In the late 2030s, summer peaks start to increase slightly due to higher numbers of ZEVs charging at the same time.

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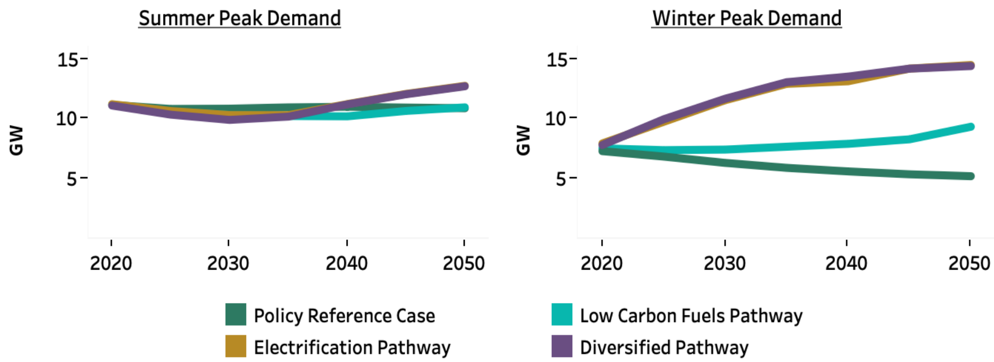
u The first 3 GW of battery storage have four-hour storage capacity deployed to meet New York State's 3 GW by 2030 storage target. The next 3-7 GW of additional battery storage have eight-hour storage capacity.

v The costs associated with siting and permitting battery storage were not considered in this study.

w The modeling provided a conservatively high projection of the peak load impact of the measures explored in this analysis for the following reasons: 1) The modeling used nine building typologies with identical load profiles, scaled to the total number of buildings in the city. In reality, load profiles are more heterogeneous. 2) Conservative estimates for heat pump performance were used. The model assumed that heat pump performance does not improve over time, though technical advancements are expected to increase performance by 2050. 3) The modeling used only two demand management strategies: dual fuel heating systems and gas heat pumps. Demand management techniques cannot be accurately modeled on a 30-year time horizon but are expected to be a method for reducing peak demand.

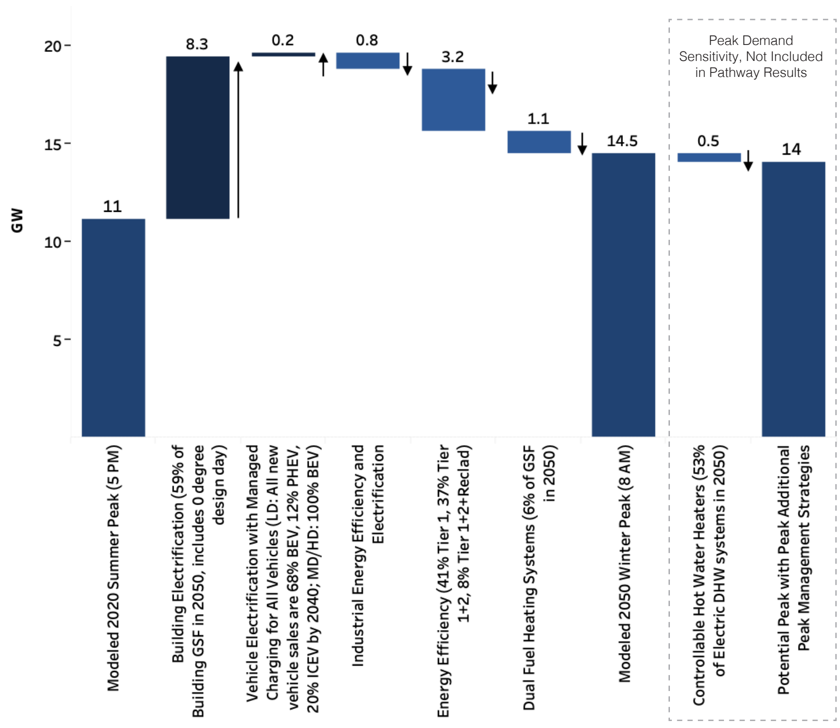
FIGURE 34: SEASONAL PEAK ELECTRICITY DEMAND IN THE PATHWAYS



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 end uses for heating. Summer peaks decrease initially across all Pathways, then increase in the Electrification and Diversified Pathways after 2040 as ZEVs proliferate.

The measures adopted in each Pathway affect the overall electricity peak demand. Building electrification, for example, draws significant energy from the grid to warm building space in winter months, causing peak demand to increase in the winter. The increase due to electrification is mitigated, however, by building energy efficiency retrofits and the use of dual fuel heating systems. Figures 35-37 show the relative contribution of measures on the final grid peak for each Pathway in 2050.

FIGURE 35: IMPACT OF KEY MEASURES ON PEAK ELECTRICITY DEMAND IN THE ELECTRIFICATION PATHWAY, 2050 COMPARED TO 2020

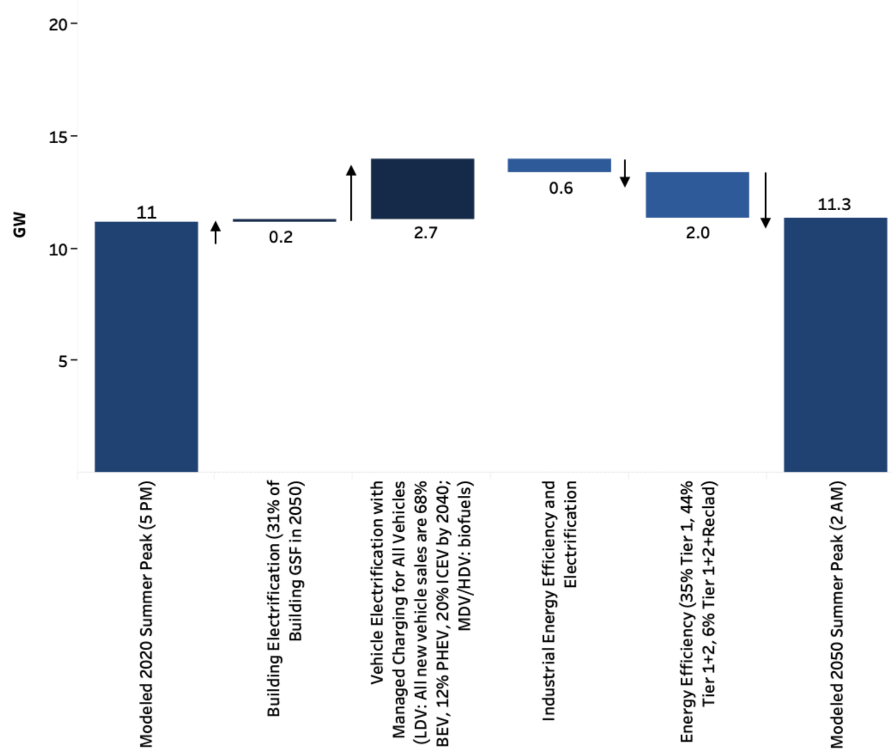


The peak electricity demand for the Electrification Pathway is 14.5 GW, which is 3.5 GW higher than the modeled peak in 2020. For reference, the historical peak demand in NYC is 11.5 GW in 2013, a year with a hot summer. The peak is increased by building and vehicle electrification but the peak demand increase is mitigated by energy efficiency and the use of dual fuel heating systems in peak hours. Controllable hot water heaters can reduce demand about 500 MW further.

Building electrification contributes the most to increased peak demand due to high use of electric heating systems in winter months. The increase in peak is mitigated, however, by energy efficiency retrofits in buildings, which reduce 3.2 GW of potential electricity peak. Dual fuel heating systems, which are assumed to be used for about 6% of building space in 2050, further reduce peak demand. Installing utility-controllable electric hot water heaters is a potential measure not included in the Pathways modeling but can reduce peak demand by approximately 500 MW. Demand management methods, such as heating systems that can switch fuels and water heaters that can reduce electricity use in peak hours, can play an important role in scenarios with high electrification rates.

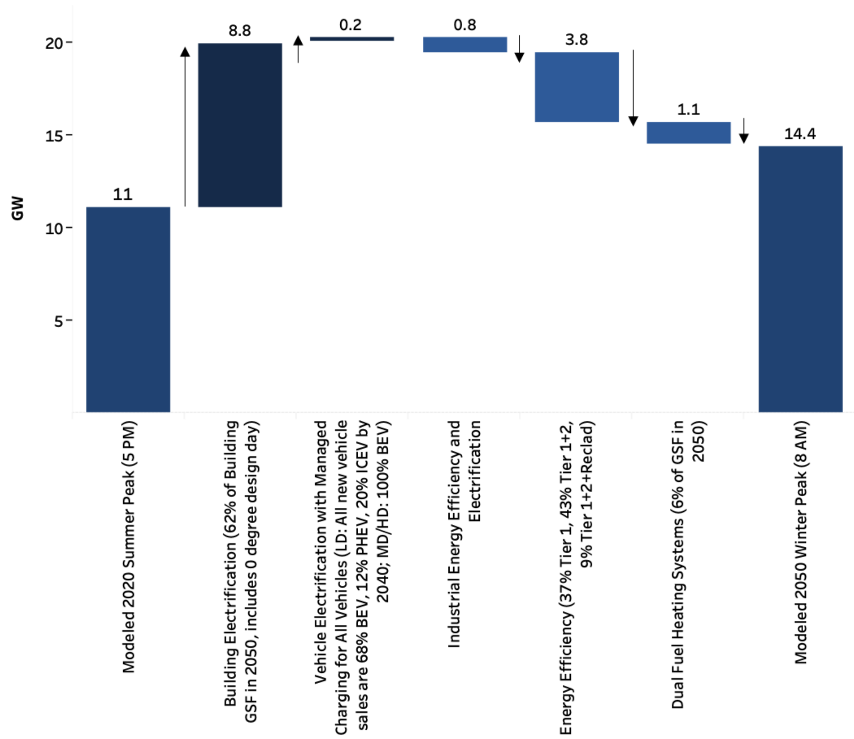
The Low Carbon Fuels Pathway has the lowest peak electricity demand in 2050. While 33% of building space adopts electric heating, building electrification does not substantially increase peak demand due to the season in which peak electricity demand occurs. When the overall peak occurs in the summer, as it does in the Low Carbon Fuels Pathway, it is not affected by winter heating load. Vehicle electrification increases the peak demand by as much as 2.7 GW due to the hour in which the peak occurs. The Low Carbon Fuels Pathway's peak demand occurs in the early morning hours in 2050, which is when most vehicles are charged due to the timed charging of the electric vehicle fleet. Building energy efficiency retrofits mitigate peak demand by as much as 2 GW. Industrial energy efficiency retrofits also reduce peak demand.

FIGURE 36: IMPACT OF KEY MEASURES ON PEAK ELECTRICITY DEMAND IN THE LOW CARBON FUELS PATHWAY, 2050 COMPARED TO 2020



The peak electricity demand for the Low Carbon Fuels Pathway is 11.3 GW, about 300 MW higher than the modeled peak in 2020. For reference, this is lower than the historical NYC peak demand in 2013, 11.5 GW. The peak is increased by building and vehicle electrification, although to a lower extent than the other Pathways. The peak demand increase is mitigated by energy efficiency in buildings and the industrial sector.

FIGURE 37: IMPACT OF KEY MEASURES ON PEAK ELECTRICITY DEMAND IN THE DIVERSIFIED PATHWAY, 2050 COMPARED TO 2020



The peak electricity demand for the Diversified Pathway is 14.4 GW, which is about 3.4 GW higher than the modeled peak in 2020. For reference, the historical peak demand in NYC is 11.5 GW, which occurred in 2013, a year with a hot summer. The peak is increased by building and vehicle electrification but the peak demand increase is mitigated by energy efficiency and the use of dual fuel heating systems in peak hours.

The Diversified Pathway measures have similar peak demand impacts as the Electrification Pathway. Building electrification raises the peak electricity demand considerably, up to 8.8 GW of power capacity is needed to heat buildings on the coldest winter day. This would constitute up to 44% of total peak demand. Vehicle electrification also increases peak demand modestly, although the peak demand impact is lower than the Low Carbon Fuels Pathway due the peak hour occurring when most vehicles are not charging. The increase in peak demand is mitigated by energy efficiency retrofits in the buildings and industrial sectors. The use of dual fuel heating systems mitigates up to 1.1 GW of peak demand, reflecting the importance of active peak mitigation strategies in scenarios with high electrification rates.

Increase in peak power demand—even while total consumption is flat or falling—increases system costs. Electricity generation and delivery infrastructure must have sufficient capacity to meet the highest momentary peak demand with an adequate margin of safety, even if that peak rarely occurs. Total system costs relate to building the electricity generation, transmission, and distribution capacity necessary to meet to peak demand. Fortunately, there are many existing solutions to help manage these peaks, as discussed in the buildings, industry, and transportation sections of this report.

NATURAL GAS

Fossil natural gas has served as a key energy resource in NYC, fueling all of the city's power plants and heating the majority of buildings. To deeply decarbonize, however, the city needs to reduce its overall energy consumption while also shifting away from fossil fuels. To help decarbonize the remaining gas use, one emissions reduction opportunity would be to use low carbon gases, which are gaseous fuels with lower emissions compared to fossil natural gas. These gases are generated from biogenic sources, chemical processes, or electrolysis powered by renewable electricity. This analysis evaluated the role of three such gases: biogenic renewable natural gas (RNG) from anaerobic digestion feedstocks, synthetic RNG, and hydrogen.

Displacing remaining fossil gas with these low carbon gases can bring emissions benefits, especially for end uses that do not electrify. Depending on how the gas is produced or derived, some types of low carbon gases can be emissions negative on a lifecycle emissions accounting basis.

Low carbon gases such as biogenic and synthetic RNG, however, do continue to emit localized nitrogen oxides (NO_x) and fine particulate matter 2.5 ($PM_{2.5}$) just as fossil gas combustion does. It is also highly uncertain whether the supply of low carbon gases can meet the city's gas demand at reasonable cost. The current policy landscape would need to shift to make low carbon gases and fuels a part of a decarbonized energy portfolio.

TABLE 7: KEY NATURAL GAS SECTOR FINDINGS FROM THE PATHWAYS MODELING

	Electrification	Low Carbon Fuels	Diversified
The supply availability and cost of biogenic RNG, a low carbon gas, are uncertain at this time.			
Annual biogenic RNG supply (technical potential), 2050	26 tBtu	61 tBtu	61 tBtu
Biogenic RNG commodity cost per mmBtu, 2050	$14	$19	$19
Fossil gas commodity cost per mmBtu, 2050	$2.5		
Synthetic RNG and hydrogen have the potential to further decarbonize remaining gas use.			
Hydrogen produced, 2050	7.3 tBtu	9.2 tBtu	5.5 tBtu
Hydrogen commodity cost per mmBtu, 2050	$18		
Synthetic RNG produced, 2050	17 tBtu	20 tBtu	32.7 tBtu
Synthetic RNG commodity cost per mmBtu, 2050	$21		
Non-fossil low carbon gas can be an important emissions reduction strategy for end uses that are not electrified across all Pathways.			
Building sector emissions in 2050 are 11% lower in the Low Carbon Fuels Pathway than in the Electrification Pathway, driven in part by the allocation of RNG to the buildings sector in the Low Carbon Fuels Pathway.			
Total gas demand across all sectors falls more than 60% while delivered energy costs increase.			
Total gas demand, 2050 (compared to 515 tBtu in 2020 model results)	182 tBtu	213 tBtu	148 tBtu
Continued maintenance and state-of-good-repair investment in the gas system is required to provide safe, reliable service and reduce emissions.			
The capital investment implications of decreasing gas demand are unknown.			

The supply availability and cost of biogenic RNG, a low carbon gas, are uncertain at this time.

Three sources of low carbon gas are modeled in this study: biogenic RNG, synthetic RNG, and hydrogen. These gaseous fuels produce little to no GHG emissions on a lifecycle basis and are a subset of low carbon fuels, which generally also includes liquid fuels used in transportation. RNG is defined as pipeline compatible gaseous fuel derived from renewable sources that has lower lifecycle carbon dioxide-equivalent emissions (CO_2e) than fossil natural gas. Biogenic RNG is RNG derived from renewable biological sources. One method of production is anaerobic digestion, in which bacteria break down organic matter to produce biogas that can be further refined to approach the purity of fossil natural gas.[149] This digestion occurs naturally in wastewater and landfills and through degradation of animal waste (Box 14).[150] Another production process is thermal gasification, or the breakdown of biomass material into component gases and ash in an enclosed reactor.

Though both biogenic RNG combustion and fossil gas combustion emit CO_2, RNG lifecycle emissions are lower, especially if the RNG is produced from anaerobic digestion (Figure 38).[x] Biogenic RNG production uses captured methane—a potent GHG—from renewable or waste sources, preventing that methane from venting directly to the atmosphere as it otherwise would. Biogenic RNG also does not produce emissions inherent to traditional oil and gas upstream production. However, biogenic RNG would likely travel primarily through existing transmission and distribution pipeline infrastructure, which could result in similar levels of methane leakage.

Box 14: National Grid Investments in Renewable Natural Gas

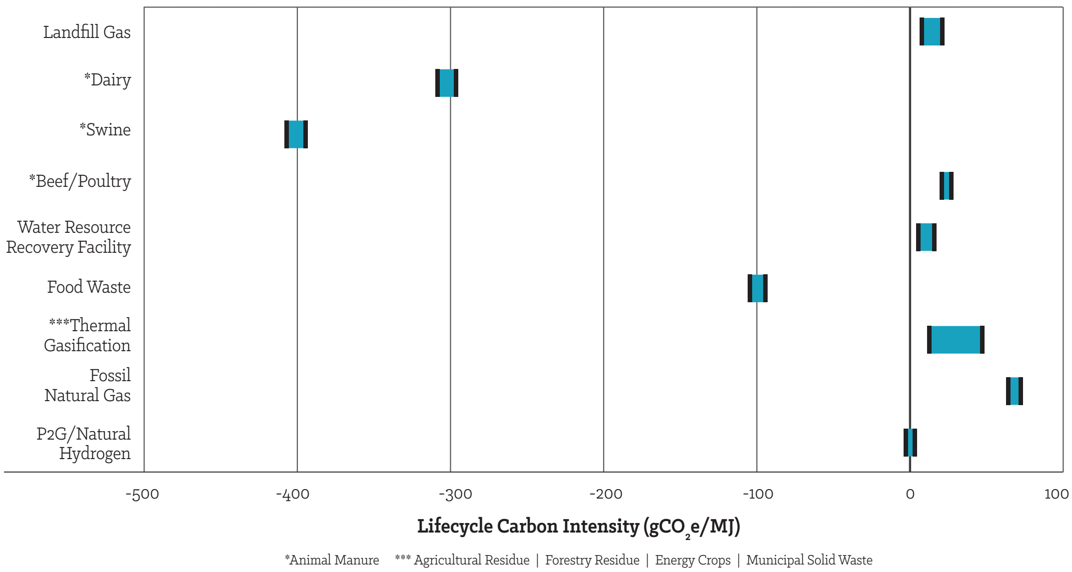
National Grid is developing innovative energy solutions, including its ongoing efforts at Newtown Creek, NYC's largest wastewater resource recovery facility, in Brooklyn. In collaboration with the NYC Department of Environmental Protection (NYCDEP), National Grid is building an anaerobic digester gas conditioning system that will use biogas from wastewater and food scraps to produce pipeline-quality biogenic RNG. In combination with NYCDEP's efforts to boost biogas production and divert food scraps from landfills toward beneficial co-digestion at its Newtown Creek facility, these projects have the potential to produce enough RNG to heat more than 5,000 homes in NYC, reducing more than 90,000 tons of CO_2e.[151]

For emissions reductions from the use of any low carbon gas to materialize, adequate amounts must be imported into the city. However, biogenic RNG availability is highly uncertain. Fundamentally, supply to the city depends on feedstock availability and pipeline buildout to facilities like farms, wastewater treatment plants, and landfills, the vast majority of which fall outside of city boundaries and jurisdictional control. In 2019, there were 119 operational RNG facilities in the entire United States, producing over 50 tBtu in total, roughly one-tenth of NYC's current gas demand. Of those facilities, two are in New York State and eight are in nearby Pennsylvania.[152] Overall, the industry is immature and faces significant upstream infrastructure, cost, environmental, and public acceptance hurdles. To reflect this fundamental uncertainty, this analysis developed three biogenic RNG supply scenarios to examine the implications of low, medium, and high supply availabilities through 2050 (Box 15).

In consultation with members of the Technical Advisory Committee (TAC), this study modeled low carbon fuel scenarios with only biogenic RNG exclusively derived from anaerobic digestion (i.e., low and medium supply scenarios) in the Pathways. The analysis did not include low carbon gas derived from thermal gasification in any of the Pathways; therefore, none of the Pathways model a high biogenic RNG supply scenario. While thermal gasification has been technically proven, its large-scale deployment remains in earlier stages of commercialization.

x While RNG provides a climate benefit compared to fossil gas, synthetic RNG, biogenic RNG, and fossil gas combustion contribute similarly to local air pollution.

FIGURE 38: LIFECYCLE CARBON INTENSITY OF RENEWABLE NATURAL GAS FROM VARIOUS FEEDSTOCKS



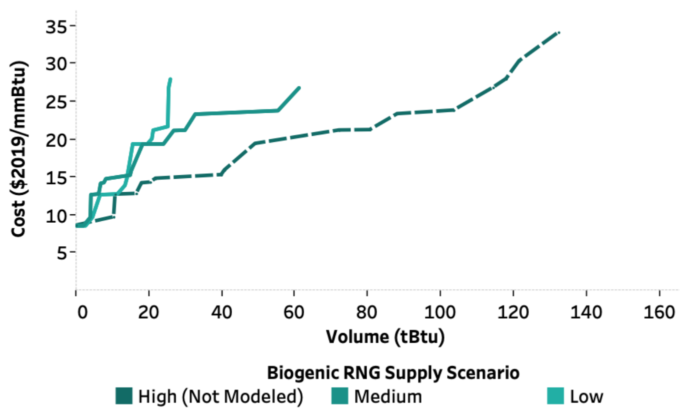
This graphic shows the lifecycle emissions factor ranges for RNG derived from a number of feedstocks, fossil gas, and hydrogen generated from renewable electricity. **Note:** *thermal gasification was not modeled.*

The policy framework to support the development and use of low carbon gases for thermal applications does not exist. It is also recognized that due to the energy associated with the thermal gasification process, lifecycle emissions from these feedstocks can be higher than those of anaerobically digested ones. This approach is conservative, and with technology development and appropriate regulation, thermal gasification feedstocks may eventually become an important contributor to biogenic RNG supply.

The modeled low and medium supply scenarios highlight the challenge of using biogenic RNG to meet city gas demand. Gas demand drops significantly across all Pathways between 2020 and 2050. Homes and businesses increasingly electrify end uses, and about 90% of buildings adopt energy efficiency measures. The amount of biogenic RNG technically available in the low and medium scenarios would meet only 18% and 40% of 2050's lowest projected gas demand, respectively. While biogenic RNG is not the only gaseous fuel leveraged in the Pathways to meet anticipated gas demand, rapid development of this sector would be needed even to meet biogenic RNG-specific projections. In the Low Carbon Fuels Pathway, the estimated biogenic RNG supply available to the city in 2050 is 61 tBtu—22% more than total 2019 U.S. production.

Industry immaturity, limited supply feedstocks, high infrastructure costs, and sparse regulatory support also contribute to high biogenic RNG commodity costs relative to fossil natural gas. Biogenic RNG at its medium and low supply potential is projected to cost about five to seven times more than fossil gas in 2050 (Figure 39).

FIGURE 39: BIOGENIC RENEWABLE NATURAL GAS SUPPLY IS SENSITIVE TO FEEDSTOCK AVAILABILITY



This figure shows cost curves for biogenic RNG across the low, medium, and high supply scenarios against their supply estimates. **Note**: *The high biogenic RNG supply estimate, which includes biogenic RNG derived from thermal gasification, was not applied in any Pathway.*

Box 15: Biogenic Renewable Natural Gas Supply Scenarios

This study developed three RNG production potential estimates reflecting low, medium, and high supply scenarios, which incorporate feedstock, project deployment, technology development, and economic constraints facing the industry.* Ultimately, only the low and medium supply scenarios were used in the Pathways.

This analysis assumed landfill gas, animal manure, water resource recovery facilities, and food waste were possible feedstocks for anaerobic digestion. Every supply scenario uses anaerobic digestion technology, which is proven and commercially available. The high supply scenario also considers agricultural residues, forestry and forest residues, energy crops, and municipal solid waste (MSW) as feedstocks for thermal gasification. While both anaerobic digestion and thermal gasification use biomass feedstocks, anaerobic digestion is typically used for feedstocks with high moisture content, and gasification is used for feedstocks with low moisture content.

The low supply scenario was used in the Electrification Pathway. It includes only select RNG feedstocks in the U.S. Energy Information Administration's (EIA) Mid-Atlantic Census Region, which includes New York, New Jersey, and Pennsylvania. Available RNG resources are further limited by NYC's share of regional non-electric generation natural gas consumption, which in 2017 was equivalent to roughly 19% of the region's consumption.

The medium supply scenario was used in the Low Carbon Fuels and Diversified Pathways. It expands the geography of available RNG resources to the EIA Census divisions of New England, South Atlantic, East North Central, and East South Central, roughly capturing the area east of the Mississippi River. This reflects the city's current fossil gas supply area. This potential was again limited by NYC's share of the area's non-electric natural gas consumption, equivalent to roughly 5.7% of the region's 2017 total.** In 2050, the amount of biogenic RNG technically available in this scenario is 61 tBtu.

The high supply scenario used the same geographic resource area as the medium supply scenario but explores the potential for thermal gasification in addition to anaerobic digestion. For modeling purposes, it was assumed that thermal gasification feedstocks were economically and sustainably viable. Technical potential is 132 tBtu in 2050. If this higher quantity of RNG were available, it could potentially help to further decarbonize buildings and industrial end uses that do not electrify, meeting 62-89% of the city's gas demand by 2050, depending on the Pathway. However, because the largescale deployment of thermal gasification remains in early stages of commercialization, this study only used scenarios with biogenic RNG derived from anaerobic digestion.

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* The methodology used builds on the national RNG resource assessment published by the American Gas Foundation in 2019 and leverages other key resources such as the U.S. Department of Energy 2016 *Billion Ton* report, the U.S. Environmental Protection Agency's (EPA) AgStar Project Database, the U.S. EPA Landfill Methane Outreach Program, and the U.S. Department of Agriculture Livestock Inventory.

** At the time of modeling, the 2017 EIA Natural Gas Consumption dataset was the most recent, complete version available by state and sector. NYC natural gas consumption relative to NYS consumption was approximated using a 2010 dataset publicly available on NYC OpenData. This share was then applied to 2017 NYS and regional consumption volumes.

Synthetic RNG and hydrogen have the potential to further decarbonize remaining gas use.

There are two other low carbon gases modeled in the Pathways: synthetic RNG and hydrogen. Synthetic RNG is derived through a process called electrolysis in which electricity is used to split water into hydrogen and oxygen, and the hydrogen is combined with CO_2 to create methane. Hydrogen generated through electrolysis can also be isolated and used directly as a low carbon gas.

Hydrogen combustion, unlike RNG combustion, produces no Co_2 emissions. It also does not leak GHG emissions as it travels through pipelines. However, lifecycle emissions for both fuels are dependent on the electricity source used to power the electrolysis process. This electricity can be fossil-generated with carbon capture applied at the generation plant, or renewable-generated. This study only considered synthetic RNG and hydrogen derived from renewable electricity. All Pathways leverage excess, or curtailed, renewable electricity from the electricity sector for synthetic RNG and hydrogen production.

Because hydrogen and synthetic RNG can also be blended into the remaining gas supply, this study examined how these sources of low carbon gas can supplement the limited supplies of biogenic RNG available in each Pathway. The modeling assumed that excess renewable generation in the electricity sector across New York State could be used to produce hydrogen and synthetic RNG. Hydrogen is first generated from existing excess renewable generation until a "blend limit" is met. This study assumed a hydrogen blend limit of 15% of pipeline throughput or 5% of energy content. Once this limit is reached, and assuming there is still excess renewable generation, the modeling allowed for synthetic RNG production and blending to further decarbonize the gas system. Further investigation into relevant pipeline requirements, interconnection, and buildout is needed (Table 8).

Today, carbon-neutral hydrogen technologies and markets are nascent; supply and costs are highly uncertain. In 2020, 99% of U.S. hydrogen was produced through fossil fuel-powered processes like steam methane reforming and coal gasification. Only 1% of U.S. hydrogen, or 100,000 metric tons, was produced through electrolysis, and not all electricity used in electrolysis was from zero-carbon energy resources. At present, hydrogen production using zero-carbon electricity costs 2.5 to 4 times more than hydrogen production using steam reforming or gasification with carbon capture and storage.[153]

To reflect uncertainty in industry development and supply availability, this study modeled supply and commodity cost for hydrogen and synthetic RNG. Hydrogen' commodity cost is about seven times higher than fossil gas commodity cost in 2050, and synthetic RNG is about nine times as costly. 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 8: ANNUAL LOW CARBON FUELS PRODUCTION FROM CURTAILED RENEWABLE ELECTRICITY, 2030-2050

		Electrification	Low Carbon Fuels	Diversified Pathway
2030	Synthetic RNG Produced (tBtu)	0	0	0
	Hydrogen Produced (tBtu)	0.5	0.6	0.8
	Renewable Electricity Required (MWh)	212,000	266,000	316,000
2040	Synthetic RNG Produced (tBtu)	9.2	5.5	23
	Hydrogen Produced (tBtu)	8.8	11.2	7.4
	Renewable Electricity Required (MWh)	6.9 million	6.3 million	11.7 million
2050	Synthetic RNG Produced (tBtu)	17	20	33
	Hydrogen Produced (tBtu)	7.3	9.2	5.5
	Renewable Electricity Required (MWh)	9.3 million	11.1 million	14.5 million

For example, the United Kingdom government published a 10-point plan and energy whitepaper in 2020 outlining the future role of hydrogen. Several demonstration projects are underway in the country. The European Union (EU) has set a target for 40 GW of green hydrogen production and individual countries have outlined strategies and targets for hydrogen production and, most importantly, investment. In all EU countries, demonstration projects for production at scale are now being scoped, and a pan-European hydrogen backbone concept has been developed to repurpose strategic gas assets.

Due to feedstock constraints, emerging technologies, and high production costs, low carbon gases may not reach the scale or cost required to reasonably support deep decarbonization and emissions goals. Within the Pathways, while gas use overall declines significantly, the remaining fossil gas consumption is equivalent to total pipeline gas demand minus supply of low carbon gases; therefore, it is a function of biogenic RNG, synthetic RNG, and hydrogen availability. Some Pathways hedge against low carbon gas supply uncertainty more than others. For example, high rates of building electrification in the Diversified Pathway reduce building sector gas and steam demand, in turn reducing the gas needed for direct consumption and for the steam system. The Low Carbon Fuels Pathway has a lower building electrification rate; building sector gas and steam use are higher relative to the Diversified Pathway, leaving tenants and building owners more reliant on gas and more exposed to the risk of low carbon gas supply not materializing.

Non-fossil low carbon gas can be an important emissions reduction strategy for end uses that are not electrified across all Pathways.

Biogenic RNG is allocated to particular end-use sectors in priority order that differs among the Pathways (Table 9). Across all Pathways, biogenic RNG is first allocated to the East River cogeneration plant, where gas is used to generate power and steam for Con Edison's steam system. This plant is a highly efficient combined heat and power facility that provides steam for the city's building end uses while offering electricity sector emissions benefits compared to typical natural gas combined cycle generation plants. Reducing emissions in the steam system provides lower emissions heat to buildings that stay on steam, while low carbon gas allocation to the buildings sector serves building end uses like heating and DHW systems. Hydrogen and synthetic RNG are generally allocated in the same priority order; for hydrogen, a blend limit of 15% of pipeline throughput by volume was applied in calculations.

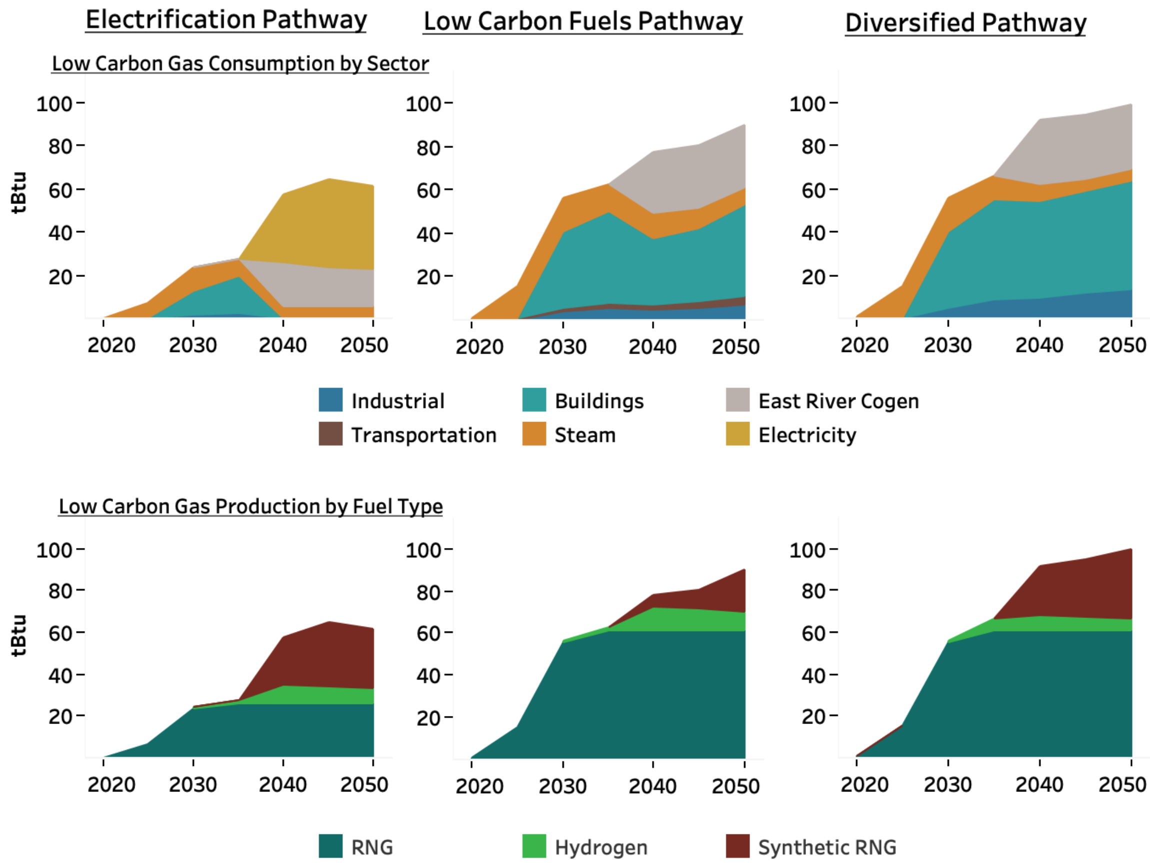
While this allocation approach was used for the purposes of the Pathways modeling, this study did not make any assumptions nor examine how low carbon gases would be logistically delivered and distributed to specific sectors.

TABLE 9: LOW CARBON GAS ALLOCATION ACROSS PATHWAYS

	Electrification	Low Carbon Fuels	Diversified Pathway
First Priority	Steam	Steam	Steam
Second Priority	Power	Transportation	Buildings/ Industry
Third Priority	Buildings/ Industry	Buildings/ Industry	Power

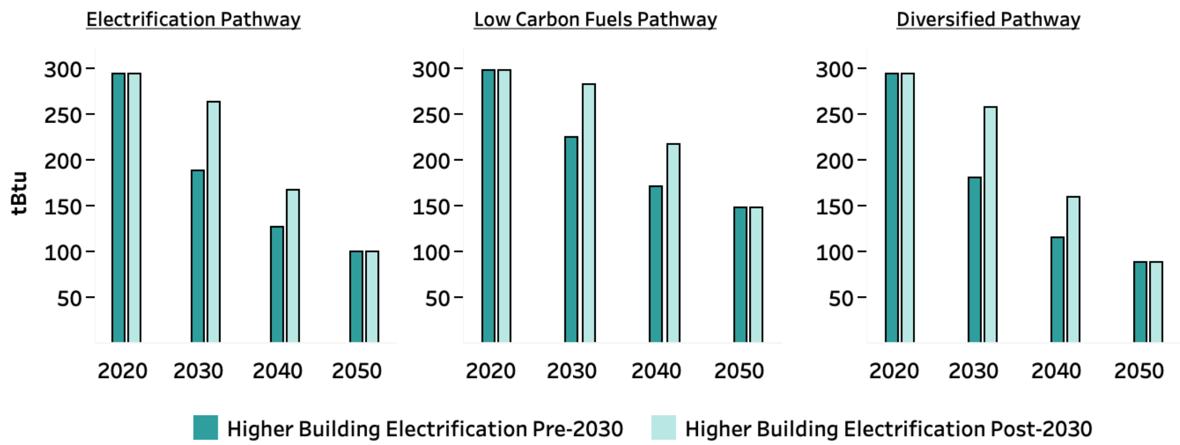
In the Electrification Pathway, low carbon gas allocation to the electricity sector enables retaining flexible gas-fired generation capacity with no associated GHG emissions. Overall, this Pathway demands less low carbon gas than other Pathways but sources gas differently; it assumes the lowest biogenic RNG supply potential entering the city and dedicates 7-10 GW of solar capacity upstate to supplement synthetic RNG and hydrogen production between 2040 and 2050. These low carbon gases are prioritized to the electricity sector to support end use electrification, allowing 4 GW of gas power plants to continue operating in the city (Figure 40).

FIGURE 40: LOW CARBON GAS PRODUCTION AND CONSUMPTION BY SECTOR ACROSS PATHWAYS



Overall, the Electrification Pathway relies less on low carbon gases—inclusive of biogenic RNG, synthetic RNG, and hydrogen—than other Pathways, and the majority of what is available is allocated to the electricity sector. To help support electricity sector needs, the Electrification Pathway assumes dedicated solar resources are available for the production of synthetic RNG. The Low Carbon Fuels and Diversified Pathways allocate significant quantities of RNG to the building sector. Across all Pathways, the East River cogeneration facility consumes a proportionally large share of RNG to facilitate steam system decarbonization. **Note**: *The East River cogeneration facility provides steam to the Con Edison steam system as well as electricity.*

FIGURE 41: ANNUAL GAS USE (FOSSIL AND LOW CARBON) IN THE 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. The impact on gas use of an alternative building electrification scenario in which electrification mostly occurs before 2030 or after 2030 is also shown. The "Higher Building Electrification Pre-2030" scenario was used in the Pathways modeling.

The Electrification and Diversified Pathways require significant amounts of battery capacity but the availability of RNG reduces the overall battery capacity needed.

Low carbon gases can facilitate GHG emissions benefits for buildings that do not electrify end uses. In the Electrification Pathway, RNG is not allocated to the buildings sector; therefore, the approximately 40% of buildings that do not electrify still largely rely on fossil gas to power heating and DHW systems (except for buildings remaining on the steam system). The Low Carbon Fuels Pathway prioritizes low carbon gas allocation to the buildings sector. As a result, even with half the number of buildings electrifying in this Pathway compared to the Electrification Pathway, the buildings sector GHG emissions of the Low Carbon Fuels Pathway in 2050 are 11% lower than that of the Electrification Pathway.

Energy efficiency in particular is a key measure to mitigate the risk of limited low carbon gas supply. If low carbon gas was not available to the buildings sector in the Low Carbon Fuels Pathway, overall citywide emissions still decline by 75% due to the extensive energy efficiency investments assumed in this Pathway (in addition to 100% zero-emission electricity, as assumed in all Pathways).

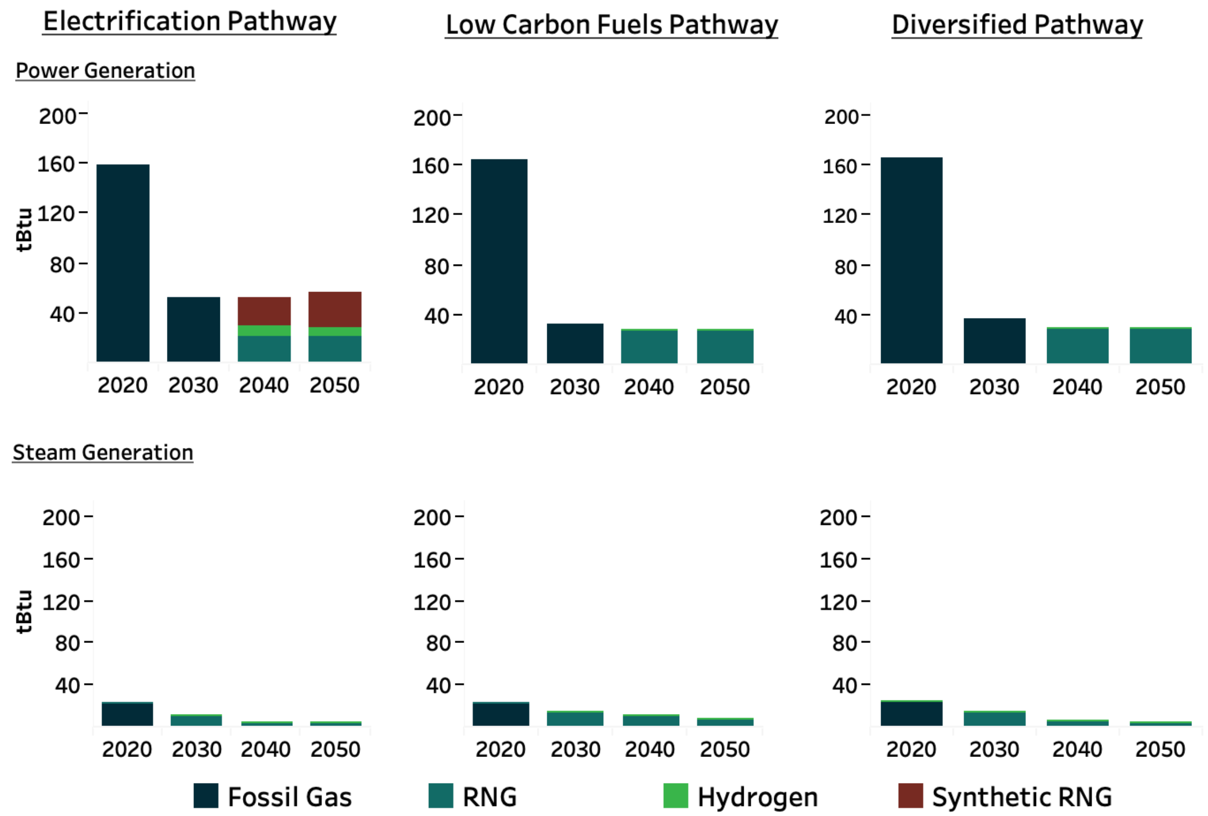
Total gas demand across all sectors falls more than 60% while delivered energy costs increase.

Across all Pathways, demand for gaseous fuels declines largely due to reduction in natural gas power generation to meet clean electricity goals, energy efficiency efforts, and electrification of end uses. In 2020, total gas demand exceeds 500 tBtu; by 2050, demand drops to or below 212 tBtu. Gas use in the buildings sector falls 51-70% across the Pathways, with the most modest decline in the Low Carbon Fuels Pathway (Figure 41). With shrinking throughput of gas and a declining customer base as approximately 30-60% of buildings electrify, the cost per unit of gas delivered increases.

Across all Pathways, gas use for electricity and steam generation falls by an even greater amount than for the buildings sector (Figure 42). In all cases, annual gas use for electricity and steam transitions from fossil to entirely low carbon gas by 2040.

As delivered costs increase, more customers may find it economical to electrify end uses. This fuel-switching would continue to 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 42: ANNUAL GAS USE (FOSSIL AND LOW CARBON) IN STEAM AND POWER GENERATION, SELECT YEARS



In the electricity sector, fossil gas use drops to zero between 2030 and 2040 and is replaced entirely by low carbon gases. The steam system also becomes fully reliant on low carbon gases by 2030. In the Electrification and Diversified Pathways, all low carbon gas used for steam generation by 2040 is at the Con Edison East River cogeneration facility that efficiently generates electricity and steam. The Low Carbon Fuels Pathway includes continued use of additional steam boilers.

Continued maintenance and state-of-good-repair investment in the gas system is required to provide safe, reliable service and reduce emissions.

Due to regulatory requirements, gas utilities must provide safe, reliable service to customers and are responsible for pipeline infrastructure in their service territories. Investments to replace leak-prone pipes in the gas system are currently required by regulators to minimize gas leaks from pipes for safety reasons, no matter the volume and composition of gas flowing through the pipes. These investments could also have some climate and service reliability benefits. The continued use of methane-based fuels across all Pathways increases fugitive emissions from 6% of the city's emissions in 2020 to between 11 and 15% of the city's emissions by 2050, highlighting the importance of continued efforts to reduce leaks from local distribution systems.[y,154]

Capital cost control could be facilitated through coordinated geographical targeting of electrification. Failure to do so could result in increased system integrity costs to the remaining smaller customer base. If significant new capital project development slows, regulators may need to consider alternate ratemaking strategies that help utilities and shareholders recover costs, relying less on capital expenditure returns and more on maintenance and system efficiency. Other predicted and unpredicted challenges could arise as the city and utilities grapple with decreasing gas consumption.

y As of 2019, 35% of National Grid's and 42% of Con Edison's pipelines are small diameter cast iron and unprotected steel, and both utilities have implemented significant capital programs based upon State and Federal safety and reporting requirements to replace these potentially leaky pipes over the coming decades.

DISTRICT ENERGY

District energy systems are centralized heating and cooling systems that serve multiple buildings via water or steam distribution pipes. The Con Edison steam system is the largest of all district energy systems in the city and Brooklyn Navy Yard's (BNY) industrial campus hosts the second largest steam system in the city. The plant that generates the steam for BNY, the Brooklyn Navy Yard Cogeneration Plant (BNYCP), provides steam to Con Edison's system in Manhattan as well as separately serving industrial customers at the BNY campus. Other district energy systems in NYC operate independently at colleges and universities, hospitals, housing cooperatives and business districts.

Decarbonizing the city's district energy systems that produce and circulate steam is an opportunity to reduce emissions in buildings that are less suitable for heating system retrofits and currently use district steam. For very large buildings and industrial buildings, continued use of district steam systems avoids costly renovations associated with installing on-site heating and DHW equipment. In particular, buildings that were originally designed to use steam from a district system may not have space to install on-site equipment and have different maintenance and operational experience. However, maintaining district steam systems while demand falls presents a challenge. Decarbonizing large district steam systems requires using low carbon gas-fired heating equipment or electric boilers. Decarbonizing smaller campus district energy systems can use geothermal energy in addition to low carbon gas.

TABLE 10: KEY DISTRICT ENERGY SYSTEMS FINDINGS FROM THE PATHWAYS MODELING

	Electrification	Low Carbon Fuels	Diversified
Continued district steam use for very large commercial buildings, institutional buildings, and industrial facilities avoids costly retrofits.[z]			
The proportion of very large commercial buildings citywide (in square feet) that use Con Edison district steam in 2050 (compared to 70% in the Policy Reference Case)	47%	67%	47%
Demand for the Con Edison steam system falls steeply by 2050, presenting challenges for managing infrastructure and associated costs.			
Percent decline for Con Edison's steam system production by 2050, compared to 2020	65%	54%	65%
Percent decline for BNY's steam system production by 2050, compared to 2020		54%	
Gas-powered district steam generation is assumed to switch to low carbon gas by 2040; electric steam generation is introduced for Con Edison's system in 2040 but is limited by low efficiency and high capital costs compared to gas-fired steam generation.			
Trillion British thermal units (tBtu) of steam generated from low carbon gas in 2050 (compared to 23 tBtus generated from fossil gas in 2019)	10.5	15.7	10.5
mmBtus of electricity used to produce steam in 2050 (no district steam was generated from electricity in 2019)	630,000	-	450,000
Campus steam systems implementing geothermal energy systems can reduce electricity and gas consumption in campus buildings.			
Campuses that adopt geothermal energy for steam generation		63	

z Very large buildings are buildings greater than 500,000 square feet and are predominately commercial. There are about 500 very large commercial buildings in NYC, concentrated in Manhattan, with over 380 million square feet of space. Institutional buildings include hospitals and health care centers, schools, religious buildings, and universities. Industrial buildings include factories and warehouses.

Continued district steam use for very large commercial buildings, institutional buildings, and industrial facilities avoids costly retrofits

The Con Edison steam system is the nation's largest and oldest district energy system. Citywide, 16% of heating and hot water demand (on a square foot basis) was met by the Con Edison steam system in 2019, which delivers 23 billion pounds of steam annually–the energy equivalent of powering a quarter million homes. Very large commercial buildings are some of the most iconic structures in the city and as of 2019, over 70% of their square footage relied on the Con Edison steam system for space heating and cooling and hot water services. These buildings, which are located in dense areas of Manhattan such as midtown, make up a disproportionate share of buildings sector emissions and are challenging to electrify due to their size and potential space limitations within and outside of the building to locate new on-site steam generation equipment. In the Low Carbon Fuels Pathway, 67% of very large commercial building space continues to be served by the Con Edison steam system. The Electrification and Diversified Pathways move some of these buildings off the steam system such that 47% of very large commercial building space uses Con Edison district steam.

Buildings currently served by the Con Edison steam system are heated with steam supplied by the system. In order to leave the system, each building would need to implement on-site electrified or high-efficiency gas-fired heating systems. Many of these buildings were designed and constructed to receive steam from the central system; they may not currently have space for a large boiler or heat pump system and would require additional renovations to prepare for a new on-site system, potentially incurring large capital costs. In the Low Carbon Fuels Pathway, for example, more commercial buildings rely on the Con Edison steam system than in other Pathways.

Industrial customers rely on large and small district steam systems for heat that would be difficult to replace with electric heating systems. The BNYCP provides about three million pounds of steam per year to industrial customers. BNY is a vibrant center of urban manufacturing that is home to over 400 businesses and supports over 11,000 jobs.[155] Maintaining district steam system service in industrial areas avoids the high costs of retrofitting to provide on-site steam or heat generation. All Pathways continue to supply steam to industrial customers using the BNY steam system, relying on low carbon gases to generate steam after 2030.

Demand for the Con Edison steam system falls steeply by 2050, presenting challenges for managing infrastructure and associated costs

Annual steam demand falls over the study period in every Pathway, driven by existing customers installing electric space- and water-heating equipment to meet citywide decarbonization goals. Among customers that remain on the steam network, energy efficiency measures also reduce demand. In the Low Carbon Fuels Pathway, heating and hot water demand met by the Con Edison steam system drops from 16% of total building square footage in 2019 to 13% by 2050. Only 7% of building square footage remains on the steam system by 2050 in the Electrification and Diversified Pathways as building space heated by Con Edison's steam system is reduced by over half. Remaining steam generation from the Con Edison steam system after 2040 primarily services large customers.

As a result, aggregate district steam production falls by 60% for all district steam systems in the Electrification and Diversified Pathways and falls by 41% in the Low Carbon Fuels Pathway between 2020 and 2050 (Figure 44). Cuts are even steeper on the Con Edison steam system. For Con Edison, aggregate steam production falls by over 65% in the Electrification and Diversified Pathways and falls by 54% in the Low Carbon Fuels Pathway by 2050. Steam production for the BNY steam system declines 54% in all Pathways, and BNY only maintains its industrial customers.

A smaller customer base for the Con Edison steam system in particular can make it more difficult to recover costs for system maintenance and upgrades while maintaining a safe and reliable system. This is especially important as remaining customers reduce consumption after implementing energy efficiency retrofits. Several sites that currently produce steam would no longer be needed by 2040 and after 2040, BNYCP would no longer provide steam to Con Edison's system. In this context, large investments to electrify the steam system, such as the electric boilers assumed to be installed in 2040 in the Electrification Pathway, would be more difficult to justify. Additionally, operating expenses, which are a function of maintaining the equipment, technology, and distribution system footprint, would not fall commensurate with lower demand.

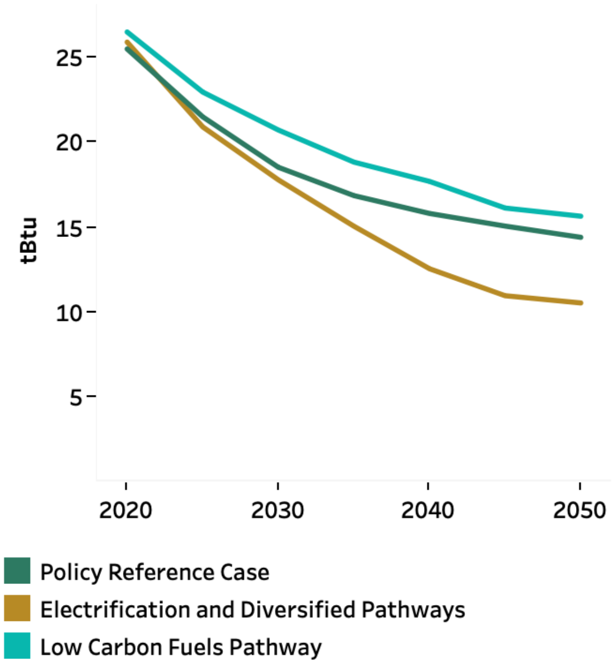
The departure from the steam system would not be uniform. Small buildings, which have less complex building systems and face lower capital costs to electrify than larger buildings, are likely to be the first to switch from steam to electric heating. Larger buildings could leave at a slower rate. As the steam system transforms, there is an opportunity to update current infrastructure to consolidate investment around servicing only the largest customers that are the most difficult to decarbonize.

Gas-powered district steam generation is assumed to switch to low carbon gas by 2040; electric steam generation is introduced for Con Edison's system in 2040 but is limited by low efficiency and high capital costs compared to gas-fired steam generation.

This study assesses two strategies to lower emissions from the Con Edison steam system: using low carbon gas in place of fossil fuels at some existing steam generating plants and replacing a subset of the generation plants with electric boilers. Gas-fired steam generation plants include boilers used to supply steam and East River cogeneration units which provide both steam and power. In all Pathways, some generating plants retire because they are no longer needed to meet demand; due to high operational efficiency, Con Edison's East River cogeneration facility is assumed to stay online through 2050.

All Pathways assume there is sufficient low carbon gas to fully supply steam system energy requirements by 2040 (Figure 43). In the Electrification Pathway, in which a smaller supply of biogenic RNG is assumed to be available to replace fossil gas, the steam system and East River cogeneration facility consume 70% of all biogenic RNG between 2020 and 2050. In the Low Carbon Fuels and Diversified Pathways, about half of all available biogenic RNG is used for steam system generation and East River cogeneration (48% and 46%, respectively).

FIGURE 43: STEAM PRODUCTION FOR DISTRICT STEAM SYSTEMS, 2020-2050



Demand for steam delivered by district steam systems (including the Con Edison steam system, BNY steam system, and small campus district systems) falls due to buildings implementing energy efficiency measures and defections from the Con Edison and BNY steam systems.

The Electrification and Diversified Pathways assume that any steam demand in excess of what is provided by gas-powered steam generation after 2040 is met by installing new electric boilers. Electric boilers are estimated to provide about 10% of total steam generation in the Electrification Pathway and 8% of total steam generation in the Diversified Pathway by 2050. These boilers are much less efficient and have higher capital cost than their gas counterparts. To counter these efficiency losses, electric boilers would primarily replace existing boiler plants in Manhattan, where steam distribution energy loss is lower than the system average.

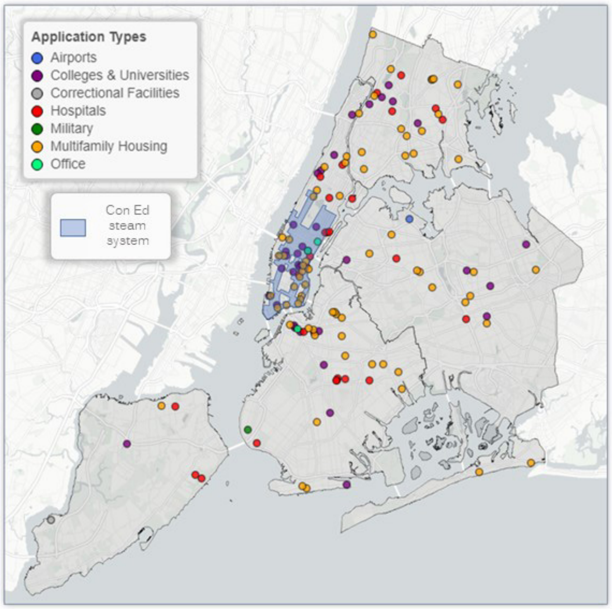
In addition to their inefficiencies and high costs, electric boilers impose disproportionate strain on electric infrastructure. In the Electrification and Diversified Pathways, electric boilers generate steam for 0.65% of the city's building stock on a square-foot basis yet contribute 700 MW to peak demand—roughly 5% of the entire city's peak electricity demand in 2050. Increasing the grid peak has significant implications on total electricity costs due to the need for more installed capacity. Installing industrial-scale electric boilers would also incur additional costs to upgrade electricity delivery but these were not quantified in the analysis.

Campus steam systems implementing geothermal energy systems can reduce electricity and gas consumption in campus buildings.

Geothermal energy and shared infrastructure can help decarbonize large buildings and institutional complexes. District energy often uses traditional gas-fired systems to generate steam and hot water to serve multiple buildings. Geothermal heat pumps, if used to replace these gas-fired systems, could convert a campus heavily reliant on fossil gas into a low-carbon, self-contained system with lower overall costs. If a geothermal-powered district energy system is coupled with combined heat and power (CHP), it would produce electricity as well as steam, improving system reliability and resilience.

This analysis identified over 100 single-owner campuses suitable for district energy system installation based on building system design. Of those, 63 sites could use a ground-source heat pump to provide adequate energy based on building heating needs and the geothermal potential of each site (Figure 44). Across all Pathways, it was assumed that these 63 sites install geothermal systems to serve all or some of their space heating and cooling requirements. Most of these sites could not serve all requirements with ground-source heat pumps. Therefore, in the Low Carbon Fuels Pathway, CHP systems partially powered by the same blend of fossil and low carbon gas used in the buildings sector are installed on geothermal district campuses to cover any additional hot water and space heating requirements. Combining geothermal energy with CHP has several benefits, including reduced pollution, increased reliability, and lower energy costs.[156] The installation of these systems offsets utility-supplied electricity and gas that campuses would otherwise use.

FIGURE 44: POTENTIAL DISTRICT ENERGY NETWORKS BY APPLICATION TYPE



Over 100 locations were identified to be suitable for installing district energy systems. Of those, 63 sites could use a ground-source heat pump to provide adequate energy.

Total capital costs of $1.7 billion are included in each Pathway for geothermal campus energy systems. Geothermal systems have highly variable costs, however, making full cost estimates uncertain. Drilling and boring required in a dense city with tight space constraints, for example, can add significant cost premiums to projects, depending on the site. The City can help reduce geothermal project costs by reducing complexity in the zoning and permitting processes.

Conclusion

This study finds that the City's existing policies, along with those of New York State, provide a strong foundation for climate progress. However, these policies alone are insufficient to reach the City's emissions reduction goals; achieving carbon neutrality by 2050 will require 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.

The following sections identify key strategies that can be used to progress toward carbon neutrality, informed by the extensive Pathways modeling conducted for this study. These strategies are centered around three key themes: modernizing the way New Yorkers use energy, reimagining the role of existing infrastructure, and reaching toward carbon neutrality.

MODERNIZE THE WAY NEW YORKERS USE ENERGY

The Pathways modeling shows that maximizing direct emissions reductions and achieving carbon neutrality will require a significant shift in how New Yorkers use energy to commute, heat their homes, and power the economy. This modernization of the city's energy use will also provide cleaner air, safer streets, and new economic development opportunities.

Modeling Insight: Energy efficiency and the rapid adoption of electrified heating and domestic hot water systems in buildings are major drivers of emissions reductions.

Insight to Action: Unlocking investments in energy efficiency and electrification measures at the scale modeled in the Pathways requires new policies and programs including building codes, permitting processes, and emissions reduction mandates like Local Law 97 of 2019. New policies must be thoughtfully implemented to reduce the financial burden on consumers, particularly on low-income households. Outreach to building owners, coordination with contractors, and financing tools can facilitate greater adoption of difficult-to-implement measures like conversions to air source heat pumps and more extensive energy efficiency measures. Pilot projects in building typologies that are harder to electrify can demonstrate feasibility and identify best practices. Workforce and business development programs can ensure a ready workforce to implement projects at the scale identified in the Pathways, while also driving economic development.

Modeling Insight: Rapid adoption of zero-emission vehicles (ZEV) and reduced dependence on personal vehicles provide emissions reductions and health benefits.

Insight to Action: Rebates and other upfront incentives can close the already declining gap in upfront costs between ZEVs and vehicles with internal combustion engines. Clear deployment targets can signal to the market the scale of adoption anticipated over time. Unlocking new charging infrastructure citywide is essential for ZEV adoption. Building codes and financial incentives can set the city on the right course to deploy the amount of charging infrastructure necessary to support the ZEV penetration identified in the Pathways. Additional investments in public infrastructure and street safety can encourage active mobility while also reducing emissions.

Modeling Insight: The demand profile for electricity will evolve as new heating and transportation loads are added to the system, and peak electricity demand is likely to increase.

Insight to Action: Modernizing how New Yorkers use energy will require greater attention to the timing of electricity consumption to avoid large increases to system peaks. Higher peaks require costly investments in new electricity generation, transmission, and distribution infrastructure. Careful rate design can encourage energy use during off-peak periods, for example by making it more cost-effective to charge electric vehicles at night. Energy storage, dual fuel heating systems, and other demand response technologies can help control costs while also minimizing impacts to customers.

A clean electricity grid is the foundation for NYC's path to carbon neutrality. Without carbon-free electricity, the potential emissions benefits of building and vehicle electrification would not be fully realized.

REIMAGINE THE ROLE OF EXISTING INFRASTRUCTURE

The reliable and safe operation of existing energy infrastructure—especially the networks of wires and pipes that deliver electricity, gas, and steam into buildings across the city—is a linchpin of the local economy, supporting social, public health, and other essential services. This study finds that NYC's energy infrastructure will need to be reimagined as a flexible platform for low carbon energy sources, connecting NYC to significant amounts of new clean energy, integrating distributed and local resources within the city, and supporting flexible demand management applications across the grid.

Modeling Insight: A clean electricity grid is the foundation for NYC's path to carbon neutrality. Without carbon-free electricity, the potential emissions benefits of building and vehicle electrification would not be fully realized.

Insight to Action: Meeting the State's goal of 100% zero-emission electricity by 2040 will require unprecedented amounts of new clean electricity resources such as offshore wind, solar, and hydropower. Ongoing coordination with New York State and the region, including the New York Independent System Operator (NYISO), will be necessary to ensure that new transmission is built to connect these resources to NYC, overcoming siting and interconnection challenges.

Substantial amounts of largescale batteries could provide the dispatchable electricity to meet peak demand as existing power plants retire. However, the amount of storage that could be required will necessitate new strategies to rapidly site and deploy this technology, especially given the space constraints in the city. There may be opportunities for creative siting—for example, by repurposing sites of retired power generating stations.

Providing low carbon gas to power plants could be another option for dispatchable electricity, although different types of low carbon gas will result in different air quality impacts. The increased reliance and demand on the electric grid amplifies the importance of maintaining a grid that is reliable and resilient—a topic that requires further research.

Modeling Insight: The gas network can deliver renewable natural gas (RNG) and hydrogen to help decarbonize the most challenging to electrify end uses. Gas demand is projected to fall in NYC in all Pathways by more than 60% between 2020 and 2050.

Insight to Action: Additional policy frameworks are needed to help support the decarbonization of the gas sector. Low carbon fuels policies should consider emissions reduction benefits; geographic and jurisdictional issues for resources that may not be located in the same city or state; environmental impacts; social equity issues in relation to siting and resource development; and local air quality considerations.[a] Example policies include RNG portfolio standards and mandates for increasing proportions of GHG-neutral fuels. Feasibility studies or pilot projects could support technology development and reduce the cost of RNG. Such projects could also raise awareness for potential suppliers, like farmers and municipalities, that are hoping to reduce their own carbon footprints and identify additional revenues. Demonstration projects are also needed to better

a While RNG provides a climate benefit compared to fossil gas, synthetic RNG, biogenic RNG, and fossil gas combustion contribute similarly to local air pollution.

understand how hydrogen could be integrated into the energy supply.

The Con Edison steam system provides an important avenue for emissions reductions in very large buildings that were not designed with in-building heating equipment. The modeling shows that one way to ensure that the Con Edison steam system can contribute to decarbonization is through the use of low carbon gas to generate steam. This topic should be further explored.

While the gas system integrates new low carbon resources, it will also have to manage declining total gas use, a trend that will exacerbate the challenge of maintaining a safe, reliable, and cost-effective gas system. Managing this challenge will require innovative thinking and new regulatory approaches. Coordinated action will be needed to limit stranded assets in the city, reduce liabilities for gas utilities, and shield customers from delivered cost increases, particularly those who do not electrify. While many utility matters fall to the State, the utilities and the City can help manage the consumer impacts of the evolving gas system by supporting strategic electrification of buildings, educating customers of anticipated changes, and involving key investors and financial organizations in developing pathways to pay for early retirement of some assets.

REACH TOWARD CARBON NEUTRALITY

While this study shows that reducing NYC's emissions 80% or more by 2050 is technically feasible, it will require rapid, sustained, and successful efforts across individuals, businesses, and government entities. Achieving the City's goal of carbon neutrality will require going even further, including potentially offsetting emissions that are too costly or impractical to eliminate directly. This study finds that NYC will need to begin laying the foundation for carbon neutrality today in ways that will also support achieving the City's nearer-term goals.

Modeling Insight: Forecasting long-term changes in energy and emissions is becoming increasingly difficult. At the same time, ongoing technology innovation and changes in consumer preferences will alter the landscape of potential decarbonization measures that are available over the next 30 years.

From Insight to Action: New technologies and use cases are constantly emerging across all sectors. Changes in cost and performance of carbon-reducing solutions are accelerating, driven by difficult-to-predict innovations occurring around the world. Additionally, economics and consumer behavior can change in short order: the onset of the global COVID-19 pandemic and its economic ramifications were impossible to predict and have made historic changes to U.S. emissions. Finally, there are risks that key measures may not materialize at the pace and scale included in the Pathways.

These uncertainties underscore the importance of maintaining optionality by pursuing a portfolio of measures simultaneously, regularly reassessing the City's strategy, and adopting technology-neutral policies when and where possible. Strategies that target long-term emissions reductions must identify short-term actions that stand up to long-term uncertainty. Regularly evaluating progress toward emissions goals, key technology developments, and opportunities for new abatement strategies will help manage uncertainty.

Innovation will ease the cost and difficulty of reaching high levels of GHG emissions reductions and could radically alter the ideal decarbonization approaches for NYC. The emissions reduction measures assessed in this study represent commercial or near-commercial technologies. Continued innovation in technology, policy, and business models can provide new options and opportunities for NYC. Innovations across the technology spectrum—ranging from the efficiency of dishwashers to breakthroughs in zero-carbon fuels—can continue to change the possibilities and importance of different measures. Other areas with the potential for breakthrough innovation that could radically change NYC's approach include long-duration and seasonal storage, geothermal district energy systems, solar-powered low carbon gas production, and carbon dioxide removal. The ingenuity and drive of New Yorkers can be a wellspring of ideas for how best to reduce emissions in the city. Early demonstration and pilot testing of novel energy and infrastructure solutions can engage the strength of the existing business ecosystem. The extensive network of innovative companies, individuals, and organizations in NYC can create innovations tailored to the complexities of the city.

Modeling Insight: Across the Pathways, 10-19% of GHG emissions remain by 2050 due to technology limitations and cost constraints.[b]

From Insight to Action: Until innovations emerge to address hard-to-decarbonize end uses, carbon offsets are needed to reach economywide carbon neutrality. Emissions offsets support the City's carbon neutrality goal by allowing for a limited number of direct emissions in the city to be reduced elsewhere. Carbon offset projects should meet specific environmental integrity principles: unambiguously owned and independently auditable projects should result in real, additional, permanent, transparent, and measurable emissions reductions. Carbon accounting for these projects should also include any emissions increases elsewhere that result from the project's implementation. Other considerations like cost, location, economic development strengths, and environmental co-benefits differ among offset options and should be carefully considered. Additionally, the quantity and timing of offsets must be considered carefully. Offsets should be leveraged as an interim measure and phased out as other technologies and emissions abatement strategies are implemented. If offsets are offered too early or too often, policymakers, innovators, and emitters may shift focus away from direct mitigation efforts.

While several carbon dioxide removal technologies currently exist, the markets for related offsets are still relatively undeveloped. Establishing a policy framework should begin early and coordinate with local, state, and regional stakeholders.

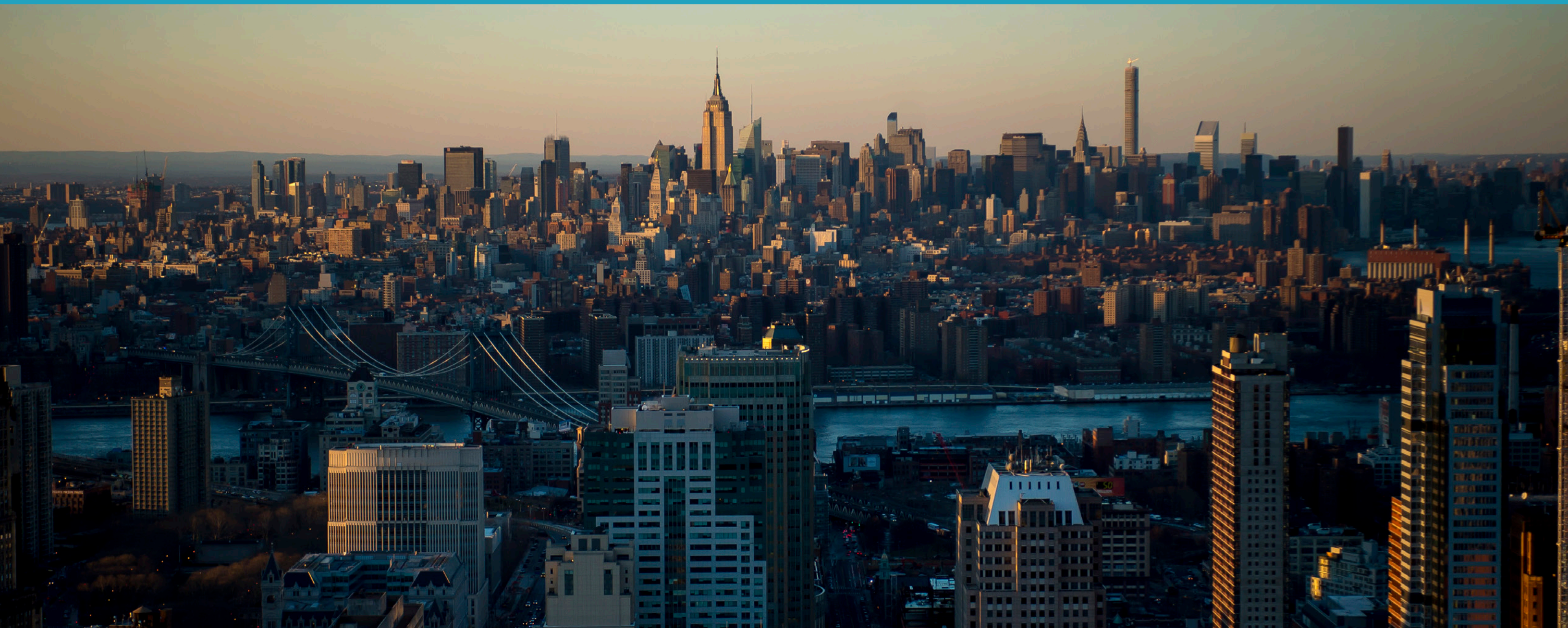
Modeling Insight: Though Pathways modeling is a valuable tool to compare alternative emissions reduction trajectories, there are additional topics and uncertainties that require further study.

From Insight to Action: While this study helps inform the path ahead, it also raises several areas that warrant additional analysis. Some issues emerge as an implication of the key findings, while other areas for further research are currently too complex or early in their development to properly assess with the same rigor as the measures modeled in this analysis.

Additional areas warranting urgent analysis include:

- the reliability and resiliency implications of a zero-emission electricity grid and future resource options;
- cost allocation, legacy asset management priorities, future infrastructure investments, and cost allocation for the natural gas system;
- geothermal, district thermal networks, and other district energy solutions;
- smart and connected urban systems;
- vehicle-to-grid (V2G) integration; and
- advanced demand side management options.

b Emissions reductions are relative to NYC's 2005 baseline GHG emissions level.



Modeling Insight: Emissions reductions occur across sectors and rely on actions from a number of stakeholders, including significant efforts from NYC's energy utilities.

From Insight to Action: It takes a city to transform a city. Reducing the city's emissions 80% and more requires the contributions of all parts of society. Government, utilities, businesses, advocacy groups, and individuals all have unique roles to play in shaping a rapid, just, and affordable transition to a low carbon future. Enhanced coordination among all of these groups is essential.

Utilities can play an outsized role in reducing emissions. The energy sector is central to every part of urban life, yet at present it is the primary contributor to climate change. Eliminating GHG emissions from the energy system without compromising reliability is perhaps the central challenge of the clean energy transition. This study finds that NYC's energy delivery systems maintained by Con Edison and National Grid will only grow in importance as enablers of cleaner end uses: the electricity system can support the electrification of buildings and more than a million vehicles; the natural gas system can deliver low carbon fuels to end uses too costly and complex to electrify; low carbon gases can also provide fuel to electricity generators that provide reliability services; and the steam system can provide low carbon energy to some of the largest and most iconic buildings in the city.

Enhanced coordination with other jurisdictions is essential. Most of the modeled emissions savings through 2050 are driven by policies outside of the immediate control of the City. The State's target of 100% of electricity met by zero-emission energy by 2040 and federal vehicle fuel economy standards are two examples. Enhanced coordination between the City and other jurisdictions—including those whose policies constrain or enhance the City's efforts—will be increasingly important as the world moves forward together to combat the climate crisis.

This study finds that NYC's energy delivery systems maintained by Con Edison and National Grid will only grow in importance as enablers of cleaner end uses: the electricity system can support the electrification of buildings and more than a million vehicles; the natural gas system can deliver low carbon fuels to end uses too costly and complex to electrify; low carbon gases can also provide fuel to electricity generators that provide reliability services; and the steam system can provide low carbon energy to some of the largest and most iconic buildings in the city.

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