

"What's in Stock: Integrated Modeling of Building Electrification, Energy Efficiency, and Stock Turnover for New York City"

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ABSTRACT

A lead theme in today's state and local climate action plans is to "electrify everything" while decarbonizing electric generation. Passenger vehicle electrification is accelerating as battery costs fall. Building electrification, especially the fuel-fired heating systems that comprise a large share of typical buildings' "Scope 1" or onsite greenhouse gas (GHG) footprint, faces stiffer challenges. This paper explores core issues in heating system electrification by unpacking the methodology and results of the authors' modeling work in the 2021 *Pathways to Carbon Neutral NYC* study. This analysis of New York City's entire building stock is arguably the deepest dive to date into the technical and market issues that a major city faces in forging realistic pathways to carbon neutrality. Specifically, this paper:

- Summarizes the overall technical feasibility analysis used to estimate heating system electrification potential in the City's building stock;
- Describes the diffusion curve and stock turnover model methods used to project electric heating system adoption rates across 20+ building typologies;
- Unpacks key modeling results that illuminate relationships between energy efficiency, heating electrification, energy use, GHG emissions, and electric system peak demand;
- Suggests implications for decarbonization policy and program design; and
- Identifies areas for future research and analysis.

Introduction

The purpose of the *Pathways to Carbon Neutral NYC* study was to provide insight into key decarbonization options, risks and tradeoffs through developing a range of pathways to meet at least 80% greenhouse gas (GHG) emissions reductions relative to a 2005 baseline. The study was a joint partnership between city government (NYC Mayor's Office of Sustainability), and investor-owned utilities (Con Edison and National Grid), and therefore required coordination and collaboration between key stakeholders with a range of priorities.

The study was multi-sectoral, including buildings, transportation, and industry end-uses, plus electricity and natural gas supply, and also district energy and waste. This paper focuses on ICF's buildings end-use analysis. In 2019 buildings represented 68% of the City's GHG emissions, and over 5 billion square feet as shown in Figure 1 and Table 1, so were a key focus of the study. The buildings analysis built upon prior studies on NYC's building stock, notably "*One City Built to Last Technical Working Group Report: Transforming New York City Buildings for a Low-Carbon Future*" (TWG report). The TWG report categorized NYC's buildings stock into 21 distinct typologies shown in Figure 2, based on building group, vintage, and height.

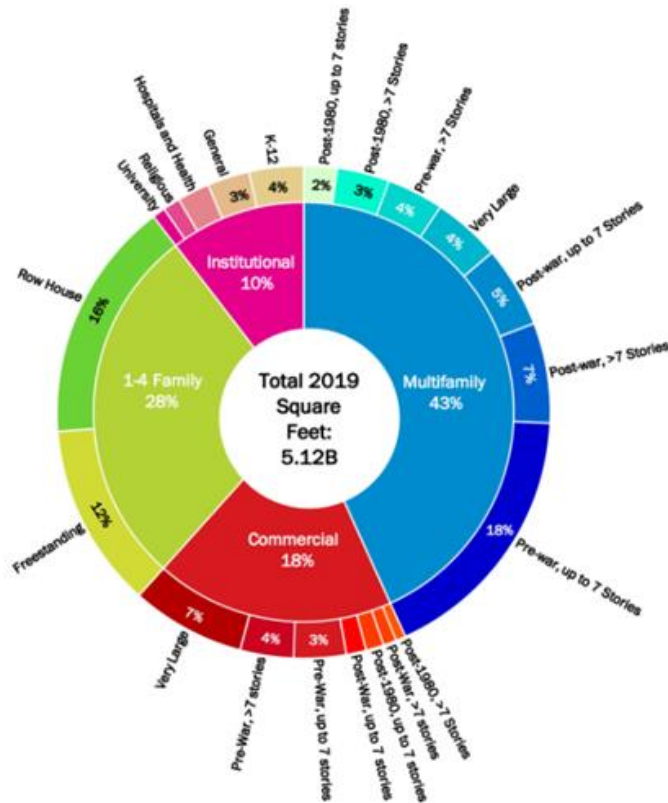


Figure 1. Floor area of building typologies Source: Pathways to Carbon Neutral NYC, Figure 5

Table 1. Building Typology Summary

Building Group	Building Typology
1-4 Family	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

ICF simulated each of these typologies through a set of energy models that were used to quantify changes in energy use and associated GHG emissions impact from energy efficiency and building electrification measures adopted in each of the study’s pathways.¹ The models, originally developed by the TWG, included a baseline (or reference) building, and then simulated the impacts of various upgrades that were based on the TWG work, but were also expanded to simulate multiple energy efficiency ‘Tiers’ or measure bundles. The retrofit packages we modeled were:

- **Electrification:** replacement of existing heating and hot water equipment with electric equipment. The electric technologies modeled include air source heat pumps (ASHPs) for space heating and heat pump water heaters (HPWHs) for domestic hot water. In some typologies, electric instantaneous water heaters or electric boilers were used instead of heat pumps. Additionally, in some typologies cooking end uses were also electrified.
- **Low Carbon Fuels:** replacement of existing fuel-fired equipment with high efficiency gas equipment, such as boilers and condensing tankless water heaters, and cooling equipment with currently available high-efficiency models.²
- **Tier 1 Energy Efficiency:** Included less-expensive measures, which were installed most commonly across large fractions of each typology’s total floor area. For residential buildings, Tier 1 included low-flow water fixtures, high-efficiency ‘white goods’ appliances, air sealing, controls, and lighting upgrades. For larger multifamily and commercial typologies, Tier 1 energy efficiency included more expensive items like elevators and building control systems.
- **Tier 2 Energy Efficiency:** Included envelope retrofits such as insulation and window replacements and was generally more costly than Tier 1 energy efficiency, except for very large buildings. Tier 2 measures were applied less extensively than Tier 1 packages.
- **Recladding:** The final (at least commonly applied) energy efficiency tier included more extensive and costly building envelope upgrades, such as exterior wall insulation of masonry buildings.

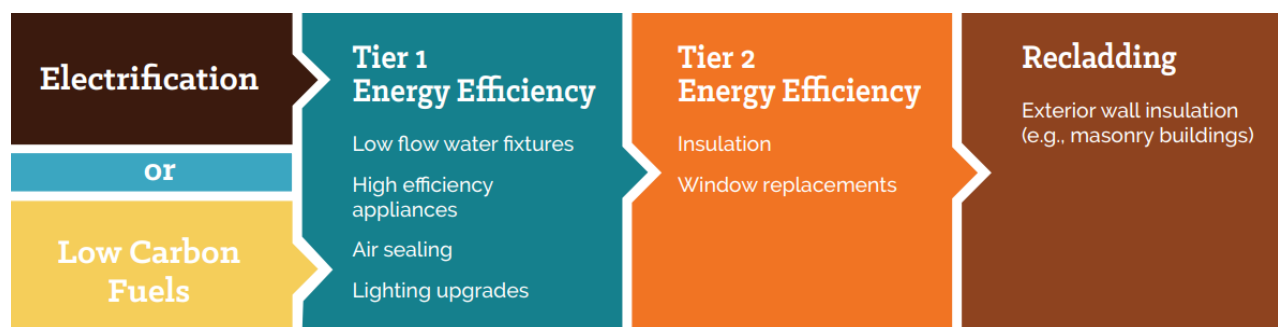


Figure 3. Building Retrofit Packages. *Source:* Pathways to Carbon Neutral NYC Final Report, Figure 3

¹ 1-4 family typologies were modeled with BEopt, and all other typologies were modeled with eQuest; eQuest was used because it was the model employed by the TWG, and this project built on that simulation work.

² While the “Low Carbon Fuels” retrofits for this buildings sector analysis consist only of energy efficiency measures, the broader pathways analyses did decarbonize fuels in various proportions (e.g., renewable natural gas, and biofuels for vehicles), so this term was used throughout the study.

As shown in Figure 3, the ‘Tiers’ of energy efficiency are assumed to be implemented in sequence. For example, every building with Tier 2 energy efficiency upgrades would also have Tier 1; and every building with Recladding would have Tier 1 and Tier 2 efficiency upgrades. energy efficiency upgrades implemented.

Each of the baseline/reference buildings and retrofit packages were modeled in detail, with simulation results including 8760-hour load profiles. These simulated results were then calibrated to observed historical energy use from the New York City Greenhouse Gas Inventory and Local Law 84 (LL84) data; LL84 requires buildings of 25,000 square feet or larger to conduct and disclose annual energy performance benchmarking analysis. This step increased confidence in the simulation results.

Heating system electrification feasibility analysis

A key part of the study was developing credible projections of the trajectory of electrification in NYC’s buildings, taking into account technical feasibility and other factors for each building typology. Because the New York State legislature enacted the Climate Leadership and Community Protection Act in 2019, requiring the state’s power sector to become carbon neutral by 2045, building electrification became a salient strategy in this study, and so realistic estimates for the rate of electrification in the coming decades were of great interest. ICF was thus tasked with a ‘deep dive’ effort to develop these estimates, in a collaborative process involving the study sponsor team (NYC Mayor’s Office of Sustainability, Con Edison and National Grid), and informed through a 23-member Technical Advisory Committee including buildings experts and other stakeholders with substantial knowledge and experience in these issues.

Deep Dive Feasibility Assessment

Because of time and budget limitations, this effort focused on two of the most common typologies, Multifamily/ Pre-war/ up to 7 stories and Commercial/ Pre-war. greater than 7 stories. ICF devised an assessment approach using a combination of two ‘scores’ that were qualitative yet data-driven and informed by expert guidance: a technical feasibility score and a market preference score. These scores were used for each typology to project the potential adoption of various heating technologies (e.g., variable refrigerant flow (VRF), packaged terminal heat pump (PTHP), multi-split heat pump, air-to-water heat pump, ground source heat pump (GSHP), and the lowest-cost replacement of a standard-efficiency gas boiler).

The technical feasibility score was established based on heating system installation cost, with adders to account for other costs that could be incurred (e.g., electrical system upgrades, envelope modifications for a packaged terminal heat pump). We used the City’s Local Law 87 (LL87) data, which requires the buildings covered by LL84 to also conduct energy audits, establish existing heating system types, identify possible technical barriers to electrification, and estimate the need for building modifications to overcome those barriers. For this feasibility analysis, cost-effectiveness was not calculated, though installation costs were part of the analysis. Cost-effectiveness calculations came later in the project, once technology choices were finalized and upgrade packages were modeled for each building typology, as part of the project’s integrated pathways analysis.

The market preference score was quantified as a numerical range from ‘not preferred’ to ‘highly preferred,’ based on two factors. The first factor was “Technology Market Maturity,” which assessed a technology’s availability, City installation history, and capability to meet heating demands (e.g., cold climate heat pumps). For example, gas boilers were ‘highly preferred’ because they are currently the most common equipment type in the City, whereas air-to-water heat pumps were less preferred because of limited availability. The second factor was “Technology Applicability to Typology,” taking into account the likelihood of each equipment type to be feasible for use in a given typology. For example, space and land constraints were considerations for ground source heat pumps, which made them less preferred in most areas of the City.

The technical feasibility and market preference scores were combined and normalized, and then were used as inputs to a Bass diffusion curve to project market adoption rates. A Bass diffusion curve is a differential equation that describes how new products are adopted in a market. Two key 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.

A range of common “coefficients of innovation” and “coefficients of imitation” was evaluated based on an NREL study³, and used to inform values for this specific analysis. A range of coefficient values was established based on LL87 data on the age of natural gas boilers in NYC buildings. While not a perfect data set, LL87 data sufficed to set bounds for high and low technology adoption ranges. These values were then used as assumptions for ‘high’ ‘moderate’ and ‘low’ electrification in the pathways construction process. The final input to the Bass diffusion curve was the assumed year of introduction of a technology (e.g., an efficient boiler or heat pump), which was estimated based on input from the Technical Advisory Committee.

We used these combined market preference and technical feasibility scores and inputs to the Bass diffusion curve equation to project adoption rates for electric heating technologies in each building typology. Figure 4 below shows a sample of these results: it reveals a gradual decline in existing heating systems (labeled as “Baseline Systems” in the chart which consist primarily of natural gas and oil-fired boilers), and substantial growth in installations of both new standard efficiency non-condensing gas boilers and electric heating systems. In this example, gas boilers are much more likely to be selected than any single electrification measure, because they are the incumbent technology and the lowest-cost replacement. Each individual heat pump system results in a range between 1% to 13% market share in 2050, meaning a total of approximately 30% of this typology was electrified. Other results showed much higher rates of electric system adoption. The adoption curves we developed were based on equipment costs, efficiency, and market conditions at the time the study was conducted. Therefore, future changes in these parameters (e.g., lower costs) could result in increased adoption of a given technology.

³ <https://www.nrel.gov/docs/fy18osti/70138.pdf>

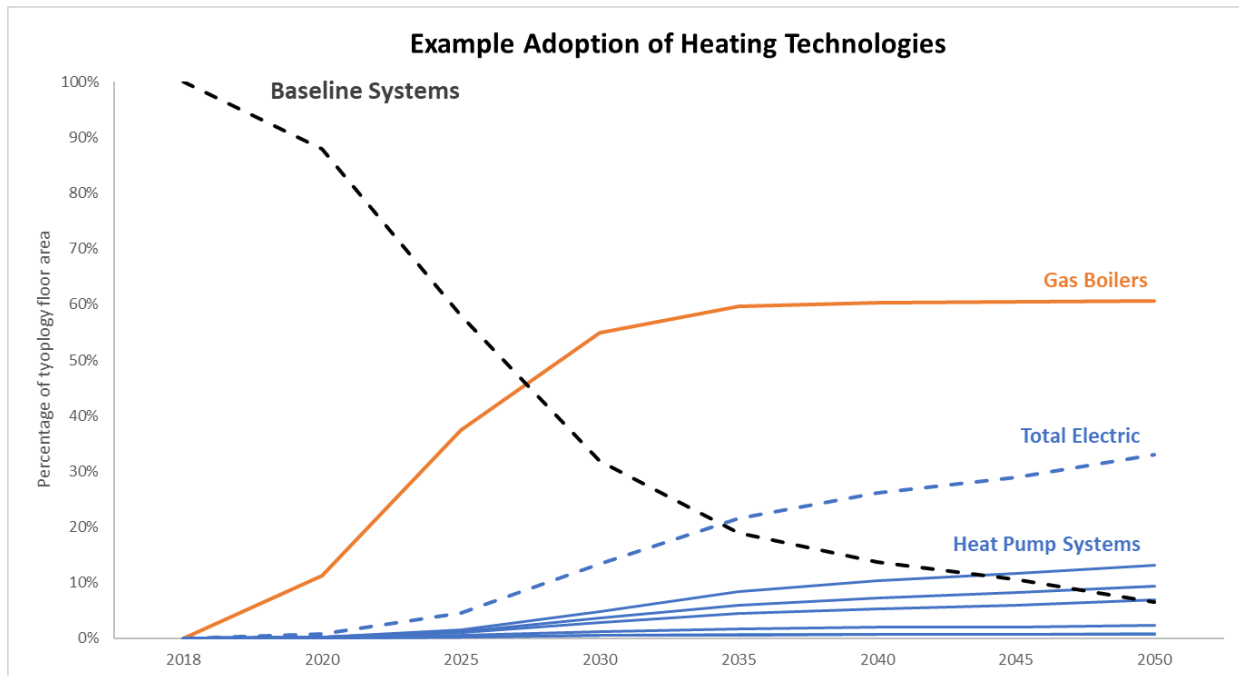


Figure 4. Example technology adoption curves from deep dive feasibility results. *Source:* ICF interim work product

Applying the feasibility assessment across the full building stock

The deep dive feasibility outputs were then used to project adoption rates for electric heating technologies across the full set of 21 building typologies. But instead of assessing a full range of electrification technologies, this wider analysis assessed heating electrification rates via a simpler approach. This involved developing an additional factor to modify the technical feasibility score to reflect characteristics of each typology that make it more or less likely to adopt electrification technologies. For most typologies, we used factors based on existing heating system types found in LL87 data. For example, if there was a significant portion of packaged terminal air conditioners (PTACs) in a typology, then it was assumed that the most likely electrification system would be a (PTHP). Conversely, if the building was served by district steam, it was viewed as less likely to install any type of heat pump system.

We then modified the market preference score depending on other building typology characteristics. For example, if a typology was unlikely to have sufficient mechanical room space, or staff available to help plan and implement electrification the market preference score was discounted. In similar fashion to the deep dive analysis, these modified scores were applied to each typology using LL87 data to estimate the share of buildings that were likely to electrify.

Stock turnover modeling

To project the rate of electrification over time, a stock turnover model was developed using LL87 data, and defining key inputs and assumptions. The model is based on a replace-on-burnout assumption, i.e. that heating equipment is replaced at the end of its rated service lifetime.

- Equipment lifetimes were established based on the New York State Technical Reference Manual with one exception. Building heating systems located in Manhattan were

assumed to have a longer service life, reflecting study team knowledge of the logistical challenges of replacing major systems in a dense urban environment.

- For each typology, the distribution of heating equipment age in LL87 along with equipment lifetimes was used to estimate the percent of typologies that would be expected to replace their heating equipment each year.
- Finally, a limit of 6% annual stock turnover was imposed in the model, based on historical boiler permit data. This constraint was added because the LL87 data showed a significant number of systems that were near the end of their expected service life. It served as a reality check on the number of systems that could realistically be expected to be replaced, in line with historical replacement observed in NYC.

This stock turnover model, along with the Bass diffusion curve inputs from the feasibility analyses, were used to estimate building heating systems that could be electrified through the study period. Figure 5 shows an example estimate for a ‘high electrification’ scenario where heating systems serving approximately 60% of the citywide floor area are electrified.

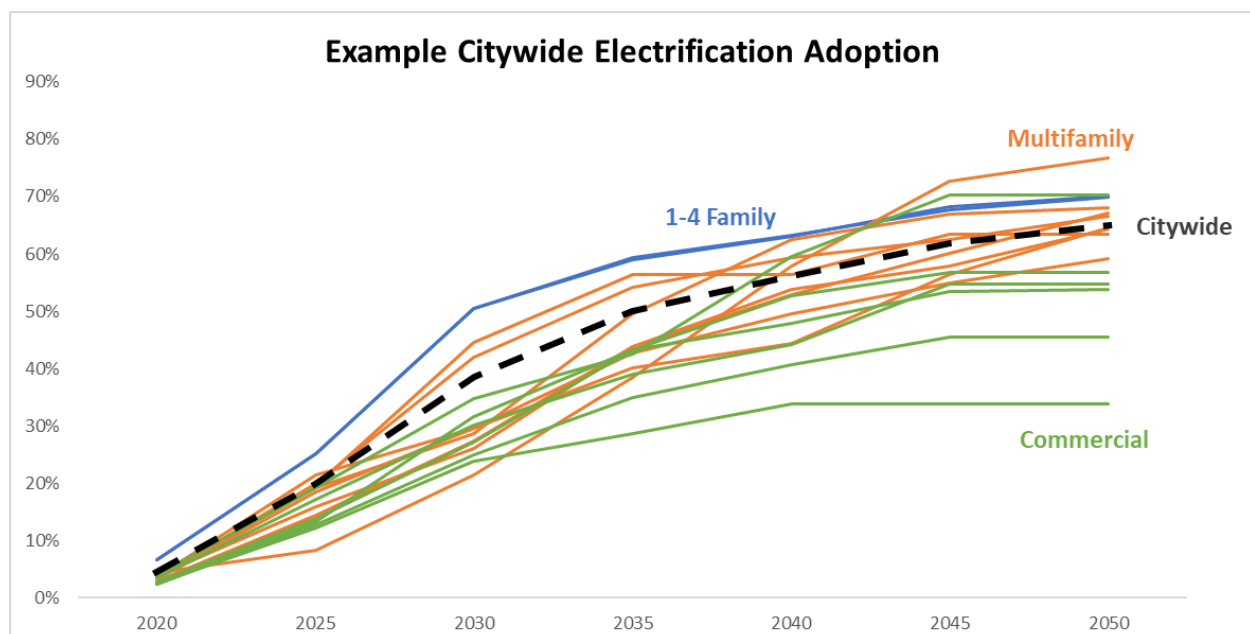


Figure 5: Example adoption curves based on feasibility results. *Source: ICF interim work product*

Pathways Construction Process

The pathways construction process was based on key elements of the analysis described above:

- Energy models used to represent 21 unique building typologies, and a range of electrification, low carbon fuels, and energy efficiency tiers
- Deep dive technical feasibility analysis of electrification technologies accounting for costs and market preferences
- Development of Bass diffusion curves to show a range of ‘high’ ‘moderate’ and ‘low’ electrification

- Inputs - tab contains all user inputs**

 - Select an electrification adoption **scenario** from the options generated via the Technical Feasibility Deep Dive.
Electrification Adoption Category: High Electrification Select an option (see "Adoption Factors" for more details).
 - Modify the relative allocation of **Low Effort EE**, **High Effort EE** and **Recladding**, and the percentage of **Hydronic Conversion**.

Input Type **Simple input (same for all typologies)** *Enter the values below; the values will be used for all typologies*

Low Effort EE 0% *estimates 0-100%*

Low Effort EE + High Effort EE 0% *estimates 0-100%*

Low Effort EE + High Effort EE + Recladding 0% *estimates 0-100%*

Percent Hydronic Conversion 0% *estimates 0-100%*

Percent buildings with no EE (not used) 0% *estimates 0-100%*

3. Select other inputs.

Keep all buildings currently on the Co2D Stream Loop

District Steam Methodology RNG

RNG Scenario high

Outputs

View City-wide scenario results

2050 % emissions reduction 83.5%

2050 Total Net Cost (millions 2019 \$) \$10.17

Annual Energy Consumption by Fuel Type

Inputs - Detailed Edit

Typology ID	Typology	Low Effort EE	Low Effort EE + High Effort EE	Low Effort EE + High Effort EE + Recladding	No EE (LDC Only)	Percent Hydronic Conversion
R1	Low Family, Freestanding	0%	0%	100%	0%	0%
R2	Low Family, Row, Single	0%	0%	100%	0%	0%
M1	Multifamily, Post-1980, > 7 stories	0%	100%	0%	0%	0%
M2	Multifamily, Post-1980, up to 7 stories	0%	100%	0%	0%	0%
M3	Multifamily, Post-war, > 7 stories	0%	100%	0%	0%	0%
M4	Multifamily, Post-war, up to 7 stories	0%	100%	0%	0%	0%
M5	Multifamily, Pre-war, > 7 stories	0%	100%	0%	0%	0%
M6	Multifamily, Pre-war, up to 7 stories	0%	100%	0%	0%	0%
M7	Multifamily, Very Large	0%	100%	0%	0%	0%
C1	Commercial, Post-1980, > 7 stories	0%	100%	0%	0%	0%
C2	Commercial, Post-1980, up to 7 stories	0%	100%	0%	0%	0%
C3	Commercial, Post-war, > 7 stories	0%	100%	0%	0%	0%
C4	Commercial, Post-war, up to 7 stories	0%	100%	0%	0%	0%
C5	Commercial, Pre-war, up to 7 stories	0%	100%	0%	0%	0%
C6	Commercial, Pre-war, > 7 stories	0%	100%	0%	0%	0%
C7	Commercial, Very Large	0%	100%	0%	0%	0%
I1	Institutional, General	0%	100%	0%	0%	0%
I2	Institutional, Healthcare & Research	0%	100%	0%	0%	0%
I3	Institutional, K-12	0%	100%	0%	0%	0%
I4	Institutional, Religious	0%	100%	0%	0%	0%
I5	Institutional, University	0%	100%	0%	0%	0%

Existing Construction GFA (M2) **5,130,960,665** 2018-2019 Existing Construction GFA (M2) 2020-2021 Existing Construction GFA (M2) 2022-2023 Existing Construction GFA (M2) 2024-2025 Existing Construction GFA (M2) 2026-2027 Existing Construction GFA (M2) 2028-2029 Existing Construction GFA (M2) 2030-2031 Existing Construction GFA (M2) 2032-2033 Existing Construction GFA (M2) 2034-2035 Existing Construction GFA (M2) 2036-2037 Existing Construction GFA (M2) 2038-2039 Existing Construction GFA (M2) 2040-2041 Existing Construction GFA (M2) 2042-2043 Existing Construction GFA (M2) 2044-2045 Existing Construction GFA (M2) 2046-2047 Existing Construction GFA (M2) 2048-2049 Existing Construction GFA (M2) 2050-2051 Existing Construction GFA (M2) 2052-2053 Existing Construction GFA (M2) 2054-2055 Existing Construction GFA (M2) 2056-2057 Existing Construction GFA (M2) 2058-2059 Existing Construction GFA (M2) 2060-2061 Existing Construction GFA (M2) 2062-2063 Existing Construction GFA (M2) 2064-2065 Existing Construction GFA (M2) 2066-2067 Existing Construction GFA (M2) 2068-2069 Existing Construction GFA (M2) 2070-2071 Existing Construction GFA (M2) 2072-2073 Existing Construction GFA (M2) 2074-2075 Existing Construction GFA (M2) 2076-2077 Existing Construction GFA (M2) 2078-2079 Existing Construction GFA (M2) 2080-2081 Existing Construction GFA (M2) 2082-2083 Existing Construction GFA (M2) 2084-2085 Existing Construction GFA (M2) 2086-2087 Existing Construction GFA (M2) 2088-2089 Existing Construction GFA (M2) 2090-2091 Existing Construction GFA (M2) 2092-2093 Existing Construction GFA (M2) 2094-2095 Existing Construction GFA (M2) 2096-2097 Existing Construction GFA (M2) 2098-2099 Existing Construction GFA (M2) 2100-2101 Existing Construction GFA (M2) 2102-2103 Existing Construction GFA (M2) 2104-2105 Existing Construction GFA (M2) 2106-2107 Existing Construction GFA (M2) 2108-2109 Existing Construction GFA (M2) 2110-2111 Existing Construction GFA (M2) 2112-2113 Existing Construction GFA (M2) 2114-2115 Existing Construction GFA (M2) 2116-2117 Existing Construction GFA (M2) 2118-2119 Existing Construction GFA (M2) 2120-2121 Existing Construction GFA (M2) 2122-2123 Existing Construction GFA (M2) 2124-2125 Existing Construction GFA (M2) 2126-2127 Existing Construction GFA (M2) 2128-2129 Existing Construction GFA (M2) 2130-2131 Existing Construction GFA (M2) 2132-2133 Existing Construction GFA (M2) 2134-2135 Existing Construction GFA (M2) 2136-2137 Existing Construction GFA (M2) 2138-2139 Existing Construction GFA (M2) 2140-2141 Existing Construction GFA (M2) 2142-2143 Existing Construction GFA (M2) 2144-2145 Existing Construction GFA (M2) 2146-2147 Existing Construction GFA (M2) 2148-2149 Existing Construction GFA (M2) 2150-2151 Existing Construction GFA (M2) 2152-2153 Existing Construction GFA (M2) 2154-2155 Existing Construction GFA (M2) 2156-2157 Existing Construction GFA (M2) 2158-2159 Existing Construction GFA (M2) 2160-2161 Existing Construction GFA (M2) 2162-2163 Existing Construction GFA (M2) 2164-2165 Existing Construction GFA (M2) 2166-2167 Existing Construction GFA (M2) 2168-2169 Existing Construction GFA (M2)

With these key elements in place, the study team along with the Technical Advisory Committee set out to construct three pathways that were reasonable, met the overall GHG emission goals, and balanced stakeholder priorities. Given this balancing act, there is no one correct or optimal answer; to support this process, ICF developed an Excel based ‘pathways construction tool’ that allowed the study team to vary key inputs such as:

- The pathways construction tool used some simplifying assumptions to provide interim estimates of impacts relative to a 2005 baseline, so that the team could decide on key buildings inputs before moving on to the full modeling process. These interim outputs provided included:

- GHG emission reductions
- Summer and winter electric grid peaks
- Energy consumption, costs, and savings

3-581

- Capital costs of building upgrades
- Net present value of technology investments

Ultimately the project team landed on three pathways that represent a range of scenarios, all of which achieve significant decarbonization: the Electrification, Low Carbon Fuels, and Diversified pathways as shown in Figure 7, where percentages of retrofits and electrification represent the percentage of floor area impacted. Heating and hot water systems were electrified in all electrification instances; in some typologies, additional end uses were electrified, such as cooking or laundry. Further detail on the allocation of efficiency and electrification measure packages across the individual buildings typologies is shown in Figure 8.

	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* ⁴	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)		

Figure 7. Key Buildings Pathways Parameters. *Source:* Pathways to Carbon Neutral NYC Table ES-1⁵

⁵ Note that the heat pump COPs represent coldest-temperature performance; annual COPs are much higher. The dual-fuel system ratings are COPs for the electric equipment.

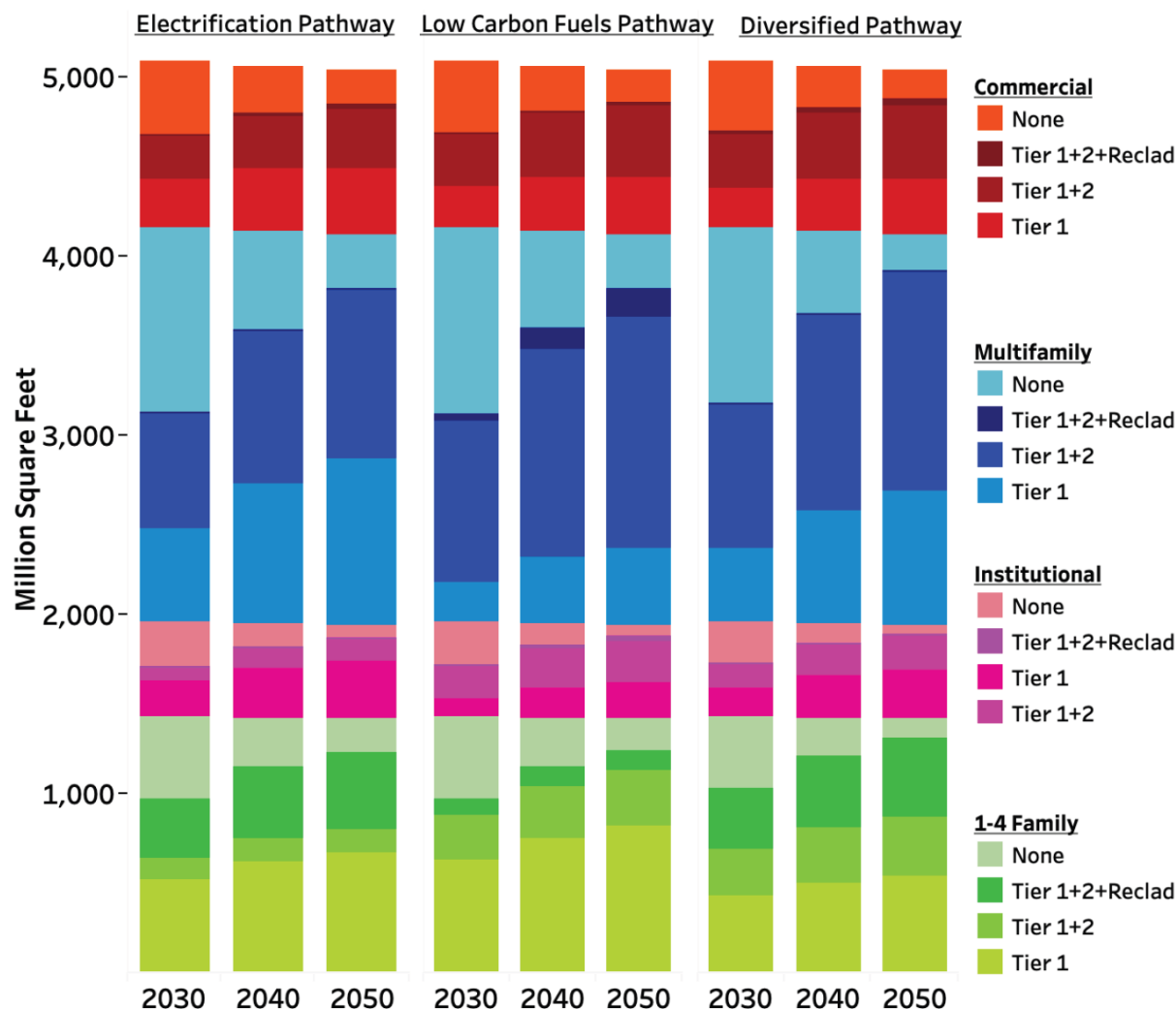


Figure 8: Cumulative implementation of efficiency measures across building typologies. *Source:* Pathways to Carbon Neutral NYC, Figure 22

Key Modeling Results

GHG emission reductions

The buildings simulation results were uploaded into ICF's IPM power sector model; the changes in electricity demand were then modeled to capture upstream (Scope 2) emissions at the powerplant level. Emission reductions from reduced onsite fuel combustion were calculated directly using emission factors. Refrigerant leaks from heat pumps were also factored into the analysis, as was gas system methane leakage. Energy efficiency was a principal driver of GHG emission reductions, and at least some tier of energy efficiency was applied to at least 85% of the building stock by 2050 in each pathway. While the complexity and interrelatedness of the pathways multisector modeling limited the ability to tease out the specific effects attributable to any single technology, Figure 9 shows that efficiency was one of the largest contributors.

Efficiency effects were realized as part of both electrification and low carbon gas heating system solutions, as both represented efficiency gains over the systems modeled in the reference case.

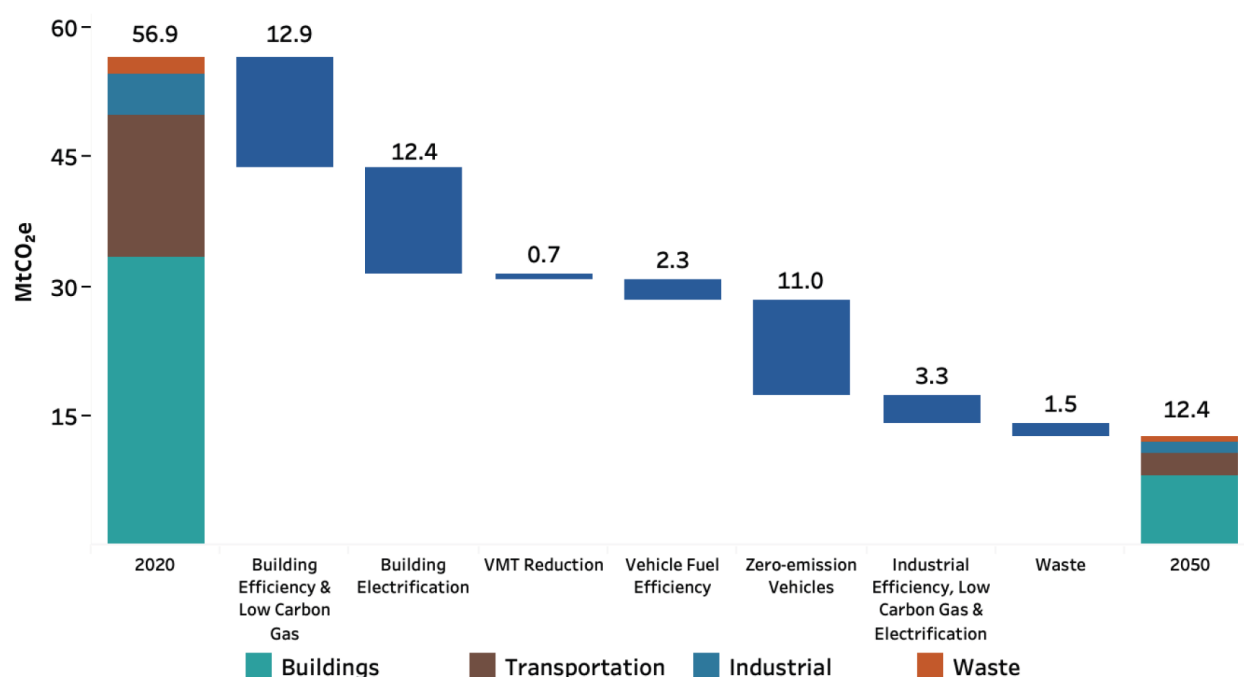
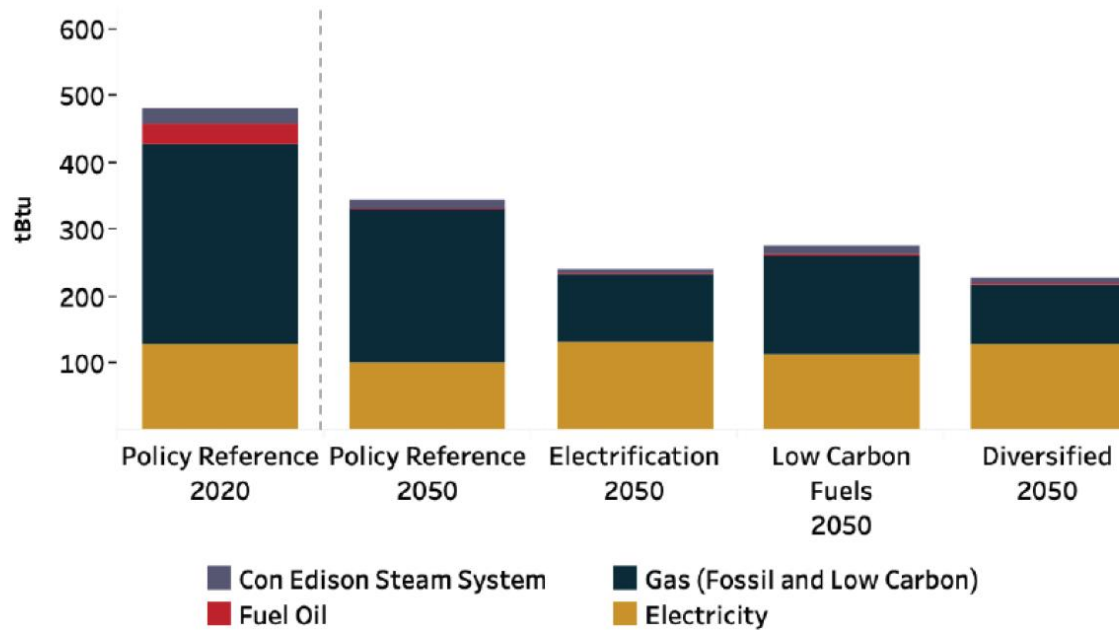


Figure 9. Efficiency’s Contribution to GHG Emission Reductions in the Electrification Pathway. *Source:* Pathways to Carbon Neutral NYC, Figure 17

Energy consumption

Figure 10 represents the ‘efficiency effect’ on energy consumption across the pathways: total energy use in City buildings falls by up to half in the three pathways. These savings occur from a combination of the three tiers of energy efficiency, and from the efficiencies gained from high-efficiency electric heating as well as gas heating systems. What is harder to represent graphically is the essential role efficiency played in reducing heating and cooling loads. Tier 2 measures especially, representing primarily building envelope improvements, were key to reducing total energy use, total energy costs, heating system sizing, and peak electricity demand.



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

Figure 10. Building Energy Use Across Pathways, 2020-2050. Source: Pathways to Carbon Neutral NYC, Figure 25

Peak electricity demand

Efficiency was also a key component of peak demand reduction. As Figure 11 illustrates, electrification alone would have nearly doubled Con Edison's system peak demand, and would have shifted the system peak to the winter season. ICF modeled the effects of building efficiency robustly in this respect: our building simulation modeling developed 8760-hour load shape files, which were aggregated and used as inputs to modify the system load curve that was modeled in our IPM power sector model. The Figure shows that efficiency alone would offset 3.2 of the projected 8.3 GW of added peak. We also modeled the impacts of very modest levels of market penetration of dual fuel heating systems and hot water direct load controls, which would contribute another 1.6 GW of peak reduction. Together, these demand side resources would offset over half of the system peak increase; more aggressive pursuit of such flexible load measures would likely bring peak demand back close to reference case levels.

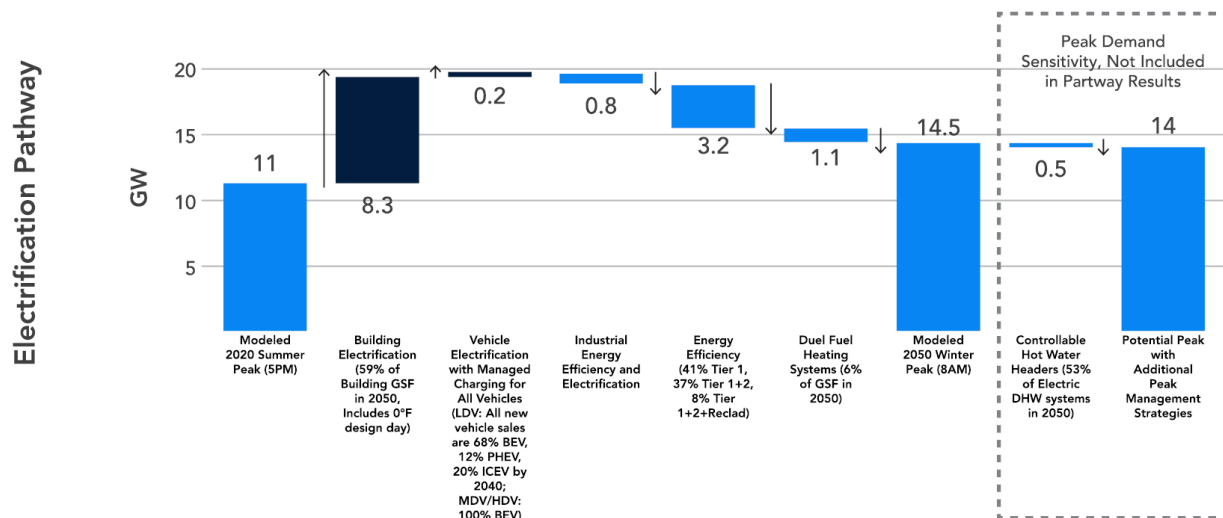


Figure 11. Efficiency's Contribution to Peak Load Reduction. *Source:* Pathways to Carbon Neutral NYC, Figure 35

Implications for policy and program design

This analysis shows that energy efficiency remains a cornerstone of decarbonization strategies. Very high rates of energy efficiency installation are required to realize energy and GHG emission reduction goals in all pathways. Such high deployment rates present major challenges: while combinations of utility program incentives, labeling programs like ENERGY STAR®, building codes and appliance standards are likely to capture most of the Tier 1 savings in measures like lighting, appliance, and electronics, realizing Tier 2 savings consisting mostly of envelope improvements remains challenging. Much of the City's older building stock is of masonry construction, which limits wall insulation options, and window replacements can be costly if not undertaken on an end-of-life basis. Recladding is most expensive of all; some building owners consulted in the study opined that they would tear down and rebuild rather than retrofit with such high-cost measures.

The modeling results also show that ambitious GHG emission reductions can be attained without 100% building stock electrification. The electrification pathway electrifies only about 60% of the City's total building floor area, in part because our deep dive analysis of the technical feasibility and cost issues involved in electrifying some building typologies showed that 100% electrification was not realistic. Barriers to electrification include:

- Historic landmark designations, which cover a measurable share of the City's building stock, limit the kinds of retrofits that may be needed to fully implement efficiency and electrification measures.
- Space limitations, in terms of mechanical room space, roof space, or outdoor ground level space, can limit choices for placing the outdoor condenser units for heat pumps.
- Architectural features on building facades can limit the practicality of mounting outdoor condenser units on exterior walls. The need to address condensate freezing issues further complicates such applications.
- Building wiring and service panel characteristics can require expensive upgrades to support some electric heating systems. In some cases, utility service capacity into the building may also require expansion.

While many of these issues can be addressed, and innovations are already under development in that area, this analysis adds a note of sober realism to simplistic notions of electrifying an entire building stock. Gaining high levels of electrification will take time, money, and ingenuity; and the electric heating market adoption curves convey a sense of urgency. For example, the analysis projects roughly 35% of heating system replacements converting to electric systems between 2020 and 2025. That level of uptake is almost certainly not being attained in current markets.

The discussions that this project engendered have included policy discussions along many lines, including:

- Phasing out fossil fuel use in some end use applications,
- Deploying new financing mechanisms that allow long-term, secure, low-interest mechanisms, such as Property Assessed Clean Energy (PACE) financing, and
- Revamping utility customer efficiency programs to better support electric technology investments, through higher incentives and revised cost-effectiveness tests that better value GHG emission reductions.

Areas for future research and analysis

As is typically the case, this project experienced limits in its ability to analyze every topic of interest, due to time and budget limitations. Looking forward, additional effort could be well spent in such areas as:

- **Further analysis of dual-fuel heating system feasibility and cost.** Leaving some fossil fuel heating systems in place, while meeting most of the heating load with electric technologies, is technically and economically feasible in many cases. Controls exist to automatically shift from heat pump to furnace operation at defined heating load thresholds, such that furnace fuel consumption is a small fraction of total heating consumption.
- **Further analysis of load flexibility solutions combined with electrification.** Demand response options are proliferating in this Internet of Things age; HVAC thermostats, lighting systems, electric water heaters, even refrigerator compressors can be remotely addressed and controlled. A more robust analysis of these options in the City study would likely have been able to keep system peak electricity demand much closer to historical levels.
- **Application of this methodology in building stock with different existing HVAC configurations.** New York's building stock is among the nation's most challenging to electrify, with its high share of older, steam-heated buildings without central AC. These buildings require either installation of air ducted systems, or more likely, ductless minisplit or VRF systems. In other regions, such as the Sunbelt, where ducted central AC is almost universal and heating loads are lower, installing heat pumps is a much simpler and more cost-effective option.
- **Field-based data collection and analysis of electric heating systems.** It will be important to move from modeling to field verification of electric heating system performance, especially for smaller systems that can replace window AC or PTACs. In New York's older stock, these kinds of units may become viable options, but need more field documentation to gain customer and industry acceptance.

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