Meeting the Challenge: Scenarios for Decarbonizing New York's Economy

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February 19, 2021

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Executive Summary

When the *Climate Leadership and Community Protection Act* (the Climate Act)[1] was passed in 2019, it placed New York State at the forefront of ambitious climate legislation. This commitment generated numerous questions about what the Climate Act's targets will mean for the state, including:

- **How will the state meet these goals for dramatic greenhouse gas (GHG) emissions reductions?** What actions are required today and in the future? Which technologies will be central to achieving the Climate Act's goals?
- **What is the economic impact of meeting the Climate Act's goals?** What capital investments are required to facilitate various emissions reduction options that achieve the state's targets?
- **How will New York's energy utilities and power generators meet the requirements for this transition?** These companies and their customers contributed more than 40%[2] of New York State's GHG emissions reductions from 1990 to 2016, and their involvement is critical to the state's ability to achieve its goals. How will this energy transition occur?
- **How does the NFGDC energy network, as part of the broader energy system, participate in the transition to a decarbonized future state?** How can the NFGDC infrastructure support decarbonization while maintaining energy system reliability and resiliency?

To assess the Climate Act's impacts on the energy system and the communities it serves, NFGDC engaged Guidehouse to evaluate potential scenarios for meeting 2050 GHG reduction goals and implications for its service territory. This report describes the findings of this analysis.

The Scenarios

To test the impacts of achieving the Climate Act's goals, we constructed three potential future scenarios. Our scenarios, as Figure 1 details, consider the interplay of electrification and low carbon gas adoption in the achievement of the Climate Act's targets.

[1] Available at: https://climate.ny.gov/

[2] The New York State Energy Research and Development Authority (2019). "New York State Greenhouse Gas Inventory 1990-2016." Available at: https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/greenhouse-gas-inventory.pdf

Figure 1. Decarbonization Scenarios

	Reference Case	High Electrification	Selective Electrification
Assumptions	The Climate Act was not promulgated, and New York targets the 2016 Clean Energy Standard goals. (Defined by the Energy Information Administration's [EIA's] *Annual Energy Outlook 2019* reference case)	The Climate Act's targets are achieved almost exclusively through electrification without consideration of cost, and fuel sources are phased out to the greatest extent feasible.	The Climate Act's targets are achieved by balancing electrification with low carbon fuels, when fuels represent a more cost-effective option from a $/GHG reduction perspective.
Purpose	Provides a benchmark against which to compare the actions associated with meeting the Climate Act's targets.	Portrays a future vision that has been presented by many stakeholders in the Northeast.	Provides a vision for decarbonization that includes leveraging existing energy infrastructure and the element of customer choice.

Evaluating the Scenarios

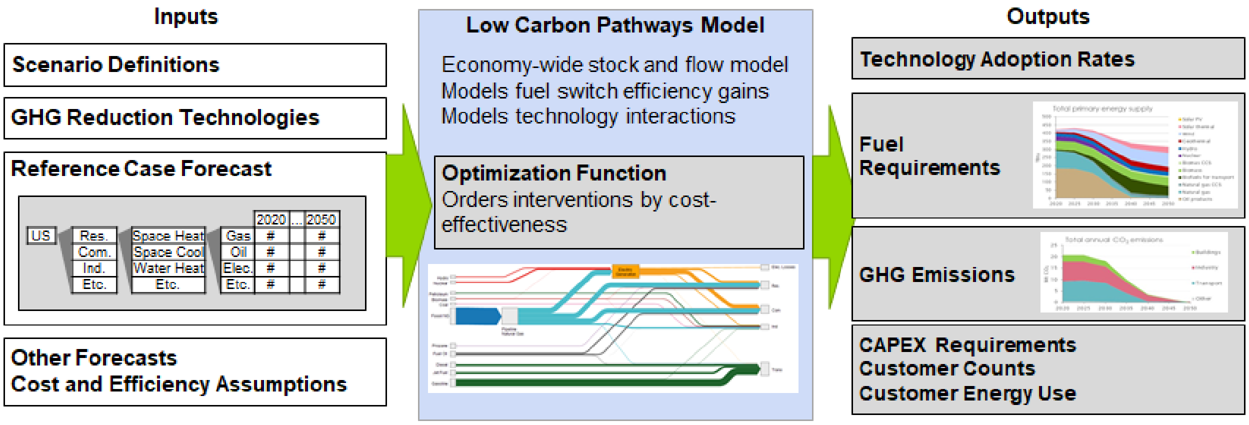
We used Guidehouse's low carbon pathways (LCP) analytical model to evaluate the scenarios. The LCP model determines the least-cost combination of technologies from a capital investment perspective to achieve a GHG emissions reduction target, given the constraints of each modeled scenario, by:

- Estimating the energy consumption and demand, capital costs, and emissions impacts of deploying different technologies to decarbonize the energy system.
- Accounting for interactions between the technologies and ranking the available GHG emissions reduction technologies in order of cost-effectiveness, in terms of dollars of capital investment per ton of GHG emissions abated.
- Considering region-specific factors—including policy, energy demand, electric generation, renewable natural gas (RNG) potential, hydrogen, HVAC equipment saturations, and vehicle usage.

The decarbonization targets set out in the Climate Act are technically achievable through various pathways.

Figure 2 provides a schematic of the LCP model and illustrates the inputs, operations, and outputs of the model.

Figure 2. Schematic of LCP Model Inputs and Outputs



Key Findings

Multiple pathways can achieve the decarbonization targets set out in the Climate Act, but a pathway that is more inclusive can do so in a way that provides solutions for hard to electrify sectors and results in crucial resilience and reliability benefits. Our analysis led to the following three key findings.

#1 Achieving the Climate Act's targets requires accelerating efficiency improvements for transportation, buildings, and appliances.

Decarbonization of the transportation sector is critical to achieving the Climate Act's emissions reduction targets. Emissions from transportation increased 25% from 1990 to 2016, and the transportation sector currently produces over one-third of New York State's GHG emissions.[3] Energy efficiency (from building shell improvements and high efficiency heat pumps and appliances) is another critical element for reducing GHG emissions. The *Reference Case* scenario assumes significant gains in energy efficiency[4] due to updated building codes, appliance standards, and utility energy efficiency rebates. Additionally, automobile fuel economy standards increase in the *Reference Case*. The *High Electrification* and *Selective Electrification* scenarios each assume that further efficiency improvements reduce building envelope and appliance energy consumption by an additional 10% due to improvements in building codes and standards. Further, switching gasoline to electric vehicles, coupled with 10% more efficiency from additional technology improvements results in energy intensity reductions in the residential (32% overall), commercial (23% overall), and transportation (42% overall) sectors.[5]

[3] The New York State Energy Research and Development Authority (2019). "New York State Greenhouse Gas Inventory 1990-2016." Available at: https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/greenhouse-gas-inventory.pdf

[4] The *Reference Case* scenario is based on the EIA's *Annual Energy Outlook 2019*, which projects that from 2018 to 2050, increases in energy efficiency will cause energy intensity to decline by 22% in the residential sector, 13% in the commercial sector, and 32% in the transportation sector.

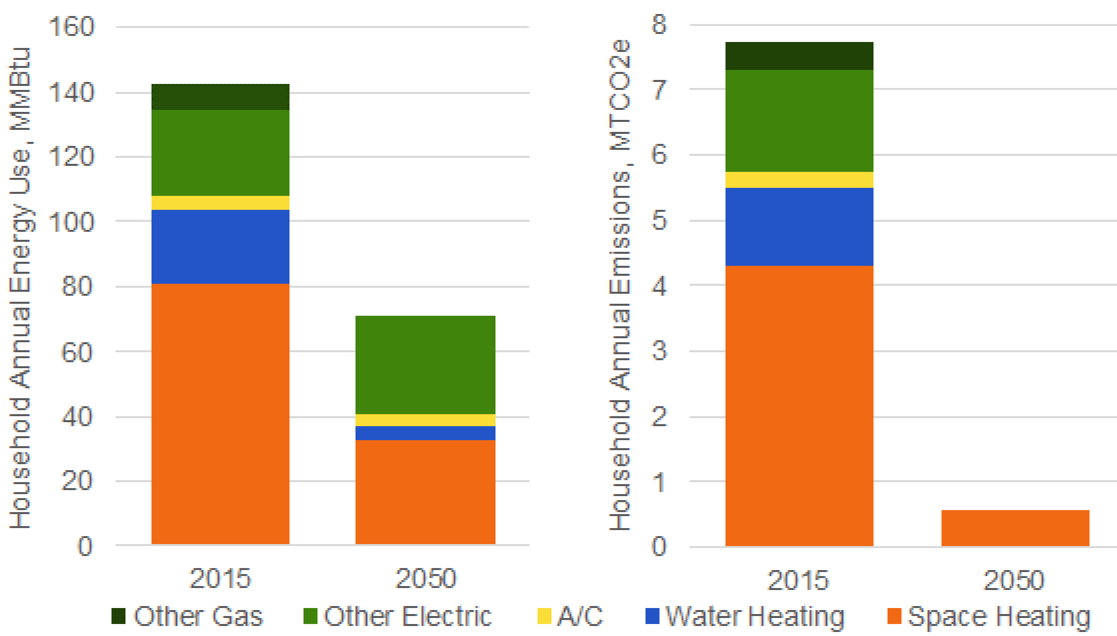
[5] "Energy intensity" is measured by the quantity of energy required per unit output or activity. For buildings, energy intensity is usually expressed in energy use per sq.ft of building space; for transportation, it is expressed as energy use per vehicle mile.

#2 The *Selective Electrification* scenario demonstrates the critical importance of including all options in developing an effective decarbonization pathway.

The *Selective Electrification* scenario accomplishes the Climate Act's GHG emission reduction targets using a variety of technologies, with each providing significant GHG reductions. For typical residential customer energy use, energy consumption and GHG emissions are assumed to decrease through building envelope and appliance energy efficiency measures, and through the use of high efficiency heat pumps (whether whole-home electric or dual-fuel), as Figure 3 illustrates. An individual customer's GHG footprint will be further reduced by decarbonization measures implemented upstream of the customer. Renewable power generation will reduce the emissions from customers' electric consumption, and RNG and hydrogen enriched natural gas (HENG) will reduce the emissions from customers' pipeline gas consumption. The dual-fuel heating option available in the *Selective Electrification* scenario will also mitigate growth in winter peak demand and improve system resilience in cold climate regions. This finding demonstrates the value of allowing all emissions reduction options to play a role in achieving New York State's emissions reduction targets.

Figure 3. Reduction in Energy Use and GHG Emissions from Selective Electrification

Example: Single-family home, NFGDC territory, switching from natural gas to dual-fuel heat



Intervention	Energy Savings	Emissions Reduction
Building Shell Efficiency	15%	14%
Heat Electrification & Dual Fuel Systems	30%	30%
Appliance Efficiency	5%	4%
Renewable Elec. Generation	n/a	27%
Carbon Capture & Storage	n/a	10%
Low-Carbon Fuels (RNG, Hydrogen)	n/a	7%
Total	**50%**	**93%**

#3 The *Selective Electrification* scenario offers an effective pathway to decarbonize high temperature industrial processes and heavy-duty trucking.

The *Selective Electrification* scenario assumes greater use of the existing gas pipeline infrastructure, relative to the *High Electrification* scenario. The *Selective Electrification* scenario retains clearer pathways for the utilization of low carbon gases, which will be critical to decarbonizing hard-to-electrify industrial and transportation end uses. Not only does the *Selective Electrification* scenario offer a pathway to further decarbonize these end uses, it also mitigates the risk of disproportionately burdening other market sectors with deeper decarbonization requirements to offset limited pathways for the industrial sector.

The Selective Electrification scenario offers additional benefits, particularly related to the crucial elements of the reliability and resilience of the energy system.

Summary

The study findings illustrate the value of the *Selective Electrification* scenario for effectively meeting the Climate Act's GHG emissions reduction targets. The *Selective Electrification* scenario leverages existing infrastructure to provide a comprehensive solution to achieving the Climate Act's decarbonization targets. In addition, it offers an important pathway for decarbonization of the industrial and transportation end uses, which are the most difficult to electrify.

Beyond the findings of the analysis completed for this study and discussed in detail in this report, the energy system envisioned through the *Selective Electrification* scenario offers additional benefits, particularly related to the crucial elements of energy system reliability and resilience.[6] As an example in cold weather climates like western NY, the American Gas Foundation report demonstrated that in a 2019 polar vortex case study the gas utility delivered 3.5 times the energy that was delivered by the overlapping electric utility. Significant growth in energy production from intermittent renewable resources, such as wind and solar, requires energy storage and dispatchable electricity generation capabilities to ensure that energy system resilience can be maintained. Batteries will provide some energy storage capacity, but batteries are currently not a viable solution for longer duration and seasonal storage, which are foundational elements of the existing natural gas system. An American Gas Foundation study published in January 2021 demonstrates that "Utilities, system operators, regulators, and policymakers need to recognize that resilience will be achieved through a diverse set of integrated assets … policies need to focus on optimizing the characteristics of both the gas and electric systems."[7]

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[6] This study did not analyze these issues in depth since they are treated in prior studies, including Guidehouse's *2020 Gas Decarbonisation Pathways* study: Guidehouse (2020). "Gas Decarbonisation Pathways 2020-2025." Available at: https://gasforclimate2050.eu/publications/

[7] American Gas Foundation (2021). "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience" Available at: https://gasfoundation.org/2021/01/13/building-a-resilient-energy-future/

How to Use the Results of this Study

This study's analysis demonstrates various pathways to achieving the Climate Act's goals. Policy makers and regulators would benefit from further evaluation of how to use our existing energy infrastructure and optimize future investments to decarbonize the New York economy.

Illustrating the technical and financial viability of the *Selective Electrification* scenario is the first step to understanding the alternative pathways on the road to decarbonizing New York's energy system and meeting the Climate Act's targets. This study's results illustrate the benefits to maintaining robust pipeline transmission and distribution networks across the state and investing in low carbon gas technologies as part of New York's decarbonization plan. However, the policies, regulations, and incentives in place at the state and federal level are insufficient to encourage the required investment in a decarbonized gas system and equitable distribution of the associated costs. The State of New York should encourage specific levels of production for low carbon renewable fuels such as RNG and HENG by setting achievable milestones.

Delivering on the vision of the energy system outlined in the *Selective Electrification* scenario will require engagement from policymakers, regulators, utilities, and stakeholders across New York. Table 1 lists strategies and associated actions that can support the creation of the energy system envisioned in the *Selective Electrification* scenario.

Table 1. Strategies and Actions to Support Delivery of the *Selective Electrification* Scenario

Strategy	Key Actions
Increase the supply of RNG and hydrogen in the gas system and the use of these low carbon fuels in downstream sectors to deliver a pathway for near-term GHG emissions reductions and a viable pathway for decarbonizing the most challenging market sectors.	• Develop and support state and federal policies consistent with those that have supported the development of solar and wind generation. • Offer encouragement and targets for RNG and hydrogen and the regulatory compact to support implementation.
Support investments to develop renewable and low carbon gas, technologies that will be required to deliver more cost-effective emissions reductions for consumers achieved in the *Selective Electrification* scenario.	• Design regulatory policies to provide long-term consistency for investors around targets and market mechanisms associated with low carbon fuels and the risks of embracing new technologies. • Encourage and facilitate research, development, and demonstration through statewide platforms, to fill gaps and drive the development of technologies with the greatest potential for the state.

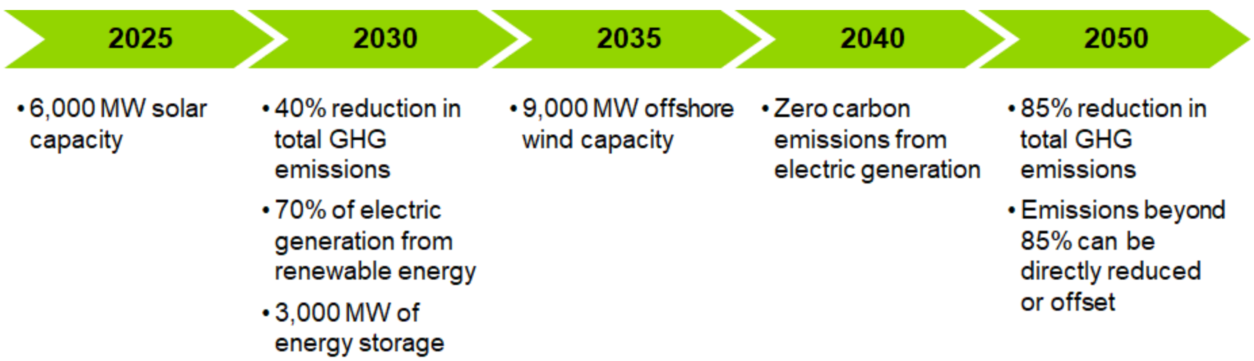
Strategy	Key Actions
Ensure energy system resilience, which will become increasingly important with the growth of intermittent renewables on the grid and the potential for increasing severity and impacts of climate-related events. Natural gas, RNG, and hydrogen can provide the required seasonal storage capacity to support the development of a resilient grid, but currently are not adequately encouraged to be developed as resilience assets. Continue to support investments that yield safe and reliable system operations.	• Identify metrics for evaluating resilience. • Require the consideration of system resilience as a part of all utility planning efforts. • Develop regulatory structures that value energy system resilience and support the amortization of resilience assets over the largest array of market segments as benefits accrue to all system users. Policies that foster complementary operations of electric and pipeline systems for resilience will reduce risks to local economies and communities.
Embed equity in the process, considering all emissions reduction technology pathways, to avoid picking winners and losers in New York's energy transition. While there will be winners and losers in the development of new technologies and solutions to power the transition, residential and commercial customers should not be penalized because they do not have the means to be early adopters of new technologies.	• Encourage policies that leverage existing infrastructure and prioritize pathways that limit costs, such as using existing infrastructure to transport renewable gas and hydrogen. • Support disadvantaged communities to ensure they can participate in decarbonizing their communities.

1. Introduction and Background

Many countries have announced pledges and proposed legislation to reduce greenhouse gas (GHG) emissions, but few jurisdictions have enacted laws to follow through on these commitments. On July 18, 2019, New York Governor Andrew M. Cuomo signed the Climate Leadership and Community Protection Act (the Climate Act) into law.[8] Among the most ambitious climate regulations in the world,[9] the Climate Act requires New York State to reduce economywide GHG emissions 40% by 2030 and 85% by 2050 from 1990 levels. It also sets interim requirements (see Figure 1-1) that the state's power sector must meet prior to 2050.

This report considers several pathways to reach the Climate Act's emissions targets and their associated costs, with varying degrees of electrification, low carbon fuels, and natural gas usage. Guidehouse analyzed these pathways on behalf of National Fuel Gas Distribution Corporation (NFGDC).

Figure 1-1. Requirements of New York Climate Leadership and Community Protection Act



The Climate Act specifies requirements for energy storage capacity and for electric generation capacity from solar and offshore wind technologies. Aside from these requirements, the Climate Act does not specify which technologies should be implemented to reduce GHG emissions.

All sectors of New York's economy contribute to the state's GHG emissions. As Figure 1-2 indicates, New York reduced economywide GHG emissions by 13% between 1990 and 2016.[10] Changes in the commercial, industrial, and power sectors drove these reductions. In the power sector, New York replaced older coal-fired power plants with lower emissions natural gas plants. GHG emissions from the commercial and industrial sectors dropped by about 34% from 1990 to 2016[10] due to investments in efficiency, improvements in building codes, and customers converting their heating systems from oil to natural gas. Meanwhile, transportation sector emissions *rose* significantly by about 25% from 1990 to 2016.

[8] New York State Senate (2019). "S.B. S6599." Available at: https://www.nysenate.gov/legislation/bills/2019/s6599

[9] As of January 2021, only eight countries and eight US states (including New York) have enacted laws requiring net zero carbon dioxide emissions by 2050. Source: Energy & Climate Intelligence Unit, Net Zero Tracker CSV data files, available at: https://eciu.net/netzerotracker/map

[10] The New York State Energy Research and Development Authority (2019). "New York State Greenhouse Gas Inventory 1990-2016." Between 1990 and 2016, economywide GHG emissions dropped from 236 to 206 $MMtCO_2e$, and GHG emissions from commercial and industrial sectors dropped from 47 to 31 $MMtCO_2e$. Available at: https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/greenhouse-gas-inventory.pdf

Figure 1-2. New York State Greenhouse Gas Inventory and Climate Act Targets

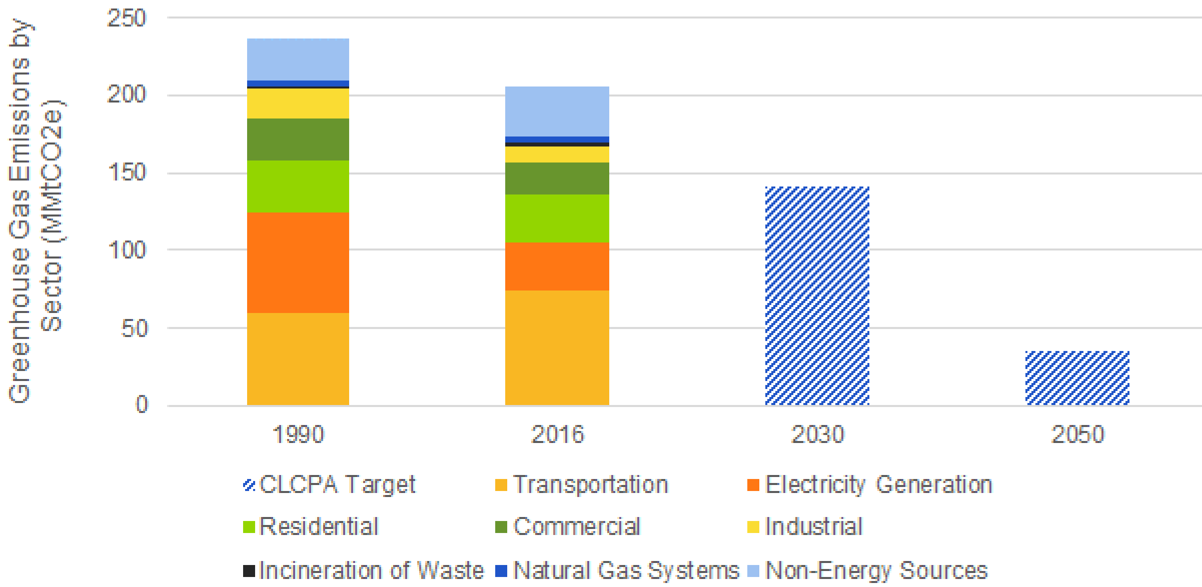


Figure 1-2 also depicts the Climate Act targets for GHG emissions reduction in 2030 and 2050.[11] To achieve the Climate Act's targets, all sectors of New York's economy must deploy GHG mitigation technologies. As of 2015, 91% of households in New York used fossil fuel as their primary source of space heating (66% of New York households use natural gas, 24% use fuel oil, and 1% use propane).[12] At present, 40% of the utility-scale electricity produced in New York is generated by burning fossil fuels, and fossil fuels provide 68% of summer peak capacity.[13] Compliance with Climate Act targets will require the state to displace its consumption of high-carbon fuels, and this reduction will impact electric utilities and natural gas utilities.

The power sector will need to retain a significant share of gas-fired generation to deliver baseload capacity when intermittent renewable sources of power are unavailable.

The Climate Act sets interim targets for decarbonizing the power sector (see Figure 1-1). It requires installation of new solar and wind generation capacity; these new renewables likely will displace a portion of the state's natural gas-fired electric generation. Guidehouse forecasts the power sector will need to retain a significant share of gas-fired generation to deliver baseload capacity when intermittent renewable sources of power are unavailable. Compared to other

[11] The New York Department of Environmental Conservation adopted 6 NYCRR Part 496, Statewide Greenhouse Gas Emission Limits, that sets limits on GHG emissions in 2030 and 2050, as a percentage of 1990 emissions, per the requirements of the Climate Act. The values in Figure 1-2 correspond to NYSERDA's "New York State Greenhouse Gas Inventory 1990-2016," which correspond to the GHG emissions associated with fuel combustion, presented in Table 4 of the rule's regulatory impact statement, available at: https://www.dec.ny.gov/docs/administration_pdf/revisedris496.pdf

[12] The New York State Energy Research and Development Authority (2019). "Patterns and Trends: New York Energy Profiles 2002–2016." Table B-2. Available at: https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/2002-2016-Patterns-and-Trends.pdf

[13] New York Independent System Operator (2020). "Power Trends 2020." Figures 13 & 14. Available at: https://www.nyiso.com/documents/20142/2223020/2020-Power-Trends-Report.pdf/dd91ce25-11fe-a14f-52c8-f1a9bd9085c2

technologies that promote grid reliability (such as battery storage), gas-fired generation is significantly less expensive and can meet reliability needs over a longer period. Since the Climate Act requires that power generation be carbon free by 2040, gas-fired generators will be required to mitigate their carbon emissions by applying carbon capture and storage (CCS) or other technologies.

A shift from fuel-fired heating to electric heating will largely drive the decarbonization of building heat. Investment in electric transmission and distribution infrastructure is required to achieve the electrification of building heating and other end uses.[14] Mass electrification of building heat will lead to a requirement for substantially more electric generation capacity during the winter heating season. The New York power grid is currently a summer peaking system, but the New York Independent System Operator (NYISO) projects New York may become winter peaking around 2039.[15] Deployment of air-source heat pumps and EVs could accelerate New York's transition from summer peaking to winter peaking. In addition, electrification of building space and water heating will result in declining natural gas demand and reduced gas customer counts, leading to higher distribution costs for the remaining natural gas customers.

There are varying perspectives regarding the role of natural gas in a low carbon economy. Climate advocates have opposed the construction of new gas transmission infrastructure in New York, and municipalities in New York and elsewhere have proposed banning natural gas connections to new construction.[16] On January 28, 2021, New York City Mayor Bill de Blasio announced his administration will ban fossil fuel connections in new construction by 2030.[17] Continued investment in resilient pipeline infrastructure creates options for future pathways. An approach that retains natural gas for selective end uses and introduces low carbon alternatives such as renewable natural gas (RNG)[18] and hydrogen could achieve New York's emission targets at a lower total capital cost than an approach that focuses solely on electrification.

An approach that retains natural gas for selective end uses and introduces low-carbon alternatives such as renewable natural gas (RNG) and hydrogen could achieve New York's emission targets at a lower total capital cost than an approach focused solely on electrification.

[14] In response to a NY Public Service Commission order, the New York utilities filed a working group report on November 2, 2020 that estimated between $16.6 billion and $17.2 billion of investment in transmission and distribution upgrades will be needed by 2030 to comply with the Climate Act's renewable capacity requirements. Available at: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={2794FC7E-D2A6-4C79-8834-4B60FA25ED1F}

[15] New York Independent System Operator (NYISO) 2020. "2020 Load & Capacity Data." Figure I-4. Available at: https://www.nyiso.com/documents/20142/2226333/2020-Gold-Book-Final-Public.pdf

[16] The city of Ithaca adopted a building policy that calls for a 2030 ban on fossil fuels in new construction, with an exception for commercial cooking. Source: Politico (2020). Available at: https://www.politico.com/states/new-york/albany/story/2020/02/25/new-york-slow-to-curb-natural-gas-in-new-construction-1263585

[17] City of New York (Jan 28, 2021). "Transcript: Mayor de Blasio Delivers 2021 State of the City Address." Available at: https://www1.nyc.gov/office-of-the-mayor/news/063-21/transcript-mayor-de-blasio-delivers-2021-state-the-city-address

[18] RNG is a gaseous fuel with lower carbon intensity and similar operational and performance characteristics to natural gas. RNG can be produced through several production technologies, including landfill gas collection, anaerobic digestion, and thermal gasification systems

1.1 Study Goals

The study evaluates pathways for decarbonizing the New York State energy system by mid-century. Many policy and technology options can contribute to accomplishing the economywide decarbonization goals enacted by policymakers. Our report examines several plausible scenarios driven by market fundamentals that can achieve net zero carbon emissions by mid-century. The study addresses the following questions:

- What are the optimal pathways for achieving the Climate Act's goals?
- How will electric and natural gas loads evolve as decarbonization is implemented?
- How can the natural gas system facilitate achievement of the Climate Act's objectives?

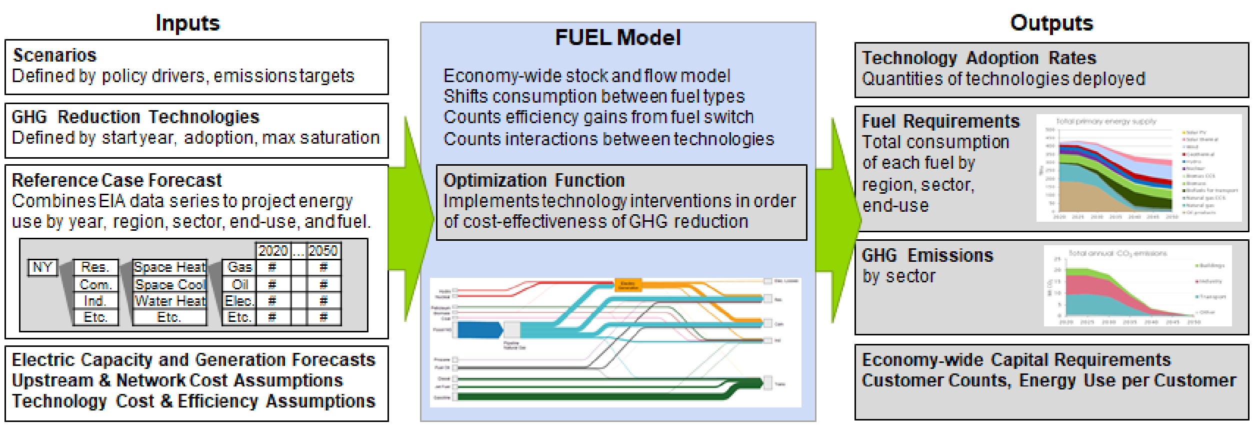
2. Methodology

2.1 Economywide Energy and Emissions Modeling

Guidehouse used its low carbon pathways (LCP) analytical model to evaluate different GHG reductions scenarios. Our economywide energy and emissions accounting model forecasts any changes in energy consumption across all sectors of the economy by fuel type and by end use. The model accounts for energy used upstream to generate electricity and energy used downstream by customers. We used the model to examine the application of carbon-reducing technologies in specific geographies. For this study, Guidehouse tailored the model to examine energy consumption and emissions for New York State and for NFGDC's territory in New York, as Section 2.3 describes.

Our LCP model compares different decarbonization scenarios to a reference case, described in Section 2.2. Each scenario is defined by a GHG emissions reduction target and an array of decarbonization technologies that are deployed to meet the emissions target. The model introduces these decarbonization technologies as deviations from the reference case. The model forecasts the extent to which each technology is deployed to meet the scenario targets and then calculates the collective energy and emissions impacts of each scenario's technology bundle. Figure 2-1 summarizes the LCP model's inputs, operations, and outputs.

Figure 2-1. Schematic of Low Carbon Pathways Model Inputs and Outputs



A key feature of our model is that it accounts for interactions between technologies and it quantifies the GHG reductions that result when technologies are deployed in tandem. For example, the emissions reductions from replacing fuel-fired heating equipment with electric heat pumps depend on the carbon intensity of the electricity supplied to power the heat pumps. By concurrently tracking upstream and downstream technology interventions, the model represents the GHG reductions that may be achieved in different scenarios.

Our LCP model also uses an optimization function to rank the available GHG reduction technologies by cost-effectiveness in terms of dollars of capital investment per ton of GHG emissions abated. To determine the pathway that meets each scenario's GHG reduction target in the least capital-intensive way possible, the model deploys the most cost-effective technologies first.

2.2 Scenario Definitions

Our analysis considers the following three scenarios, which are referenced throughout this report. These scenarios are defined around plausible future visions, including fundamental drivers such as policy/regulatory impacts, economic development, social acceptance of technology changes, and energy supply/use developments. Table 2-2 (see page 22) presents the technologies included in each scenario.

1. **Reference Case:** We established a reference case for evaluation based on the US Energy Information Administration's (EIA's) *Annual Energy Outlook 2019* reference case,[19] prior to New York's enactment of the Climate Act. In this scenario, early century decarbonization trends continue but renewable energy, energy efficiency, and electrification activities are limited. Trends proceed at a pace to meet New York's Clean Energy Standard, but emissions reductions do not meet the Climate Act's requirements. Customers continue to maintain current fuel and system choices. The existing pipeline infrastructure is fully utilized, and companies continue to invest in system enhancements to provide safe, reliable, and resilient operations. Many of these investments will increase the integrity of the system and reduce methane emissions. Shale development continues to provide low cost supply to support growing demand. Gas-fired generation complements growing renewables generation.
2. **High Electrification Scenario:[20]** In this scenario, we assume that every end use that is technically possible to electrify will be electrified by mid-century. This scenario is motivated by recent efforts to curtail or eliminate natural gas supplies—such as natural gas bans proposed by some jurisdictions—and achieves the Climate Act's emissions targets. It assumes that policies including incentives, penalties, or mandates will limit customer choice to all-electric systems. Downstream fossil fuel use will be nearly eliminated, and electricity generation will be 100% carbon free. Most natural gas infrastructure will be retired, and extensive build out of electric infrastructure will be required to maintain reliable electric supply during peak heating periods.
3. **Selective Electrification Scenario:** In this scenario, we assume that some market segments fully electrify their energy needs. However, demand components that are not cost-effective to electrify may shift to non-fossil decarbonized gas (*i.e.*, biogas, hydrogen). Electricity generation will be fully decarbonized, and the natural gas pipeline infrastructure will continue to serve market segments that were challenged in the *High Electrification* scenario. Together, the pipeline infrastructure and electric systems decarbonize and achieve Climate Act emissions targets. Customers will maintain some choice in their energy supply and natural gas infrastructure will provide resilience. While natural gas use will be reduced, it will not be eliminated, due to the availability of dual-fuel heating options that combine heat pumps with gas-fired heating systems. Much of existing pipeline infrastructure can be used to transport RNG and hydrogen-enhanced natural gas (HENG), and some standalone hydrogen systems for industrial processes are implemented. System resiliency and reliability will be similar to the *Reference Case* scenario.

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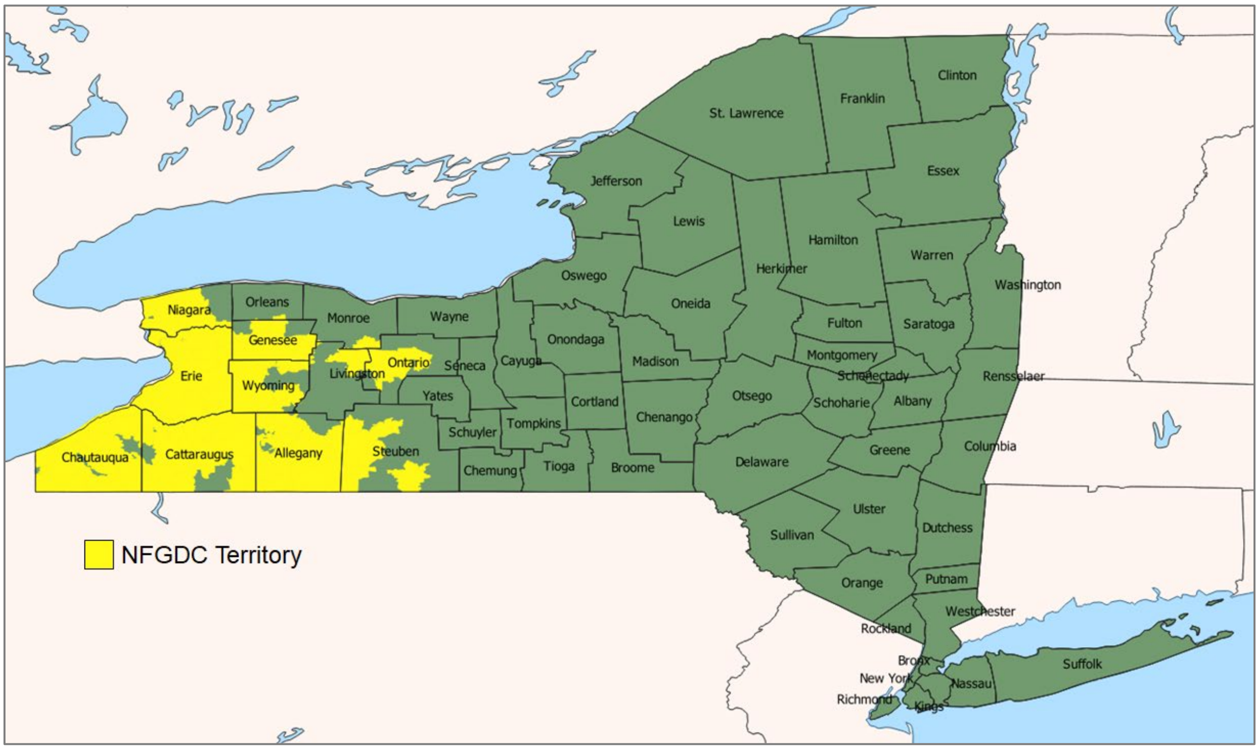
[19] US Energy Information Administration (2019). "Annual Energy Outlook 2019." Available at: https://www.eia.gov/outlooks/archive/aeo19/pdf/aeo2019.pdf

[20] Studies of decarbonization pathways often model high electrification scenarios as described here, but recent reports use different nomenclature for this scenario. Gas for Climate (2018) defines this as an "Electricity Only" scenario. E3 (2020) uses the term "Limited Non-Energy Pathway." The Brattle Group (2020) analyzed a comparable "ASHP Bookend Scenario."

2.3 Region Definitions

To account for regional differences in factors like power generation mix and fuel consumption, Guidehouse separately analyzed New York State as a whole and NFGDC's territory in New York. Figure 2-2 illustrates these regions. Appendix A describes our treatment of regional definitions in more detail.

Figure 2-2. New York State Regions Modeled



2.4 Scope of this Study

There are issues outside the scope of this analysis that will be critical to achieving mid-century GHG reduction requirements. Guidehouse recommends further analysis of the following issues:

- **Resilience:** Resilience is a set of energy system abilities that allows an energy system to prevent, withstand, adapt to, and quickly recover from damage or operational disruption.[21] Resiliency is distinct from reliability and is characterized by a response to high impact, low probability events such as extreme weather and cyberattacks. As the energy system moves toward mid-century with significant renewable and distributed generation, resiliency becomes ever more important. Further, energy system investments that enhance resilience will likely be required. In the *Selective Electrification* scenario, the pipeline infrastructure can be utilized to enhance future resilience requirements.

[21] American Gas Foundation (2021). "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience" Available at: https://gasfoundation.org/2021/01/13/building-a-resilient-energy-future/

- **Reliability:** Reliability is the ability of the energy system to deliver services in the quantity and with the quality demanded by end users. Reliability differs from resiliency in that investments and maintenance are focused on low impact, high probability events, such as power surges and sudden changes in demand or supply. In every scenario, utilities with oversight by regulators will need to continue making capital and maintenance investments in certain assets to provide a reliable energy system. Our analysis modeled a future mix of electric generation and storage that meets reliability requirements, but we did not attempt to quantify system reliability or optimize our model around reliability.

- **Retirement of Infrastructure Assets:** The natural gas distribution industry has a positive safety track record. In the past, there has been strong policy and regulatory support for utilities to invest in safe and reliable infrastructure. As an example, in 2015 the New York Public Service Commission (NYPSC) issued an order instituting a proceeding for a recovery mechanism to Accelerate Replacement of Infrastructure on the Natural Gas System.[22] Utilities have made significant capital investments in these long-lived assets in support of this order. In the *High Electrification* scenario, these assets would primarily be retired long before the end of their useful life. The capital deployed by the utility companies and their respective stakeholders would need to be recovered. In this scenario, these stranded costs would be material and require amortization beyond those end users who remain on the system. Such stranded costs were not included in the current study's economic analysis. Policymakers need to recognize that a wide array of stakeholders would need to bear these costs.

- **Equity**: Without targeted incentives or rate relief programs focused on economically disadvantaged customers, it is likely that some customer groups will be unable to afford the upgrades to their homes and businesses that are required to meet GHG emissions targets. The Climate Act stresses the importance of avoiding burdens on disadvantaged communities. Section 7.3 of the Climate Act states:

  > *In considering and issuing permits, licenses, and other administrative approvals and decisions, including but not limited to the execution of grants, loans, and contracts, pursuant to article 75 of the environmental conservation law, all state agencies, offices, authorities, and divisions shall not disproportionately burden disadvantaged communities as identified pursuant to subdivision 5 of section 75-0101 of the environmental conservation law.*[23]

  Higher income customers have fewer, though still significant, barriers to electrify, while low income households are unable to electrify without substantial targeted incentives to help them overcome the additional costs of both installing and running their electric systems. However, these costs are not the only concern. As many customers electrify their homes and leave the gas grid, it is expected that gas rates and total energy costs will increase for those that remain. The issue of who pays and how costs are equitably managed across the system was not considered as part of this study.

[22] New York Public Service Commission. Case 15-G-0151. "Order Instituting Proceeding for Recovery Mechanism to Accelerate the Replacement of Leak Prone Pipe." Available at: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={7A1320F6-3972-4F09-9CB6-ECB2F902F67B}

[23] New York State Senate (2019). "Senate Bill S6599." Available at: https://www.nysenate.gov/legislation/bills/2019/s6599

2.5 Decarbonization Opportunities

Each of the scenarios in our analysis includes a different combination of decarbonization technologies that could be deployed over the 2020-2050 analysis period. These range from upstream technologies associated with power generation and fuel supply (e.g., low carbon fuels, carbon capture, and renewable generation) to downstream technologies that are tied to specific end uses of energy (e.g., EVs, space and water heating, and energy efficiency). Table 2-1 describes each of the technologies considered in the LCP model. Appendix B discusses each of these technologies in more depth.

Table 2-1. Summary of Technologies Considered in the Low Carbon Pathways Model

Technology	Description
Renewable natural gas (RNG)	RNG is a gaseous fuel with lower carbon intensity and similar operational and performance characteristics to natural gas and can reduce GHG emissions in applications that currently use natural gas and other fossil fuels. The GHG reduction potential of RNG depends on the feedstock and production technology. We consider separate RNG production streams using anaerobic digestion and thermal gasification.
Hydrogen-enhanced natural gas (HENG)	Hydrogen can be produced through electrolysis using dedicated renewable electric generation or curtailed renewable electric generation systems (power-to-gas or green hydrogen) and through natural gas reformation with carbon capture (blue hydrogen). It can then be blended into existing natural gas pipelines to reduce GHG emissions.
Solar generation	Solar PV generation capacity will increase to meet the Climate Act's requirements and will displace natural gas-fired generation.
Wind generation	Wind generation capacity (onshore and offshore) will increase to meet the Climate Act's requirements and will displace natural gas-fired generation.
Post- and pre-combustion carbon capture power generation	Carbon capture technologies reduce the GHG emissions from natural gas, RNG, or hydrogen fuels by capturing CO_2 exhaust gas for sequestration, storage, or utilization.
Natural gas heavy duty vehicles	CNG- and liquefied natural gas-powered heavy duty vehicles are a mature technology that could be a cost-effective alternative to traditional diesel-powered vehicles.
Electric heavy duty vehicles	Different classes of passenger vehicles and trucks may be decarbonized by a transition from gasoline- and diesel-powered vehicles to EVs.
Electric medium duty vehicles	
Electric light duty vehicles	
Biofuel production for aviation	Conventional jet fuel can be displaced by biofuels to reduce the GHG impact of aviation fuels.
Industrial local green hydrogen	Hydrogen may be delivered to customers through dedicated distribution systems designed for 100% hydrogen gas, known as hydrogen clusters or districts.
Heating oil to electric heat pump conversions	Residential customers using fuel oil for heating may convert their heating systems to use electric heat pumps.
Transport efficiency	The energy efficiency of the transportation sector may be further improved beyond the federal vehicle fuel economy requirements that are currently in place.

Technology	Description
Industrial efficiency	The energy efficiency of the industrial sector may be improved by measures that target process efficiency.
The following technologies apply to both the Residential and Commercial sectors	
Heat pump water heaters (HPWHs)	HPWHs use electricity to transfer heat from ambient air to a stored water tank and are an energy efficient alternative to electric resistance water heaters and fuel-fired water heaters.
District water-loop heating and cooling	In a district energy system, a central plant or plants produce steam, hot water, or chilled water that is then pumped through a network of insulated pipes to provide space heating, cooling, or hot water for nearby connected customer buildings.
Air-source heat pumps (ASHPs)	ASHPs provide space heating and space cooling by using electricity to move heat from the outdoor space to the indoor space, and by using electric resistance heat during periods of low outdoor temperatures.
Geothermal heat pumps (GSHPs)	Similar to ASHPs, GSHPs use electricity to move heat in and out of a building's conditioned space. GSHPs exchange heat with the ground via a buried pipe loop and are more efficient than ASHPs.
Dual-fuel heating - furnace/boiler plus HP	A dual-fuel HVAC system pairs an electric ASHP with a high efficiency, gas-fired heating appliance and alternates between the two sources depending on ambient outdoor air conditions.
Building efficiency, non-insulation	High efficiency options are available for most residential and commercial building technologies, including water heating, lighting, kitchen and laundry appliances, and electronics.
Space conditioning efficiency, retrofit and new buildings	The efficiency of building envelope technologies (e.g., wall, floor, and ceiling insulation and windows) may be improved beyond current building code requirements.

Each of the technologies in Table 2-1 is limited in terms of how quickly it can be adopted and its maximum level of saturation. To develop a realistic forecast of a potential future state, our model limits the annual adoption rate and the maximum saturation of each technology. Guidehouse analyzed market trends, forecasts, and pilot-level program data to estimate the costs, typical adoption rates, and saturation limits associated with each technology. For example, the adoption rate of EVs is limited by the natural turnover rate of vehicle stock. As another example, the total saturation of HENG is limited to the proportion of pipeline natural gas that can be safely displaced by hydrogen. Table 2-2 summarizes the limitations we set for each technology in each of the modeled scenarios. Appendix B details the analysis and assumptions that inform these limits.

As Section 2.1 describes, our LCP model uses an optimization function to deploy technologies in order of cost-effectiveness. In practice, the model deploys the most cost-effective technologies first, up to the individual technology's saturation limit. The model then selects and deploys less cost-effective technologies until the economywide decarbonization target is met. Some amount of technology adoption is included in the *Reference Case* scenario, and the limits in Table 2-2 describe incremental activity beyond the reference case assumptions. For example, the *Reference Case* assumes a steady increase in transportation and building sector efficiency due to federal vehicle fuel economy standards, appliance efficiency standards, and building codes. The efficiency measures in Table 2-2 describe efficiency improvements beyond the reference case that may be spurred by more aggressive efficiency programs.

Table 2-2. Summary of Technologies Specified in the Low Carbon Pathways Model

			Max Annual Saturation Increase		Maximum Saturation Allowed in Model	
	Technology	**Unit Basis**	**HE***	**SE***	**HE***	**SE***
	RNG - anaerobic digestion	Billion Btu per year	N/A	4,200	N/A	95,000
	RNG - thermal gasification	Billion Btu per year	N/A	7,700	N/A	153,800
	HENG	H_2 as a % of natural gas supply, by energy	N/A	1.0%	N/A	4.9%
	Solar generation	% of electric supply, except nuclear and hydro	5.5%		41.0%	
	Wind generation		4.0%		45.0%	
	Post- and pre-combustion capture power generation	% of fossil electric generation	7.5%		100.0%	
	Natural gas heavy duty vehicles	% of heavy duty (diesel) load switched	N/A	6.3%	N/A	30%
	Electric heavy duty vehicles		6.3%		100%	70%
	Electric medium duty vehicles	% of medium duty (diesel) load switched	5.0%		100.0%	
	Electric light duty vehicles	% of gasoline load switched	4.5%		100.0%	
	Biofuel production for aviation	% of jet fuel switched	3.5%		100.0%	
	Industrial local green hydrogen	% of industrial load switched	N/A	5.0%	N/A	75.0%
Residential	Heat pump water heaters	% of carbon load switched	5.0%		100.0%	
	Heating oil-to-heat pump	% of fuel oil load switched	3.0%	3.0%	100.0%	100.0%
	Air-source heat pumps	% of carbon load switched	5.0%		99%	70%
	Geothermal heat pumps	% of carbon load switched	1.0%		30%	
	Dual-fuel heating - furnace/boiler plus HP	% of carbon load switched	N/A	3.5%	N/A	70%
Commercial	Heat pump water heaters	% of carbon load switched	5.0%		100.0%	
	District heating and cooling	% of carbon load switched	1.0%		10%	
	Air-source heat pumps	% of carbon load switched	5.0%		98%	70%
	Geothermal heat pumps	% of carbon load switched	1.0%		30%	
	Dual-fuel heating - furnace/boiler plus HP	% of carbon load switched	N/A	3.5%	N/A	70%
	Transport efficiency	Entire sector consumption	0.8%		10.0%	
	Industrial efficiency	Entire sector consumption	1.0%		10.0%	
	Residential building efficiency, non-insulation	Entire sector consumption (except space conditioning)	1.0%		10.0%	
	Commercial building efficiency, non-insulation	Entire sector consumption (except space conditioning)	1.0%		10.0%	
	Residential space conditioning efficiency, retrofit	Entire sector space conditioning load	1.0%		10.0%	
	Residential space conditioning efficiency, new buildings	Entire sector space conditioning load	1.0%		10.0%	
	Commercial space conditioning efficiency, retrofit	Entire sector space conditioning load	1.0%		10.0%	
	Commercial space conditioning efficiency, new buildings	Entire sector space conditioning load	1.0%		10.0%	

* Note: HE stands for *High Electrification* scenario, and SE stands for *Selective Electrification* scenario.

2.6 Investment Requirements

Guidehouse estimated the total investment CAPEX associated with technology deployment in each of the scenarios. For end-use technologies, we calculated the incremental installed costs as the cost of a new unit of that technology minus the cost of a new unit of the baseline technology. For example, the incremental cost of a whole-home heat pump is calculated relative to the cost of a natural gas heating and electric A/C system that customers would install in the absence of electrification programs. Our analysis accounts for the fact that whole-building cold climate ASHPs are substantially more expensive than conventional heat pumps that could be used in a dual fuel heating system.

For upstream technologies, we calculated absolute costs of retrofit technologies. For example, the cost of installing CCS technology is estimated relative to a zero-cost baseline where CCS is not installed. Guidehouse developed a time series of costs for each technology based on expected innovation. Our analysis of investment requirements does not include costs associated with retiring existing infrastructure.

3. Results

The following subsections describe the effects that the technologies discussed in Section 2.5 will have on overall GHG reductions and energy use.

3.1 GHG Emissions Reductions

The Climate Act's emissions reduction requirement can be achieved in the *High Electrification* and *Selective Electrification* scenarios. In both cases, high adoption of GHG mitigation technologies will be necessary to achieve the target.

With high technology adoption, both the High Electrification and Selective Electrification scenarios can achieve the Climate Act's emissions reduction requirements.

Figure 3-1 compares the GHG emissions by sector for each scenario in NFGDC's New York territory. The GHG reductions are based on an 85% reduction in emissions relative to 1990 levels. Both scenarios meet the Climate Act's requirement of 40% GHG reductions from 1990 to 2030. In both scenarios, the power sector is a major driver of decarbonization, since the Climate Act requires eliminating power sector emissions by 2040. The *Selective Electrification* scenario shows lower GHG contribution from the industrial sector, since it allows adoption of industrial green hydrogen.

Figure 3-1. Emissions in Each Scenario as a Function of Time, National Fuel Territory

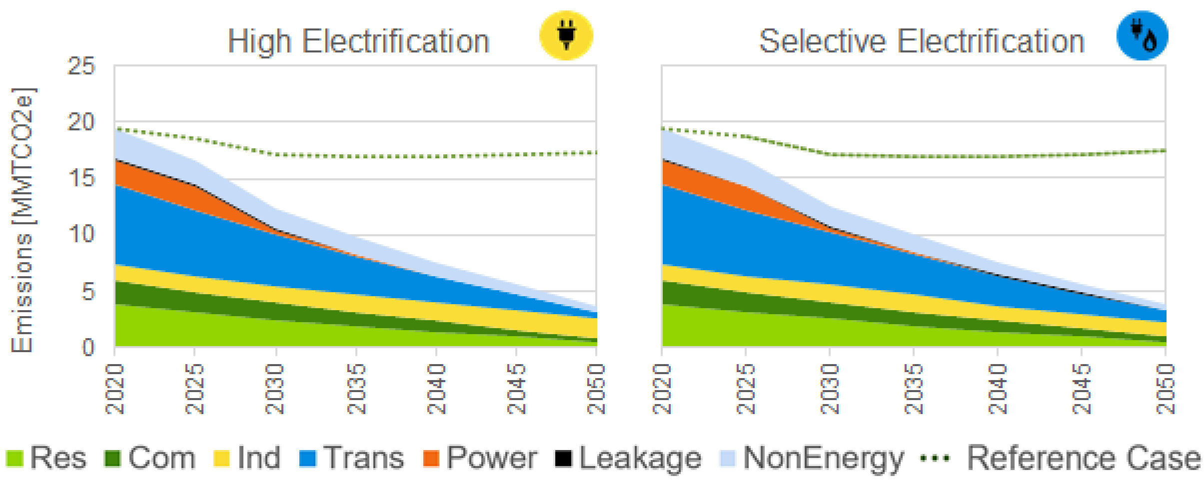


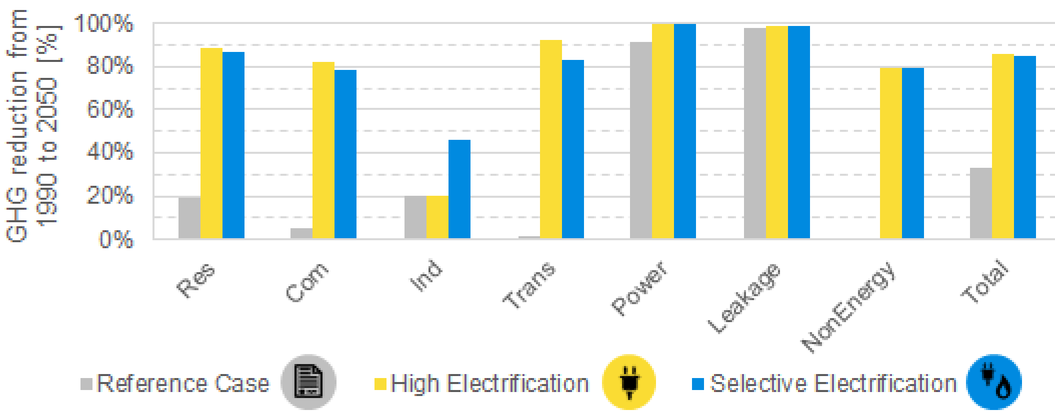
Figure 3-2 shows the proportional emissions reduction from 1990 to 2050 from different sectors in National Fuel's New York territory. The *Reference Case* shows high GHG reduction in the power sector due to New York's Clean Energy Standard and in the leakage category due to ongoing replacement of aging pipelines.[24] Compared to the *Selective Electrification* scenario, the *High Electrification* scenario shows significantly smaller emissions reductions in the industrial sector and larger emissions reductions in the non-industry sectors (Res, Com, Trans).[25] This is because the *High Electrification* scenario does not allow for the development of

[24] The Leakage category of GHG emissions shows greater emissions reduction in the *Selective Electrification* and *Customer Choice* scenarios due to the displacement of some pipeline natural gas with HENG.

[25] For the industrial sector, the *Selective Electrification* scenario shows higher GHG reductions than the *High Electrification* scenario, because the *Selective Electrification* scenario includes the industrial green hydrogen technology.

low carbon fuel infrastructure that will enable heavy industry to decarbonize. This finding points to a concern around the equitable distribution of the burden of decarbonization within the *High Electrification* scenario. Because the scenario does not provide a pathway for the decarbonization of the industrial sector, residential and commercial customers will bear a greater burden of decarbonization.

Figure 3-2. Emissions Reduction from 1990 to 2050, by Sector, NFGDC Territory



3.2 Energy Consumption

If NFGDC's territory is to decarbonize by mid-century, electricity consumption will increase, and pipeline natural gas consumption will decrease. In the *High Electrification* and *Selective Electrification* scenarios, we project that nearly all commercial customers and over 85% of residential customers will either partially or fully switch from fuel-fired heating to electric heat sources. The *High Electrification* scenario assumes that customers who electrify their heat will do so by installing whole-building heat pumps, while the *Selective Electrification* scenario allows for a high degree of hybrid dual-fuel heating systems (see Section 2.5).

In both scenarios, the steady electrification of heating will not increase residential and commercial electricity consumption as drastically as might be expected due to three factors:

1. Building improvements will increase shell efficiency and reduce heating and cooling loads over time
2. Some electric heat pump systems will replace less efficient electric resistance heating systems in use today[26]
3. Other electric end uses such as lighting, appliances, and space cooling will become more efficient over time due to increased efficiency standards and building codes

Section 3.4 provides more detail on our findings related to building energy consumption.

[26] In 2015, 10.6% of occupied households in New York used electricity as their primary heat source. Source: NYSERDA (2017). "Patterns and Trends New York State Energy Profiles: 2001–2015 Final Report", Appendix D-1. Available at: https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/2001-2015-patterns-and-trends.pdf

In 2015, 10.5% of homes in the Northeast U.S. used low efficiency electric resistance heating equipment as their primary heat source. Source: U.S. Energy Information Administration (2018). "Residential Energy Consumption Survey, Table HC6.7" Available at: https://www.eia.gov/consumption/residential/data/2015/#sh

Figure 3-3. Annual Electricity and Pipeline Gas Consumption, by Sector, NFGDC Territory

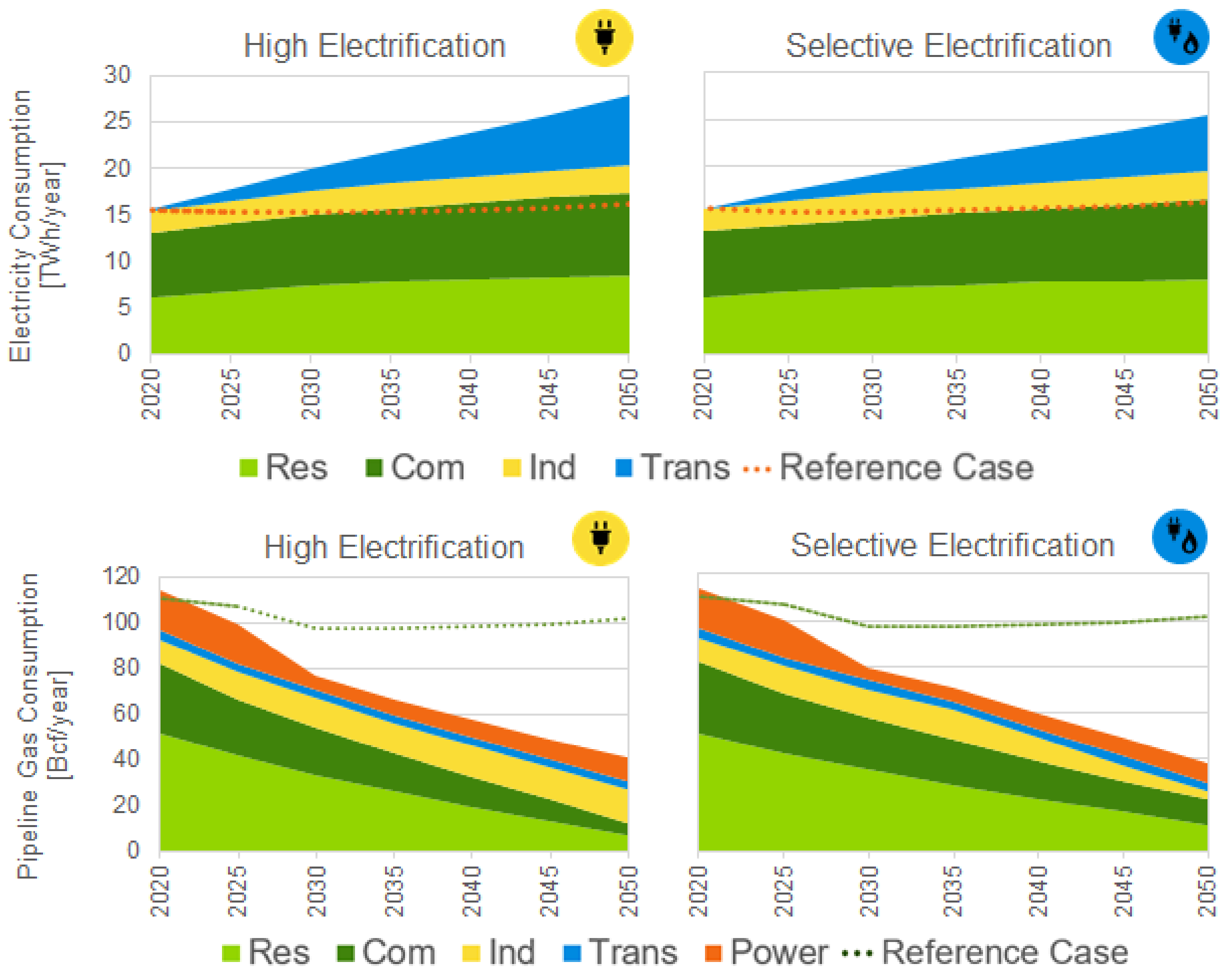


Figure 3-3 shows electricity and pipeline natural gas (including fossil gas, RNG, and HENG) consumption in NFGDC's New York territory by sector over time for each scenario. Both scenarios show increased electricity consumption in the transportation sector, driven by the introduction of light, medium, and heavy duty EVs. Electricity consumption would be greatest in the *High Electrification* scenario, while the *Selective Electrification* scenario shows more moderate growth in electric consumption over time due to its use of low carbon gaseous fuels (RNG and HENG).

The Climate Act's power sector requirements drive a reduction in power sector gas consumption from 2020 to 2030. To meet the Climate Act's renewable generation requirement, the power sector must rapidly displace natural gas-fired generation with generation from renewable sources. The residential and commercial sectors also see reduced pipeline gas consumption due to increased adoption of electric heat pumps. Energy efficiency measures reduce the overall energy needs of each sector and contribute to the downward trend in pipeline gas consumption.

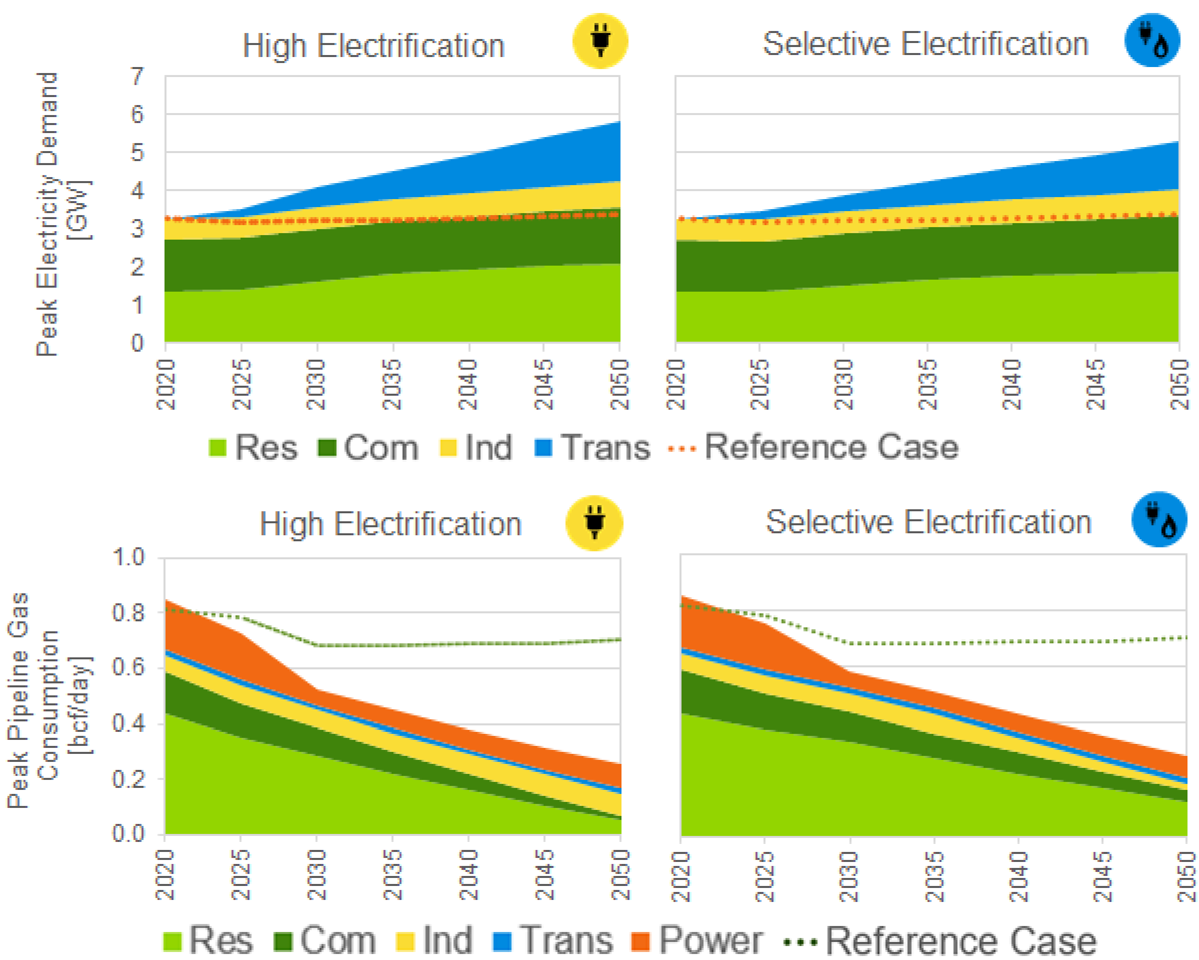
The *High Electrification* scenario shows little reduction in industrial pipeline gas consumption, while the *Selective Electrification* scenario creates a greater reduction in pipeline gas consumption because it permits the offset of industrial natural gas use with industrial local green hydrogen (a technology that is excluded from the *High Electrification* scenario).

3.3 Energy Demand

Figure 3-4 shows the peak electric demand and peak pipeline gas consumption by scenario and sector, respectively, in NFGDC's New York territory. The *High Electrification* scenario shows peak demand in National Fuel's territory increasing 2.6 GW by 2050, compared to 2.0 GW of peak demand increase for the *Selective Electrification* scenario.[27] Those scenarios show a similar decrease in peak pipeline gas consumption, but with different allocation across sectors in 2050. The *Selective Electrification* scenario shows higher gas consumption in the residential and commercial sectors and lower gas demand in the industrial sector because the *Selective Electrification* scenario includes the industrial green hydrogen technology and assumes that 50% of pipeline gas is composed of non-fossil fuels such as RNG and HENG.

The High Electrification scenario shows a statewide electric peak demand increase of 75% in 2050 relative to 2020, compared to a 60% increase in the Selective Electrification scenario.

Figure 3-4. Forecast of Peak Electric and Pipeline Gas Demand, by Scenario and Sector



27 At a statewide level, the *High Electrification* scenario shows peak demand increasing 23.2 GW by 2050, compared to 18.9 GW of peak demand increase for the *Selective Electrification* scenario

3.4 Residential and Commercial Buildings

Figure 3-5 and Figure 3-6 show changes in residential and commercial space heating consumption over time for each scenario in NFGDC's New York territory. Energy efficiency (from the building shell improvements and the inherent efficiency advantages of heat pumps) is a key driver for reducing energy consumption and GHG emissions in all scenarios. The *High Electrification* scenario relies more heavily on electric technologies, while *Selective Electrification* uses RNG, hydrogen, and dual-fuel heating to reduce GHG emissions. Both scenarios show efficiency gains from converting fuel-fired heating to electric heat pumps. These efficiency gains are slightly higher in the *High Electrification* scenario because it assumes a higher proportion of customers fully electrify their space heating needs.

Figure 3-5. Residential Space Heating Consumption, by Scenario and Fuel Type

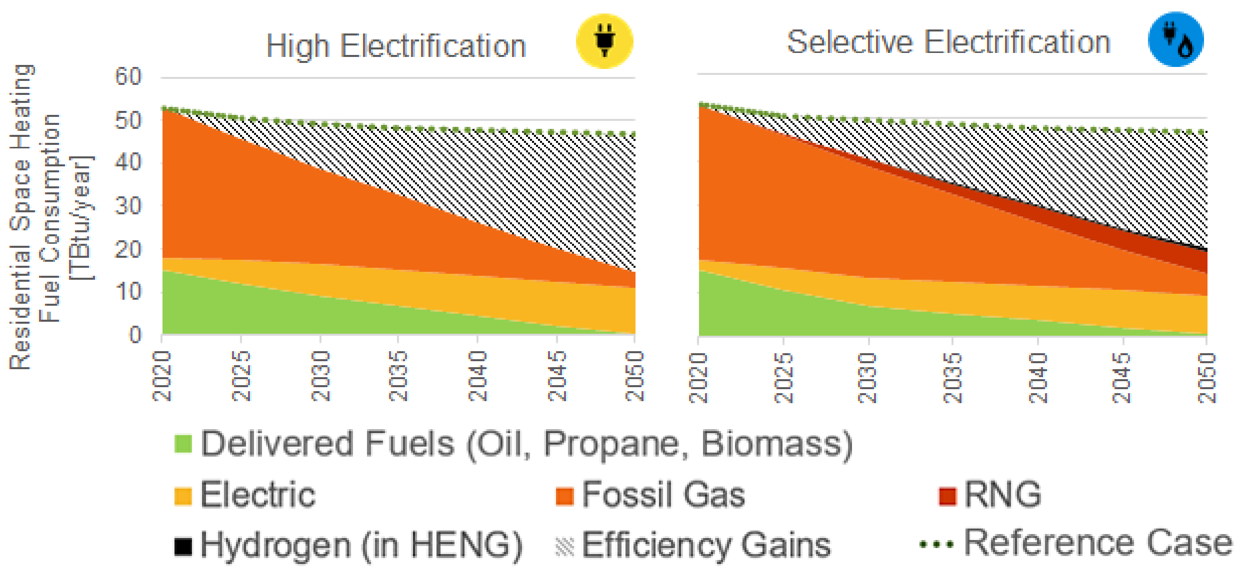


Figure 3-6. Commercial Sector Space Heating Consumption, by Scenario and Fuel Type

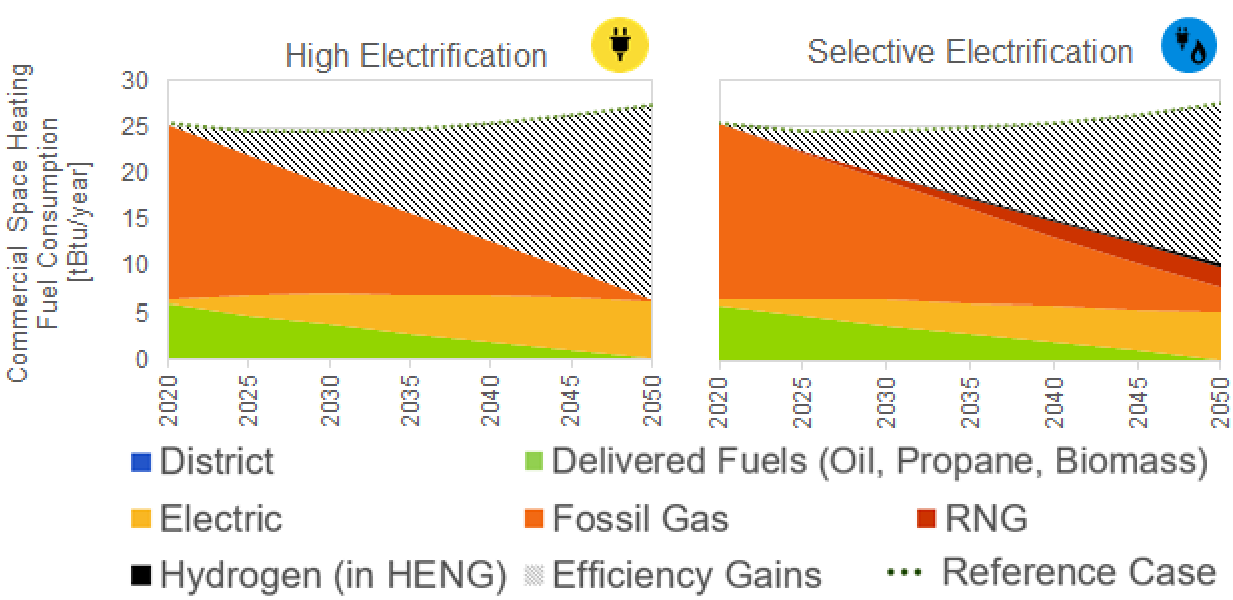
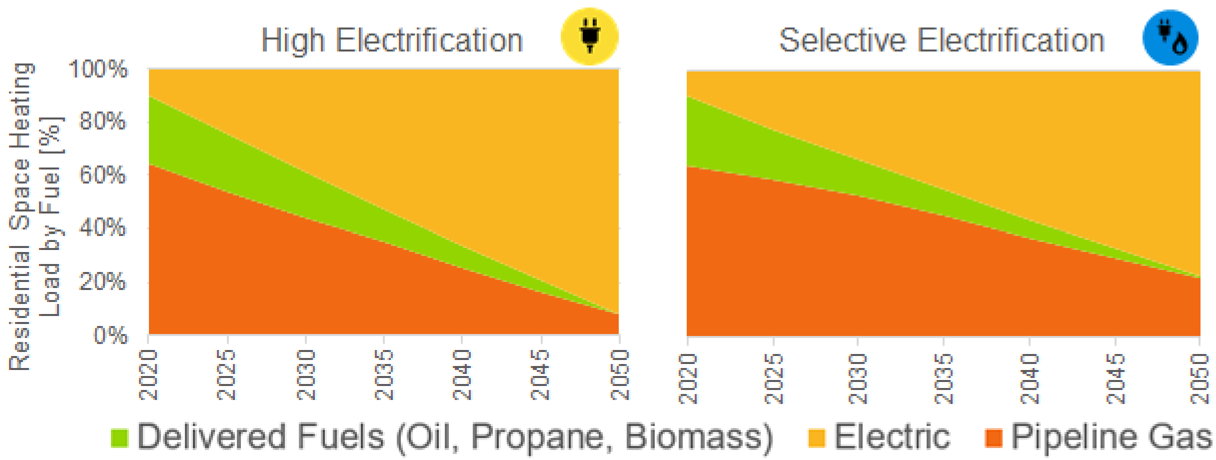


Figure 3-7 shows how the proportion of statewide residential space heating load met by each fuel type would evolve over time in both scenarios. The *High Electrification* sees a greater increase in electric space heating. The *Selective Electrification* scenario allows for a greater proportion of heating from low carbon pipeline gas, made up of a mixture of RNG, hydrogen, and fossil natural gas. Both scenarios show a gradual elimination of propane and fuel oil.

Figure 3-7. Residential Space Heating Load Met by Each Fuel Type



Guidehouse also modeled the impacts that interventions in the *Selective Electrification* scenario would have on a typical single family household in NFGDC's New York territory. Figure 3-8 shows how different residential end uses contribute to household energy consumption and associated GHG emissions in 2015 (prior to intervention) and in 2050 (after intervention). In 2015, the typical single family household consumes natural gas for space heating and water heating.[28] In the *Selective Electrification* scenario, we assume that by 2050, the typical household takes steps to improve building shell and appliance efficiency and switches to electric water heating and dual-fuel space heating.

In NFGDC's territory, an individual household's GHG footprint will be further reduced by decarbonization measures implemented upstream. Renewable power generation and CCS will reduce emissions from customers' electric consumption and in the *Selective Electrification* scenario, RNG and HENG will reduce emissions from customers' pipeline gas consumption. For this illustration, we estimate GHG emissions per household as product of energy use and emissions factors.[29] As Figure 3-8 illustrates, interventions in the *Selective Electrification* scenario can more than halve a typical household's energy consumption and reduce household GHG emissions by greater than 90%. We found that similar reductions are possible for typical homes in New York State, as described in Appendix C.3.

[28] Annual energy use in 2015 from NYSERDA (2019) Patterns and Trends, New York Energy Profiles: 2002–2016, Appendix B, representing single-family homes in New York State. Available at: https://www.eia.gov/consumption/residential/data/2015/

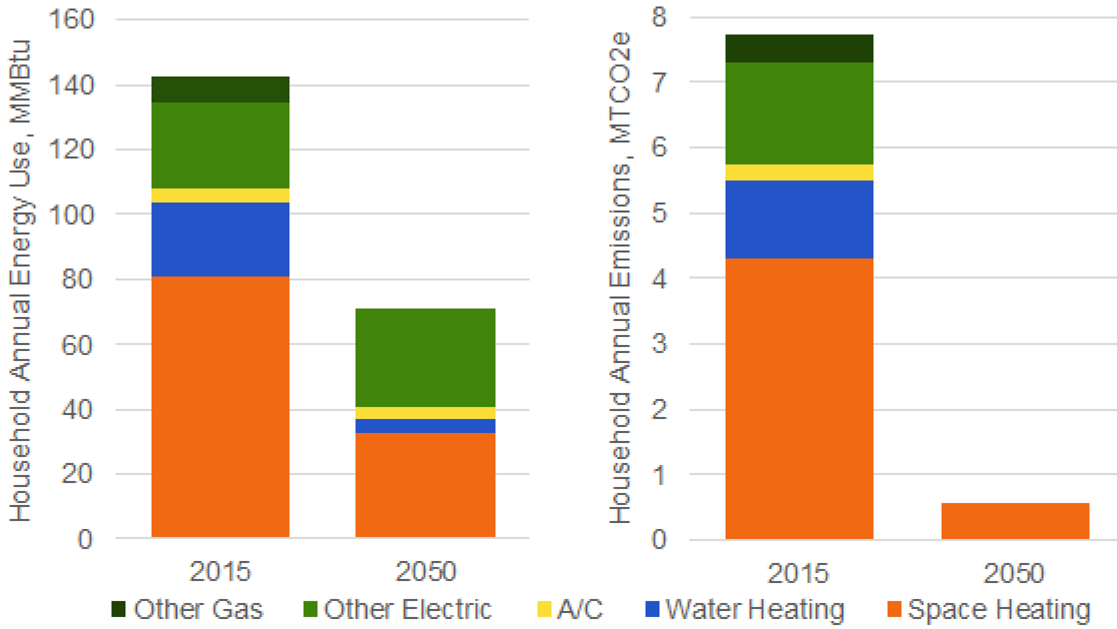
[29] Natural gas consumption has emissions factor of 53.1 kg CO_2 per MMBtu, from U.S. EPA.

U.S. Environmental Protection Agency (2014). "Emission Factors for Greenhouse Gas Inventories." Available at: https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

Electric consumption in 2020 has emissions factor of 58.7 kg CO_2 per MMBtu, from NYISO. Electric consumption in 2050 has zero emissions due to interventions that decarbonize the electric generation sector.

NY ISO. "2018 Power Trends." Figure 23 shows 0.20 tons CO_2 per net MWh, equivalent to 58.7 kg CO_2 per MMBtu. Available at: https://www.nyiso.com/documents/20142/2223020/2018-Power-Trends.pdf/4cd3a2a6-838a-bb54-f631-8982a7bdfa7a

Figure 3-8. Reduction in Energy Use and GHG Emissions from Selective Electrification
Example: Single-family home, NFGDC territory, switching from natural gas to dual-fuel heat

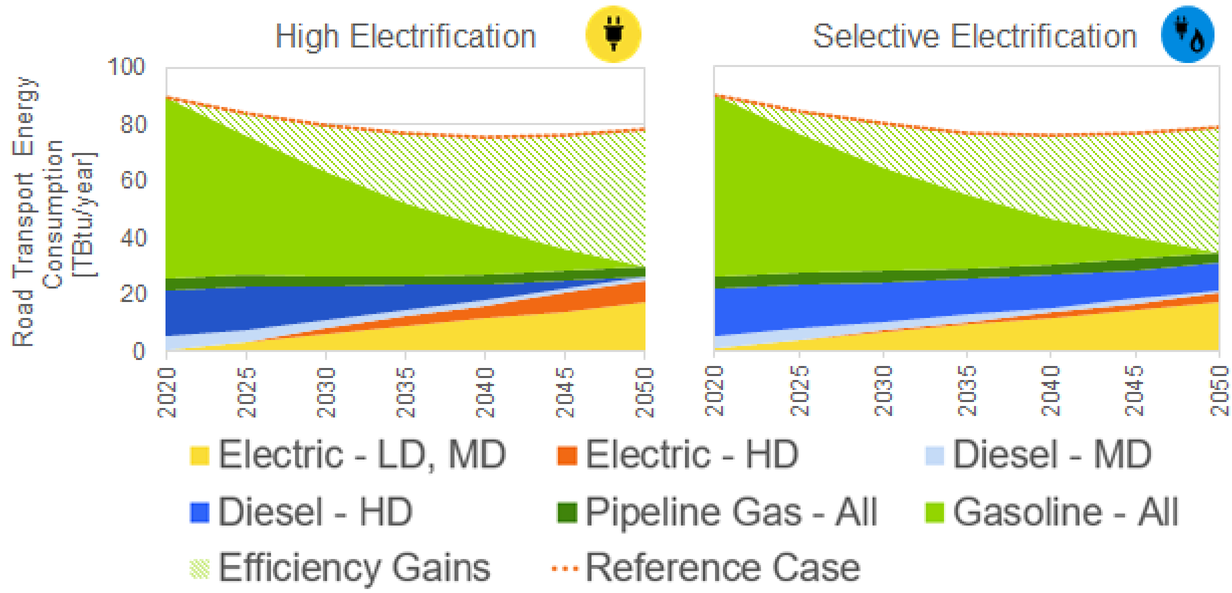


Intervention	Energy Savings	Emissions Reduction
Building Shell Efficiency	15%	14%
Heat Electrification & Dual Fuel Systems	30%	30%
Appliance Efficiency	5%	4%
Renewable Elec. Generation	n/a	27%
Carbon Capture & Storage	n/a	10%
Low-Carbon Fuels (RNG, Hydrogen)	n/a	7%
Total	**50%**	**93%**

3.5 Transportation Sector

Figure 3-9 shows the forecast vehicle energy consumption in NFGDC's New York territory for each scenario and vehicle type, and the energy consumption reduction deriving from efficiency improvements. Efficiency is a key driver of emission reductions in the transportation sector for all scenarios, and the improvement comes from two sources: general improvements in transportation efficiency and the inherent efficiency gains in switching from internal combustion engines to electric motors.

Figure 3-9. Forecast of Vehicle Energy Consumption, by Scenario and Vehicle Type



3.6 Power Sector

Natural gas-fired generation will decrease over time but will not be eliminated; it serves an essential role in addressing reliability challenges associated with intermittent renewable resources.

The Climate Act's requirements will force major changes in the power sector. Electrification of customers' end use consumption will increase electric demand and annual electric generation. The Climate Act also requires 70% of electric generation to come from renewables by 2030 and that electric generation be 100% zero emissions by 2040. We modeled scenarios to comply with the Climate Act's interim requirements for the power sector; the act requires 6,000 MW of solar capacity by 2025 and 9,000 MW of offshore wind capacity by 2035. Guidehouse's LCP model also accounts for the Climate Act requirement that 3,000 MW of energy storage capacity be installed by 2030.[30]

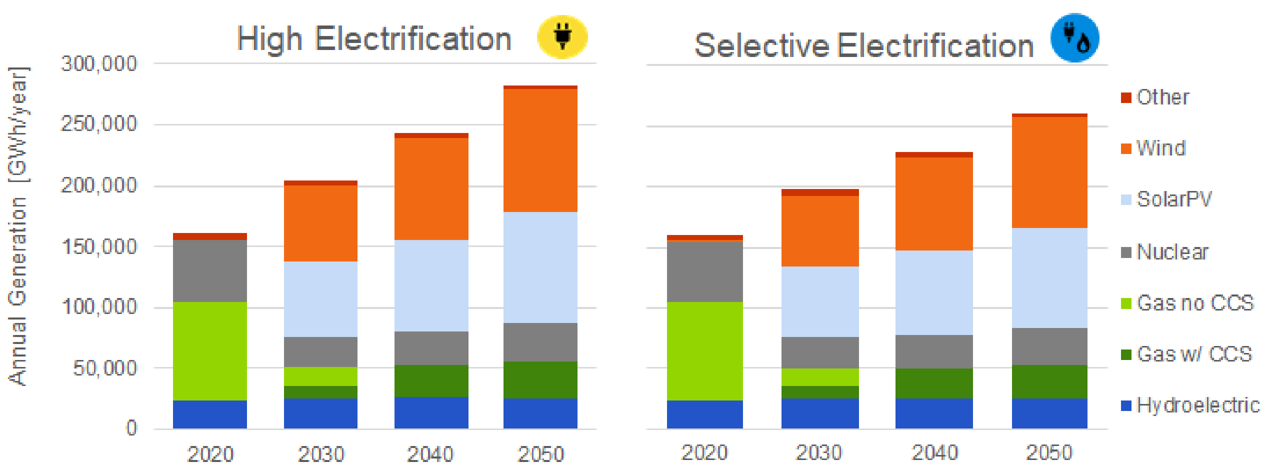
For all scenarios, we expect new solar and wind capacity to increase from 2020 to 2030 to replace retired nuclear generators and some gas-fired generators. Natural gas-fired generation will be reduced over time but not eliminated; it serves an essential role in addressing reliability challenges associated with intermittent renewable resources. To achieve the requirement of carbon-free generation by 2040, we anticipate that gas-fired generators will begin deploying CCS technology in 2030 and that CCS deployment will steadily increase until all gas-fired generators use CCS in 2040. New York has many options for carbon capture within the state

[30] Assuming linear adoption of wind, solar and energy storage capacities, the Climate Act implies the need for energy storage capacity equivalent to one-sixth of the total wind and solar (i.e., intermittent renewable) capacity. We assume that for every 6 MW of intermittent renewables installed, 1 MW of energy storage must be available. We assume that this is a necessary requirement for all levels of adoption of intermittent renewables and our LCP model includes energy storage costs as part of the cost to install intermittent renewables. The cost of storage is assumed to be the cost of utility-scale Li-ion batteries according to Guidehouse Insights forecasts (Market Data: Energy Storage Pricing Trends, Guidehouse Insights, 2Q 2020).

and surrounding areas, including oil and natural gas reservoirs, un-mineable coal seams, saline formations, offshore sandstone formations, shale basins, and basalt-rich areas. In all scenarios, our analysis accounts for the expected retirement of two Indian Point nuclear generators before 2025.

Figure 3-10 illustrates the amount of electricity generated from different energy sources for each scenario. The amount of electric generation exceeds the amount of electric consumption reported in Figure 3-3 due to transmission and distribution losses, which are assumed to be 8% of supplied electricity. In all scenarios, other fuels (coal, oil, biomass, and hydrogen) make up less than 3% of total generation throughout the 2020-2050 study period.

Figure 3-10. New York State Annual Electric Generation, by Energy Source and Scenario



3.7 Industrial Sector

The EIA's *AEO 2019* Reference Case projects that industrial energy consumption will increase 31% between 2018 and 2050, driven by economic growth and affected by low prices and resource availability.[31] This growth in energy consumption accounts for improvements in energy efficiency that are projected to reduce the energy intensity of most industrial activities by about 10%.[32]

Guidehouse found that hydrogen can play a key role in offsetting natural gas emissions in the industrial sector. The difference is material.

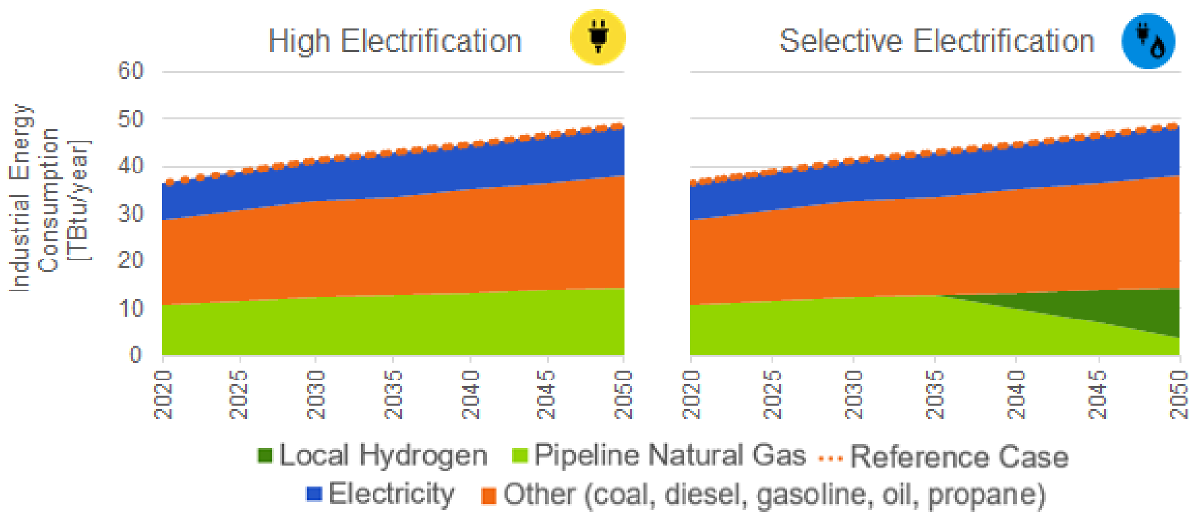
Guidehouse's LCP model includes three technologies that can affect industrial emissions: additional industrial energy efficiency beyond the reference case assumptions, RNG, and local green hydrogen as a natural gas replacement. Guidehouse found that hydrogen can play a key role in offsetting natural gas emissions in the industrial sector. The difference is material; in Figure 3-2 (page 25), the *Selective Electrification* scenario shows greater reductions in industry emissions than the *High Electrification* scenario that excludes it.

[31] US Energy Information Administration (2019). "Annual Energy Outlook 2019." Slides 149-153. Available at: https://www.eia.gov/outlooks/archive/aeo19/pdf/aeo2019.pdf

[32] *Ibid.* slides 153-154.

Figure 3-11 shows the industrial energy use by fuel and scenario. In the *Selective Electrification* scenario, pipeline gas includes RNG and HENG, as Appendix C describes. Our analysis assumed that hydrogen displaces industrial natural gas use but does not impact consumption of other fuels (e.g., diesel, coal, gasoline).[33] Further decarbonization of the industrial sector would likely require additional technologies that can replace other fuels or prevent emissions that stem from the use of those fuels.

Figure 3-11. Industrial Energy Use, by Fuel and Scenario, National Fuel Territory[34]



3.8 Non-Combustion GHGs

In addition to the emissions associated with fuel use, Guidehouse's LCP model also tracks emissions from natural gas leakage and from non-energy sources such as refrigerant leakage (globally referred to as non-combustion GHGs). The model treats these streams as follows:

1. Leakage emissions are calculated based on the makeup of the gas pipelines. The model accounts for planned pipeline replacements and replacements required for the use of HENG (in the *Selective Electrification* scenario where it is included). As Figure 3-1 and Figure 3-2 show, leakage is a small part of the state's total emissions. In all scenarios, we assume that pipeline replacement programs and system upgrades lead to a 90% reduction in natural gas leakage in 2050 relative to 1990 levels.
2. Non-energy emissions do not pertain to the energy system and so are considered out of scope for this study. For example, New York has committed to regulatory action to phase out the use of hydrofluorocarbon refrigerants, a major contributor to non-energy emissions. We assume that new programs and initiatives will reduce non-energy emissions to meet the same target imposed for the entire economy. That is, we assume that non-energy emissions decrease by 85% in both scenarios.

[33] The aggregate energy consumption data referenced in this analysis does not specify how "other" fuels are being used in the industrial sector. We assume these fuels are used in a variety of process-specific equipment and/or high-temperature applications, and that the electrification of these end uses would be less cost-effective than the other decarbonization options considered in this analysis. Based on this assumption, our analysis does not consider the electrification of "other" fuel use in the industrial sector.

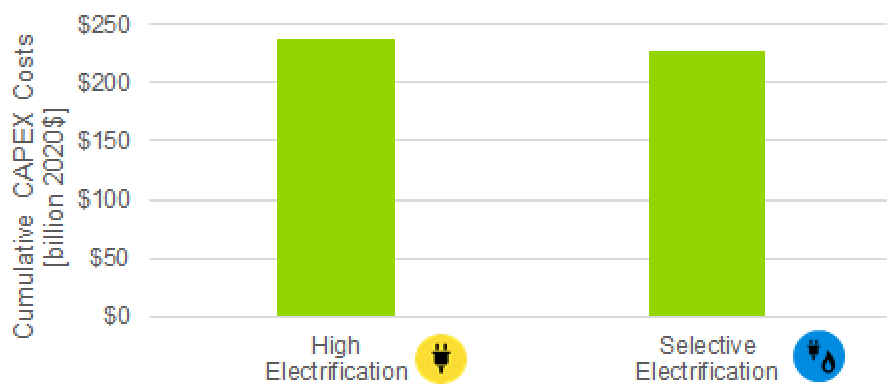
[34] Electricity emissions are counted in the power sector, but electricity consumption is assigned to each sector as exemplified in this figure.

3.9 Costs by Scenario

Figure 3-12 shows the cumulative statewide costs of each scenario from 2020 to 2050, reported in nominal 2020 dollars. All costs are incremental relative to the *Reference Case* scenario. The *High Electrification* and *Selective Electrification* scenarios are likely to require similar CAPEX over the analyzed period. However, *Selective Electrification* offers more technology options and a more diversified energy system so it preserves options to provide a more resilient system in the future; such details may impact costs in ways that are not captured by the CAPEX metric provided in Figure 3-12. Utilizing the existing pipeline infrastructure will allow stakeholders to continue to benefit from the reliability that gas utility systems provide. Additionally, the inherent characteristics of pipeline infrastructure and storage which is mostly underground support a resilient energy system.

The Selective Electrification *scenario offers more technology options and a more diversified energy system, so it preserves options to provide a more resilient system in the future.*

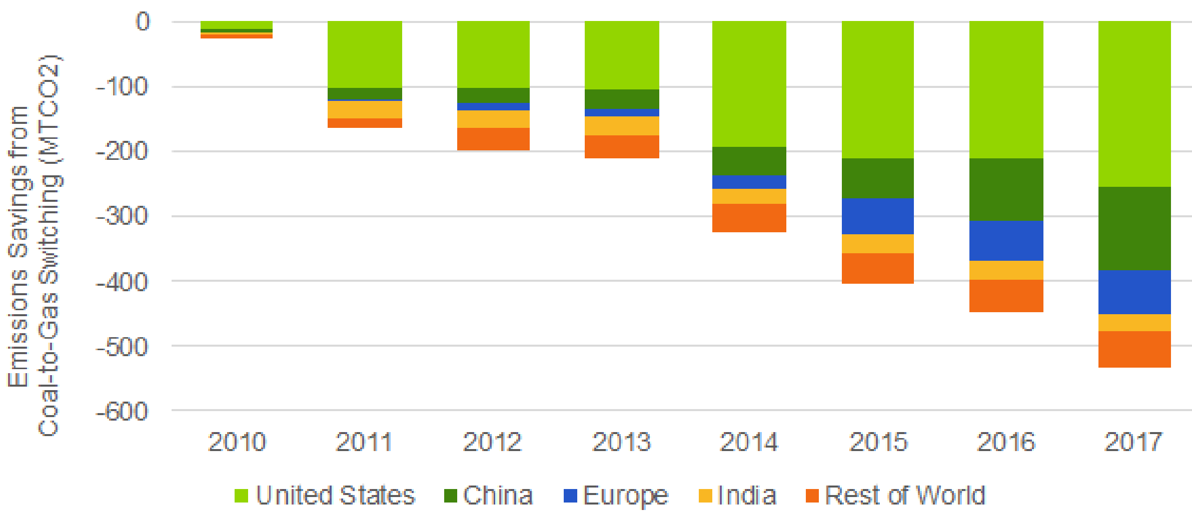
Figure 3-12. Cumulative Statewide CAPEX, Incremental to Reference Case



4. Conclusions

Many stakeholders see the natural gas system as a transitional state along the decarbonization pathway—one that has already contributed to GHG emissions reductions and whose future role will be to reduce reliance on coal-fired electric power generation, the most carbon-intensive source of electricity generation. As of 2018, the transition from coal to natural gas has resulted in a reduction of over 500 $MTCO_2$ globally and over 255 $MTCO_2$ in the US as compared to a 2010 baseline (Figure 4-1). Further CO_2 savings will result when natural gas use is reduced by renewable fuels and electricity.

Figure 4-1. CO_2 Savings from Coal-to-Gas Switching in Selected Regions, 2010-2018[35]



New York has already benefited from the use of natural gas as a lower carbon energy source, resulting in one of the most energy efficient economies in the nation. As of 2017, "New Yorkers use less energy per capita than the residents of any other state except Rhode Island."[36] However, as the state moves toward the Climate Act's mid-century decarbonization targets, additional emissions reductions will be necessary. This study shows there are viable pathways to achieving the Climate Act targets and New York's gas system can play a significant role in decarbonizing New York's energy system.

4.1 Study Results

To demonstrate the different pathways to decarbonization, Guidehouse explored two scenarios that achieve the Climate Act target of 85% decarbonization by 2050. A *High Electrification* scenario would nearly eliminate natural gas use in buildings, while a *Selective Electrification* scenario would substantially reduce natural gas use in buildings and modify the natural gas

[35] International Energy Agency (2019). "The Role of Gas in Today's Energy Transitions." Available at: https://www.iea.org/data-and-statistics/charts/co2-savings-from-coal-to-gas-switching-in-selected-regions-compared-with-2010-2018

[36] US Energy Information Administration, State Profile and Energy Estimates, New York: https://www.eia.gov/state/analysis.php?sid=NY#11

economy to include low carbon fuels such as RNG and HENG.[37] Our analysis led to the following key findings.

#1 Achieving the Climate Act's targets requires accelerating the advancement of efficiencies related to transportation, buildings, and appliances.

Decarbonization of the transportation sector is critical to achieving the Climate Act's emissions reduction targets. Emissions from transportation increased 25% from 1990 to 2016, and the transportation sector currently produces over one-third of New York State's GHG emissions.[38] Energy efficiency (from building shell improvements and high efficiency heat pumps and appliances) is another critical element for reducing GHG emissions. The *Reference Case* scenario assumes significant gains in energy efficiency[39] due to updated building codes, appliance standards, and utility energy efficiency rebates. Additionally, automobile fuel economy standards increase in the *Reference Case*. The *High Electrification* and *Selective Electrification* scenarios each assume that further efficiency improvements reduce building envelope and appliance energy consumption by an additional 10% due to improvements in building codes and standards. Further, switching gasoline to electric vehicles, coupled with 10% more efficiency from additional technology improvements results in energy intensity reductions in the residential (32% overall), commercial (23% overall), and transportation (42% overall) sectors.[40]

#2 The *Selective Electrification* scenario demonstrates the critical importance of including all options in developing an effective decarbonization pathway

The *Selective Electrification* scenario accomplishes the Climate Act's GHG emissions reductions targets using a variety of technologies, with each providing significant GHG reductions. For typical *residential* customer energy use, GHG emissions were reduced through building envelope and appliance energy efficiency measures, and through the use of high efficiency heat pumps (whether whole-home or dual-fuel). An individual customer's GHG footprint will be further reduced by decarbonization measures implemented upstream of the customer. Renewable power generation will reduce the emissions from customers' electric consumption, and RNG and HENG will reduce the emissions from customers' pipeline gas consumption. The dual-fuel heating option available in the *Selective Electrification* scenario

[37] By exploring the scenarios included in this study, we identified various pathways to a decarbonized future. There are many ways to achieve these goals, and we do not forecast that these specific scenarios are the only viable means to achieve the Climate Act's requirements. However, scenario modeling helps identify challenges associated with the current state and opportunities to develop policies and regulatory structures that will enable the execution of the legislation. The study's conclusions are specific to New York and should not be extrapolated to other regions. In particular, regions with milder climates than New York or regions with different gas and electric rates might reach different conclusions.

[38] The New York State Energy Research and Development Authority (2019). "New York State Greenhouse Gas Inventory 1990-2016." Available at: https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/greenhouse-gas-inventory.pdf

[39] The *Reference Case* scenario is based on the EIA's *Annual Energy Outlook 2019*, which projects that from 2018 to 2050, increases in energy efficiency will cause energy intensity to decline by 22% in the residential sector, 13% in the commercial sector, and 32% in the transportation sector.

[40] "Energy intensity" is measured by the quantity of energy required per unit output or activity. For buildings, energy intensity is usually expressed in energy use per sq.ft of building space; for transportation, it is expressed as energy use per vehicle mile.

will also mitigate growth in winter peak demand and improve system resilience in cold climate regions. This finding demonstrates the value of allowing all emissions reduction options to play a role in achieving the state's emissions reduction targets.

#3 The *Selective Electrification* scenario offers an effective pathway to decarbonize high temperature industrial processes and heavy duty trucking.

The *Selective Electrification* scenario assumes greater use of the existing gas pipeline infrastructure relative to the *High Electrification* scenario. The *Selective Electrification* scenario retains clearer pathways for the utilization of low carbon gases, which will be critical to decarbonizing hard-to-electrify industrial and transportation end uses. The *Selective Electrification* scenario offers a pathway to further decarbonize these end uses. It also mitigates the risk of disproportionately burdening other market sectors with deeper decarbonization requirements to offset limited pathways for the industrial sector.

4.2 Additional Considerations

Achieving the Climate Act's mid-century target will require extensive decarbonization of the energy sector at an unprecedented speed. The gas system could support this transition by:

- **Providing a complementary asset to battery storage.** Strong growth in energy production from wind and solar PV requires dispatchable electricity production by biomass and low carbon gas and storage options in times of excess electricity production. Seasonal battery storage is challenging even at substantially reduced costs.

- **Providing a pathway to decarbonize high temperature industrial processes.** Full decarbonization of high temperature industrial heating processes is currently not feasible through electric solutions. Low carbon gases (such as RNG and green or blue hydrogen) can meet the heating needs of high temperature processes while reducing the processes' GHG emissions.[41]

- **Mitigating the growth in electric peak demand.** Dual-fuel heating systems contribute less to winter electric peak demand than whole-home ASHPs do during cold periods, because at low temperatures they rely on gas-fired heating with low electric demand.

- **Ensuring the reliability and resiliency of the energy system.** In a decarbonized future, gas infrastructure will continue to support a broader energy system reliability and resiliency when it is used to transport and distribute low carbon gas and hydrogen.

[41] European Commission Joint Research Centre (2020). "Global Energy and Climate Outlook 2019: Electrification for the low-carbon transition." p.50. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC119619/kjna30053enn_geco2019.pdf

This study did not analyze these issues in depth since they are treated in prior studies, including Guidehouse's *2020 Gas Decarbonisation Pathways* study[42] and the American Gas Foundation's 2021 study on *Building a Resilient Energy Future*.[43]

4.3 Issues for Policymakers and Regulators

Demonstrating the technical and financial viability of a *Selective Electrification* pathway is only the first step on the long road to decarbonize New York's energy system to meet the Climate Act goals. Significant policy and regulatory barriers impede the reality of this future if the future framework does not support the investment needed for a safe, reliable natural gas delivery infrastructure providing added optionality for achieving the decarbonization objectives.

Over the last century, natural gas utilities have successfully built reliable, safe, and affordable energy delivery systems. Transforming this system will require investment that must be evaluated differently from previous investments. The policies, regulations, and economic frameworks that exist at the state and federal level are inadequate to encourage gas utilities to embrace the risks of new technologies, business models, and structural change required to realize a decarbonized future where gas infrastructure and supply play a significant role.

We present considerations around the policy and regulatory changes that may be required to accomplish the goals of the Climate Act by leveraging this analysis and similar work Guidehouse has performed regarding the transition to a lower carbon economy. Table 4-1 includes some of the barriers that may be encountered and some of the actions that should be taken to overcome them.

Table 4-1. Policy Issues and Opportunities

Issue 1: Regional policies and regulations should be structured to increase the supply of RNG and green or blue hydrogen in gas grids and to increase the use of these low carbon fuels in downstream sectors.

- State and federal policies similar to those that supported the development of solar and wind renewable generation will be helpful to build this market.
- New York State should mandate or encourage specific levels of production for both RNG and decarbonized hydrogen. Policymakers and regulators must understand that to achieve these production goals, utilities and private investors will likely need to undertake interstate transactions. Although many sources are available in New York, other suitable development sites may lie outside New York's borders.

[42] Guidehouse (2020). "Gas Decarbonisation Pathways 2020-2025." Available at: https://gasforclimate2050.eu/publications/

[43] 2021 . "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience" Available at: https://gasfoundation.org/2021/01/13/building-a-resilient-energy-future/

Issue 2: Consumers would benefit from regulatory structures that support the development of resiliency assets and compensate investors for providing those services.

- Low carbon solutions like RNG and green or blue hydrogen can be readily stored to supplement supply for intermittent and peaking generation. This storage capability supports the development of resilient systems.
- RNG and hydrogen are excellent sources of feedstock for long duration and seasonal storage. These attributes are especially important in cold weather climates with extreme seasonal winter demand, such as those in New York.
- Regulatory policy should directly reward investments in system resiliency and (similar to stranded costs) should be amortized over the largest array of market segments as the benefits accrue to all energy users. Failure to construct policies that foster complementary operations of electric and pipeline systems and associated resiliency will create material risks to local economies and their communities.

Issue 3: There is too much long-term uncertainty in the low carbon fuel and infrastructure market to drive the required investment from private investors.

- Investments in renewable and low carbon gases and gas infrastructure require long-term certainty provided by encouragement to energy-using sectors, investors, and project developers. Current policies fall short in providing such a framework, even though the Climate Act and the increasing focus on decarbonization demonstrate the need.
- To encourage private investment, regulatory policy should be designed to provide long-term consistency in targets associated with low carbon fuels.

List of Acronyms

This section defines key terms and acronyms used throughout this report.

AC	Air Conditioning
ASHP	Air-Source Heat Pump
Bcf	Billion cubic feet (a measure of volume)
CAPEX	Capital Expenditures
CCS	Carbon Capture and Storage
CNG	Compressed Natural Gas
CO_2e	Carbon Dioxide Equivalent
EIA	US Energy Information Administration
EPRI	Electric Power Research Institute
EV	Electric Vehicle
GHG	Greenhouse Gas
GSHP	Ground-Source Heat Pump
HE	High Electrification (scenario)
HENG	Hydrogen-Enhanced Natural Gas
HP	Heat Pump
HPWH	Heat Pump Water Heater
HVAC	Heating, Ventilation, and Air Conditioning
LCP	Low Carbon Pathways
MMBtu	Million British Thermal Units (a measure of energy)
MMTCO2e	Million metric tons of carbon dioxide equivalent (a measure of GHG)
MW	Megawatts (a measure of power)
NFGDC	National Fuel Gas Distribution Corporation
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
Solar PV	Solar Photovoltaics (a means of power generation)
RNG	Renewable Natural Gas
TBtu	Trillion British Thermal Units (a measure of energy)
TWh	Terawatt-hours (a measure of energy)
US	United States

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Appendix A. Definition of Geographic Study Regions

As described in Section 2.3, our analysis studied New York State as a whole and NFGDC's service territory in New York. Many of the inputs to Guidehouse's LCP model are based on state-level energy consumption information provided by the EIA, which was then scaled to the regional level with sector-specific scaling factors developed from data available at the county and ZIP code level. Regional statistics used for scaling include population, energy consumption, vehicle registration, and commercial and industrial employment statistics. For example, we used county level energy consumption data from the Open NY program to scale residential and commercial energy consumption and GHG emissions, and we used ZIP code level vehicle registration data to scale energy consumption and emissions in the transportation sector. Table A-1 presents summary statistics for the regions modeled in this analysis.

Table A-1. Summary Statistics for Regions Modeled

Region	Population (millions)	Total Monthly Energy Consumption (TBtu)	Total Vehicle Registrations (millions)	Commercial Employment (millions)
NFGDC Territory	1.54 (7.9%)	123.4 (10.8%)	1.09 (10.6%)	0.62 (7.0%)
Total (NY State)*	19.38 (100%)	1,144 (100%)	10.26 (100%)	8.82 (100%)

Appendix B. Decarbonization Opportunities

The scenarios considered in this analysis include different combinations of decarbonization technologies that could be deployed over the 2020-2050 analysis period. The following sections detail the opportunities and limitations of each technology we considered

B.1 Upstream Technologies

B.1.1 Renewable Natural Gas

RNG is a gaseous fuel with lower carbon intensity and similar operational and performance characteristics to natural gas, and RNG can reduce GHG emissions in applications that use natural gas and other fossil fuels. RNG reduces systemwide GHG emissions by avoiding the release of methane into the atmosphere from the natural breakdown of organic materials. Combusted natural gas has a much lower carbon intensity than pure methane when released to the atmosphere; eliminating methane emissions provides the majority of avoided GHG emissions. The specific carbon intensity of RNG is a complex calculation that depends on feedstock, production technology, and location, among other factors.

RNG or biomethane can be produced through several production technologies, including landfill gas collection, anaerobic digestion, and thermal gasification systems. Common RNG feedstocks include landfill gases, livestock waste, food waste, agricultural residues, and woody biomass. RNG facilities can use the produced gas onsite for electricity generation, boiler heating, and transportation refueling, or facilities can inject the RNG into the natural gas grid for use by gas utility customers. When distributed to these end-use customers, RNG can reduce the GHG emissions of gas appliances in buildings, gas-fired combined heat and power systems at industrial sites, or through compressed natural gas (CNG) vehicle fleets. RNG is a valuable low carbon resource for applications that are difficult or expensive to electrify.

Table B-1 highlights the RNG production potentials for each feedstock assumed for New York State, along with the applicable emissions rates. In recent years, RNG development has increased in support of federal and state decarbonization goals in the transportation and gas utility sectors. New York State has an estimated in-state RNG production technical potential of roughly 94 trillion Btu per year from available landfill, animal manure, wastewater treatment, and food waste resources through anaerobic digestion technologies. In future years, thermal gasification production technologies could increase in-state RNG technical potential by about 177 trillion Btu per year using available agricultural residues, forest residue, municipal solid waste resources, and energy crops. In 2017, New York consumed 1,394 trillion Btu of natural gas.[44] Our analysis assumes that the state's total natural gas consumption will decline over time while the state's total RNG potential will remain stable. Based on these trends, we estimate that the RNG technical potential represents about 16% of total natural gas consumption in 2020 and about 42% of total natural gas consumption in 2050.

RNG currently has a price premium over conventional natural gas, with the premium varying depending on the commercial structure of offtake agreements and whether credits are bundled

[44] U.S. Energy Information Administration. State Energy Data System, Table C1. Available at: https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/sum_btu_1.html&sid=NY

with the commodity. Per-unit RNG prices may decline over time as the market matures and production technologies improve.

Table B-1. Estimated RNG Production Potential and Emissions Rates for New York State

Process	Feedstock	Potential (Trillion Btu/Year)*				Emissions Rate (lbs CO_2e per MMBtu)**
		Low	High	Average High-Technical	Technical	
Anaerobic Digestion	Landfill gas	19.7	32.8	41.6	50.5	21.0
	Animal manure	4.5	9.0	12.1	15.1	-124.0
	Water resource recovery facilities	2.5	3.3	5.3	7.2	16.6
	Food waste	2.4	4.2	12.9	21.6	-9.9
Thermal Gasification	Agricultural waste	2.0	5.0	14.7	24.3	12.3
	Forestry and forest product residue	2.0	4.0	7.1	10.2	10.4
	Energy crops	0.6	3.0	18.1	33.2	9.7
	Municipal solid waste	19.3	43.5	76.3	109.0	6.4
	Total	**53.0**	**104.9**	**188.0**	**271.1**	

* Low, High, and Technical potentials from ICF (2019), "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment." The ICF report claims that the provided potentials are conservative, so Guidehouse calculated an average of the High and Technical cases from ICF (2019).

** Emissions rates are based on relevant Low Carbon Fuel Standard projects; data available at: https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

B.1.2 Hydrogen-Enhanced Natural Gas

In sectors currently using natural gas and other fossil fuels, hydrogen offers another low carbon gas solution to reduce GHG emissions. Hydrogen can be produced through electrolysis using dedicated renewable generation or curtailed renewable generation systems (power-to-gas or green hydrogen) and through natural gas reformation with carbon capture (blue hydrogen). It can be blended into existing natural gas pipelines using a strategy known as HENG. If implemented with low concentrations, this strategy appears to be viable without increasing risks in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network. Our research and interviews with heating technology experts indicate that hydrogen may be blended with natural gas at a maximum concentration of 15% hydrogen by volume, which could displace about 5% of natural gas supplied in HENG pipelines.[45,46] Our findings indicate that HENG technology is unlikely to be available beyond the pilot scale until 2030.

45 GRTgaz et al. (2019). "Technical and economic conditions for injecting hydrogen into natural gas networks." Available at: http://www.grtgaz.com/fileadmin/plaquettes/en/2019/Technical-economic-conditions-for-injecting-hydrogen-into-natural-gas-networks-report2019.pdf

46 Melaina, Antonio and Penev (2013). "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues." Available at: https://www.nrel.gov/docs/fy13osti/51995.pdf

B.1.3 Carbon Capture and Storage

Carbon capture technologies reduce the GHG emissions from natural gas, RNG, or hydrogen fuels by capturing CO_2 exhaust gas for sequestration, storage, or utilization. Carbon capture would generally occur at large centralized facilities such as gas-fired generation facilities or natural gas reformation systems.

New York has many options for carbon capture within the state and surrounding areas, including oil and natural gas reservoirs, un-mineable coal seams, saline formations, offshore sandstone formations, shale basins, and basalt-rich areas. Areas such as the Marcellus Shale and the Great Stone Dome could store enough carbon to offset several decades (and possibly centuries) of stationary emissions, so sequestration availability is not expected to be a major hurdle within the period of study and subsequent decades.[47,48] The model assumes that carbon capture and storage (CCS)-based power generation could meet all of New York's generation requirements. Wide commercialization of carbon capture technology will require additional R&D, pilot projects, and policy support to achieve wide commercialization. Given these requirements, our LCP model assumes that deployment of CCS will not begin prior to 2030.

In the model, CCS-based power generation competes with non-CCS natural gas combined cycle plants, solar generation, and wind generation. CCS-based power generation is assumed to include a combination of post-combustion capture retrofit plants and purpose-built pre-combustion plants; purpose-built plants are assumed to be phased in as plants available for retrofit become less common. Table B-2 summarizes these assumptions.

Table B-2. Assumed Share of Capture Technologies and Associated CAPEX Costs

Variable	Technology	2030	2040	2050
Share of capture technologies deployed per period†	Post-combustion, retrofit	100%	75%	50%
	Pre-combustion, new	0%	25%	50%
Cost to install power generation with carbon capture, per Unit of Power Generation Capacity ($/kBtu/h)‡	Post-combustion, retrofit	$578	$561	$544
	Pre-combustion, new	$1,296	$1,215	$1,134
	Combined cost	**$578**	**$725**	**$839**

† These values indicate the share of CCS-based power generation capacity that is assigned to each technology in each time period. For example, 100% post-combustion retrofit in 2030 means that 100% of the power plants with carbon capture built in 2030 will use post-combustion retrofit. The values pertain only to power plants with carbon capture; other power plant types (such as wind, solar, non-CCS combined cycle, etc.) are not accounted for in this ratio. The proportions are Guidehouse assumptions.
‡ Capture costs based on Rubin et al. (2015), "The cost of CO_2 capture and storage." Available at: https://www.cmu.edu/epp/iecm/rubin/PDF%20files/2015/Rubin_et_al_ThecostofCCS_IJGGC_2015.pdf

47 NTEL (2016). "U.S. DOE NETL methodology for estimating the prospective CO_2 storage resource of shales at the national and regional scale." Available at: https://www.osti.gov/biblio/1275480

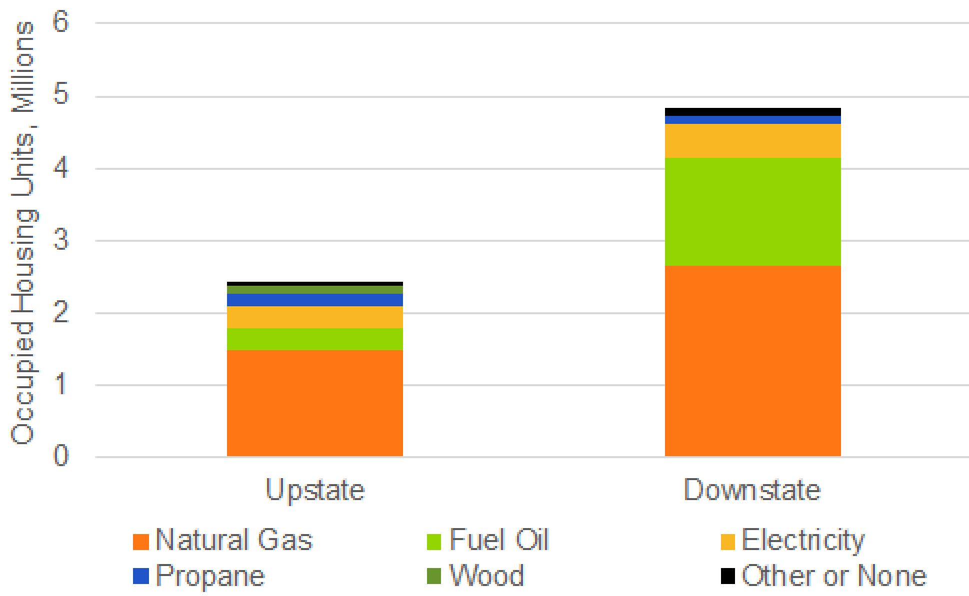
48 Cumming et al. (2016). "Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment." Available at: https://www.sciencedirect.com/science/article/pii/S1876610217317848

Guidehouse forecasts the electric generation fuel mix from 2020 through 2050. For each of the non-reference case scenarios, we assume that the power sector achieves the Climate Act requirements that 70% of electric generation come from renewables by 2030 and that generation be 100% carbon free by 2040. Natural gas-fired generation is projected to decrease over time but will not be eliminated since it serves an essential role providing reliable electric supply compared to intermittent renewable sources. To achieve the Climate Act requirement of carbon-free generation by 2040, CCS deployment is expected to begin in earnest in 2030 and will steadily increase over time through 2040, when all remaining gas-fired generators employ CCS.

B.2 Building Heat and Hot Water

In 2018, 84% of homes in New York used fossil fuels as their primary heating source.[49] Figure B-1 describes the number of households that use different heating fuels in Upstate and Downstate New York. According to NYSERDA, thermal energy use for space heating, space cooling, and hot water in New York State's residential and commercial sector constitutes approximately 37% of statewide net energy consumption.[50] The sector's reliance on fossil fuel sources results in about 32% of the state's GHG emissions coming from space and water heating.[51]

Figure B-1. Occupied Housing Units in New York, by Space Heating Fuel, 2011-2015[52]



[49] US Energy Information Administration (2020). "State Profile and Energy Estimates: New York." Available at: https://www.eia.gov/state/data.php?sid=NY#ConsumptionExpenditures

[50] The New York State Energy Research and Development Authority (2017). Renewable Heating and Cooling Policy Framework. Available at: https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/NYSERDA/RHC-Framework.pdf

[51] *Ibid.*

[52] Source: NYSERDA (2017). "Patterns and Trends New York State Energy Profiles: 2001–2015 Final Report", Appendix D-1. Available at: https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/2001-2015-patterns-and-trends.pdf

Technologies available today can be used to fully electrify the heating and hot water needs of New York's buildings. However, the *High Electrification* scenario will require electric capacity upgrades to supply roughly 30% higher peak electric demand (see Section 3.3). *High Electrification* will also require substantial expenditures by consumers to purchase and install heat pumps suitable for New York's climate. Guidehouse tested whether a more selective approach to building electrification can meet the Climate Act targets in a more cost-effective manner.

Guidehouse focused on four technologies to electrify buildings' space heating needs: whole-building heat pumps, dual-fuel heating (heat pump plus gas heat), ground-source heat pumps (GSHPs), and district heating/cooling. The subsections that follow describe these technologies in more detail. Table B-3 lists the proportion of the total space heating load assigned to each technology in the modeled scenarios. These proportions were selected to represent the fundamental definitions of the scenarios in our model. For water heating technologies, Guidehouse assumes that installed stock of fuel-fired water heaters in New York will be completely replaced by electric heat pump water heaters (HPWHs) by the year 2050.

Table B-3. Saturation Limits of Space Heating Technologies, by Scenario, 2050

Space Heating Technologies by Sector	Proportion of Heating Load Met by Technology	
	High Electrification	Selective Electrification
Residential		
Whole-Building Heat Pumps	99%	70%
Dual-Fuel Heating (ASHP plus Gas Heat)	0%	70%
Ground-Source Heat Pumps	30%	30%
Commercial		
Whole-Building Heat Pumps	98%	70%
Dual-Fuel Heating (ASHP plus Gas Heat)	0%	70%
Ground-Source Heat Pumps	30%	30%
District Water-Loop Heating and Cooling	10%	10%

B.2.1 Whole-Building Heat Pumps

Electric heat pumps provide space heating and space cooling by using electricity to move heat from the outdoor space to the indoor space and vice versa. Recent advances in cold climate air-source heat pump (ASHP) technology make it possible to use heat pumps for space heating when outdoor ambient temperatures are as low as -13ºF.[53] With these systems, most buildings in New York State could feasibly electrify their heating systems. Complete electrification of building heating loads allows the natural gas consumption of the residential and commercial sectors to be reduced to near zero, which aligns with the policy drivers of the *High Electrification* scenario. Our analysis assumed that whole-building heat pumps must be capable of cold

[53] A sample of heat pump products capable of continuous operation at -13ºF include Daikin's Aurora, Mitsubishi's Hyper-Heat, Fujitsu's Halcyon, and Lennox's MLA product lines.
https://daikincomfort.com/go/aurora/
https://www.mitsubishicomfort.com/benefits/hyper-heating
https://www.fujitsugeneral.com/us/residential/technology/xlth-low-temp-heating.html
https://www.lennox.com/products/heating-cooling/mini-split-systems/mla

climate operation, meaning that they continue to use vapor compression cycle down to 5°F, and use electric resistance heating below 5°F.

Whole-building cold climate ASHPs are substantially more expensive than conventional heat pumps and, at present energy rates, they are considerably more expensive to operate compared to conventional gas-fired equipment. An additional challenge is that high electrification of building heat will greatly increase peak electric demand during peak heating periods. To meet the peak electric demands of regions with fully electrified building heat, significant investments in electric distribution infrastructure will be needed. Guidehouse accounts for infrastructure investments upstream of the customer's electric meter (to increase transmission and distribution capacity) and investments downstream of the meter (to upgrade electrical panels and add circuits for customers who did not previously have a central AC system).

B.2.2 Ground-Source Heat Pumps

GSHPs (also called geothermal heat pumps) are similar to ASHPs in that they use electricity to move heat in and out of a building's conditioned space. While ASHPs gather heat from ambient outdoor air, GSHPs exchange heat with the ground via a buried pipe loop. GSHPs are typically more efficient than ASHPs because they exchange heat with their surroundings more efficiently, and because ground temperatures fluctuate less than ambient air temperatures. However, GSHPs have a much higher upfront cost that ASHPs due to the cost associated with installing a ground loop.

On balance, GSHPs are less cost-effective than ASHPs in terms of customer payback period and in terms of cost per GHG emissions reduction. GSHPs are expected to play a role in New York's decarbonization. Utilities in New York are experimenting with new ownership models that could facilitate wider adoption of GSHP technology, and Guidehouse projects that a small portion of customers will continue to invest in GSHP systems. Due to the high upfront costs associated with GSHPs, Guidehouse assumes that adoption of GSHP technology will be limited.

B.2.3 Dual-Fuel Space Heating

A dual-fuel HVAC system pairs an electric heat pump with a gas-fired heating appliance and alternates between the two sources depending on ambient outdoor air conditions. Our analysis assumed that dual-fuel systems use a switchover temperature of 30°F. Above 30°F, the system uses the heat pump, and below 30°F, the system uses gas-fired heating. In effect, users of dual-fuel systems electrify a portion (but not all) of their space heating energy consumption. Our analysis assumed that dual-fuel heating systems use conventional ASHPs, which are typically less expensive than cold climate capable heat pumps.

Dual-fuel heating systems address three major shortfalls of whole-home ASHPs:

1. Dual-fuel systems use heat pumps when they are most efficient, and switch to gas-fired heating at low temperatures where heat pumps are less efficient.

2. Dual-fuel systems contribute less to winter electric peak demand than whole-home ASHPs do during cold periods, because at low temperatures they rely on gas-fired heating with low electric demand.

3. Dual-fuel systems are typically less expensive to install and less expensive for customers to operate compared to whole-building cold climate heat pumps.

Dual-fuel systems contribute less to winter electric peak demand than whole-home ASHPs do during cold periods, because at low temperatures they rely on gas-fired heating with low electric demand.

It is important that analyses distinguish between conventional heat pumps that have been widely used in moderate climates for many years and the more advanced and expensive cold climate heat pumps that are required to meet the low ambient temperatures common in New York. We expect that upstate customers can electrify 60% of their heating load with a dual-fuel system, and downstate customers can electrify 80% of their heating load.[54] We assume that dual-fuel customers' non-electrified heating load will be met using natural gas-fired heating. To deliver the GHG emissions reductions mandated by the Climate Act, a pathway that uses dual-fuel heating will also need to implement technologies such as RNG or HENG that reduce the carbon intensity of pipeline natural gas.

Our analysis deploys dual-fuel heating in tandem with RNG technologies in the *Selective Electrification* scenario, but not in the *High Electrification* scenario. The incremental cost of dual-fuel systems is calculated assuming that dual-fuel heating is a replace-on-failure measure. That is, we assume that dual-fuel systems are installed to replace a prior HVAC system that is taken out of service, and they are not retrofit on to existing HVAC system. From this assumption, we calculate the incremental cost of a dual-fuel system relative to the cost of a baseline gas furnace and central AC system.

B.2.4 Heat Pump Water Heaters

HPWHs use electricity to transfer heat from ambient air to a stored water tank and are an energy efficient alternative to electric resistance water heaters and fuel-fired water heaters. The adoption of HPWHs has been limited by a variety of factors, including cost, product availability, and installation constraints. Guidehouse projects that the market for HPWHs will overcome these barriers and that nearly all New York buildings will use HPWH technology for water heating by 2050.

Depending on the specifics of the building, HPWHs may or may not require electrical upgrades for installation. Buildings that previously had an electric resistance water heater are unlikely to need upgrades as the HPWH can simply replace the previous water heater in the electrical circuit. However, buildings that had a fuel-powered water heater are likely to need upgrades as the existing circuits probably cannot handle the HPWH current rating. In modeling HPWHs, we assumed that electrical upgrades would not be necessary.

[54] To estimate the portion of heating load that may be electrified using dual-fuel heating, our analysis examined the heating degree days for representative weather stations in upstate and downstate New York, assuming that a dual-fuel heating system will use an electric heat pump to meet heating needs when the outdoor ambient dry bulb temperature is 30ºF or higher.

B.2.5 District Energy

In a district energy system, a central plant (or plants) produce steam, hot water, or chilled water that is then pumped through a network of insulated pipes to provide space heating, cooling, or hot water for nearby connected customer buildings. District heating plants can provide higher efficiencies than local heat generation with smaller-scale equipment. Con Edison operates the New York City steam system that provides district heat to a large portion of Manhattan Island and to several other systems across New York State, serving campuses and building clusters. A recent market characterization by ICF International prepared for the US EIA forecasts that district heating systems may see limited long-term growth from 2020 to 2050.[55] Guidehouse anticipates that district energy systems currently installed in New York will continue to operate but that installation of new district energy systems will be limited.

B.3 Transportation

The transportation sector is the largest contributor to GHG emissions in New York. Reducing GHG emissions to a level in compliance with Climate Act targets requires significant adoption of low and zero emissions alternative fuel transportation technologies.

B.3.1 EVs

Our LCP model considers the electrification of light duty passenger vehicles, the electrification and emergence of natural gas in medium and heavy-duty commercial vehicles, and the adoption of low emissions bio-jet fuel in commercial aviation.

The decarbonization of light duty passenger vehicles are modeled as a transition from gasoline-powered vehicles to EVs. The projected advancements in battery technology provide a pathway for reduced incremental costs of EVs over traditional gasoline alternatives. Guidehouse references market projections showing that light duty EVs will have only a small cost premium over gasoline vehicles by 2050. For medium and heavy-duty applications where electrification is more difficult, the model considers the availability of natural gas-powered vehicle technologies. These CNG- and liquefied natural gas-powered medium and heavy-duty vehicles are a relatively mature technology that could be cost-effective alternatives to traditional diesel-powered vehicles in scenarios where natural gas fuel costs remain low.

B.3.2 Low Carbon Aviation Fuel

To further decarbonize the transportation sector, sustainable aviation fuels such as aviation biofuels are considered as a technology option. While procurement of aviation biofuels was limited to about 15 million liters in 2018 (less than 0.1% of total aviation consumption), IEA estimates that scaling procurement to levels meeting 2% of international aviation demand could provide the cost reductions needed for a self-sustaining aviation biofuel market.[56] Guidehouse's LCP model considers CAPEX costs associated with this initial investment on a $/MMBtu basis.

[55] ICF and IDEA (2018). "U.S. District Energy Services Market Characterization." Available at: https://www.eia.gov/analysis/studies/buildings/districtservices/pdf/districtservices.pdf

[56] International Energy Agency (2019). "Are aviation biofuels ready for take off?". Available at: https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

B.4 Industrial

Many industrial processes are difficult to decarbonize, such as the manufacture of chemicals, steel, and cement. However, there is potential for reducing GHG emissions from these processes through adoption of RNG and green hydrogen. RNG may be used to displace a portion of the fossil natural gas supplied to industrial customers, and Section B.1.1 describes our assumptions regarding RNG deployment. Section C.2 describes how the proportion of RNG and HENG in the pipeline gas mix may increase over time in a scenario that is favorable to low carbon fuels.

Green hydrogen is a term used to describe hydrogen that is separated from water and converted to a viable fuel source through a renewables-powered electrolysis process. Recent studies that have demonstrated the feasibility of using green hydrogen in the steel industry[57] and the cement-making process.[58] Many of these technologies will not be cost-effective during this study period unless significant carbon taxes or other cost-leveling measures are applied. Separate from the HENG strategy (Section B.1.2), hydrogen may be delivered to customers through dedicated distribution systems designed for 100% hydrogen gas, known as hydrogen clusters or districts. Guidehouse's LCP model calculates the energy use and emissions impacts associated with switching a portion of the industrial sector's energy consumption from pipeline gas sources to locally produced hydrogen.

B.5 Efficiency Improvements

New York State has a variety of policies and programs that encourage the adoption of higher efficiency technologies and operational practices. Federal appliance standards and building codes by state and city agencies improve the energy efficiency of building stock over time through new building construction and replacement of existing systems at end of life. The *Reference Case* scenario is based on the EIA's Annual Energy Outlook 2019, which projects that from 2018 to 2050, energy efficiency in different sectors will be improved through building codes, appliance standards, vehicle fuel economy standards, and other actions. The EIA forecasts that increases in energy efficiency will cause energy intensity to decline by 22% in the residential sector, 13% in the commercial sector, and 32% in the transportation sector.

The baseline *Reference Case* scenario assumes the energy efficiency of buildings and transportation will increase about 15% due to current building codes, appliance standards, and vehicle fuel economy standards. Additional energy efficiency opportunities are available to further reduce energy consumption in the residential, commercial, and industrial sectors. New York State utilities and public organizations also encourage the adoption of above-code building technologies through energy efficiency incentive programs. These programs provide incremental energy savings above those already forecasted for future years from today's codes and standards.

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[57] See, for instance, Hybrit Steel in Sweden, at: http://www.hybritdevelopment.com/ ;
Voestalpine Hydrogen Production Facility in Austria, at: https://www.voestalpine.com/group/en/media/press-releases/2019-11-11-h2future-worlds-largest-green-hydrogen-pilot-facility-successfully-commences-operation/ ;
Thyssenkrupp Steel Europe's partnership for green hydrogen production, at: https://www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/green-hydrogen-for-steel-production--rwe-and-thyssenkrupp-plan-partnership-82841 ;

[58] Doyle, Amanda (2019). "Producing cement using electrolysis". Available at: https://www.thechemicalengineer.com/news/producing-cement-using-electrolysis/

- Building envelope technologies (wall, floor, and ceiling insulation and windows) are a core component of most buildings and carry long lifetimes, leading to infrequent retrofits or replacements. Consequently, most buildings have an existing building shell that performs well below today's building code requirements for new construction. Upgrading the insulation, windows, and air sealing of existing buildings to code or above-code performance would reduce the HVAC energy consumption of the building. In our model, we capture those potential improvements through technologies that reduce the space conditioning load in new and existing residential and commercial buildings.

- High efficiency options are available for most residential and commercial building technologies, including water heating, lighting, kitchen and laundry appliances, electronics, and industrial processes. However, higher efficiency products or control systems that reduce energy consumption for major equipment typically have an incremental cost premium over baseline options. We capture those potential improvements through the general efficiency improvement technologies for residential and commercial buildings.

- Like residential and commercial buildings, industrial facilities can benefit from the various efficiency improvements described previously. They also can benefit from improvements to process efficiency. We capture those potential improvements via the industrial efficiency measures technology.

- Transportation sector efficiency improvements can come from various sources, such as improved logistics, self-driving vehicles, increased reliance on public transportation, among others. Those potential improvements are captured by the transport efficiency improvements technology.

Recent reports from the Electric Power Research Institute (EPRI) and NYSERDA estimate that energy efficiency measures could result in a 35% reduction in energy use and a 30% reduction in GHG emissions.[59,60] The *Reference Case* scenario accounts for efficiency improvements that will result from codes and standards that have already been enacted. NYISO's *2019 Load & Capacity Data* report forecasts that building codes and efficiency programs will reduce end-use electricity consumption by 15% in 2050.[61] Guidehouse's LCP model assumes that further energy and GHG savings are possible through more aggressive action by efficiency programs, and that these activities could increase energy efficiency by another 10% in the residential, commercial, industrial, and transportation sectors. The potential improvements in efficiency are shown in Table 2-2 under the appropriate technology. The unit cost of those improvements in shown in Table B-4.

[59] The New York State Energy Research and Development Authority (2018). "New Efficiency New York." p.2 Available at: https://www.nyserda.ny.gov/-/media/Files/Publications/New-Efficiency-New-York.pdf

[60] Electric Power Research Institute (2020). "Electrification Scenarios for New York's Energy Future. " p.5. Available at: https://www.epri.com/research/products/3002017940

[61] New York Independent System Operator (2019). "2019 Load & Capacity Data Report." Table I-1b. Available at: https://www.nyiso.com/documents/20142/2226333/2019-Gold-Book-Final-Public.pdf/

Table B-4. Estimated Incremental Energy Efficiency Costs for New York State[62]

	Cost [$ per MMBtu saved/year]			
Technology	**2020**	**2030**	**2040**	**2050**
Residential space conditioning efficiency, retrofit	282	311	344	380
Residential space conditioning efficiency, new buildings	282	311	344	380
Commercial space conditioning efficiency, retrofit	104	115	127	140
Commercial space conditioning efficiency, new buildings	104	115	127	140
Residential building efficiency, non-insulation	226	250	276	305
Commercial building efficiency, non-insulation	177	196	216	239
Transport efficiency	43	43	43	43
Industrial efficiency	183	202	223	247

[62] To estimate the cost per annual energy savings associated with energy efficiency upgrades, we reviewed the benefit-cost models of several utilities in the Northeast U.S. These benefit-cost models contain data on the customer cost and energy savings for individual measures, based on historical program spending and studies that evaluate energy savings.

Appendix C. Detailed Results

Detailed results tables regarding technology adoption, pipeline fuel mix, and figure data are provided in the following sections.

C.1 Technology Adoption

As Section 2.1 describes, Guidehouse's LCP model uses an optimization function to model the deployment of decarbonization technologies in order of the technologies' cost-effectiveness. The model assumes that technologies with the lowest cost per GHG abated will be adopted first and technologies with a high cost per GHG abated will be adopted last. For each scenario, our model increases the amounts of technology adoption until the scenario's GHG emissions target is achieved. The outcome is that cost-effective technologies are deployed to the maximum extent possible, while higher cost technologies may see more moderate adoption or may not be adopted at all.

The scenario definitions influence the adoption rates of different technologies. Compared to other scenarios that allow RNG, HENG, and dual-fuel building heat, the *High Electrification* scenario requires higher adoption of whole-building heat pumps to meet the Climate Act's emissions targets. Table C-1 presents the adoption rates assigned to each technology in the LCP model, as a result of the model's optimization function. These results are distinct from the model inputs presented in Table B-3, which describe the saturation limits imposed on the model.

Table C-1. Technology Adoption Rates Modeled in National Fuel Territory

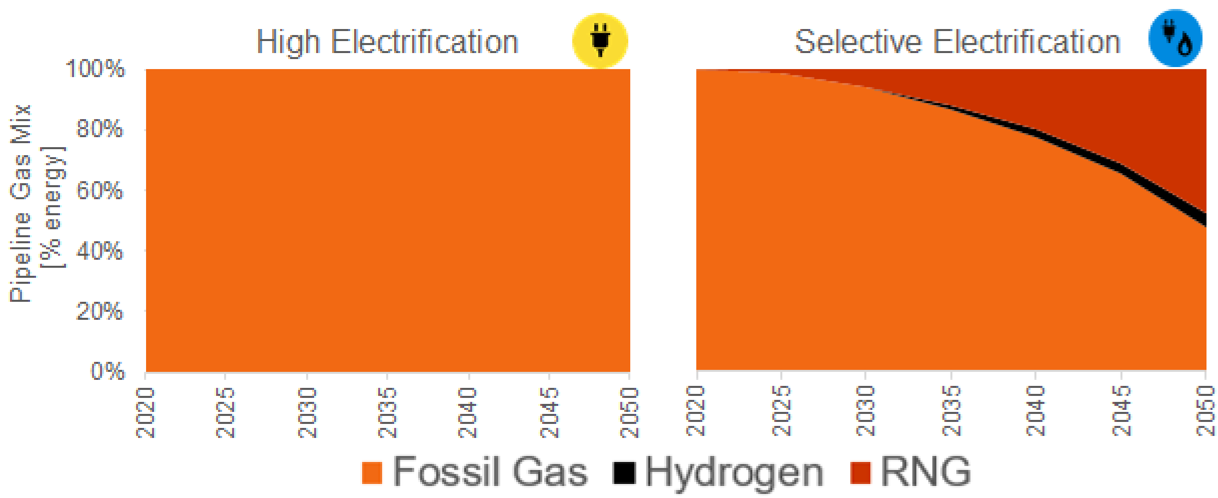
Technology	Unit Basis	Technology Adoption Rate in 2050 HE*	SE*
RNG - Anaerobic digestion	Billion Btu per year	N/A	8,500
RNG - Thermal gasification	Billion Btu per year	N/A	13,800
Hydrogen-enhanced natural gas	H_2 % of natural gas supply by energy	N/A	5%
Solar generation	% of elec. supply, except nuclear and hydro	41%	41%
Wind generation	% of elec. supply, except nuclear and hydro	45%	45%
Post- and pre-combustion capture power generation	% of fossil electric	100%	100%
Natural gas heavy duty vehicles	% of heavy duty (diesel) load switched	N/A	2%
Electric heavy duty vehicles	% of heavy duty (diesel) load switched	100%	37%
Electric medium duty vehicles	% of medium duty (diesel) load switched	2%	2%
Electric light duty vehicles	% of gasoline load switched	100%	100%
Biofuel production for aviation	% of jet fuel switched	100%	100%
Industrial local green hydrogen	% of industrial load switched	N/A	75%
Heat pump water heaters (HPWH), residential	% of carbon load switched	100%	100%
Heating oil to heat pump conversions, residential	% of fuel oil load switched	100%	100%
District water-loop heating and cooling, residential	% of carbon load switched	0%	0%
ASHP Whole-building, residential	% of carbon load switched	87%	30%
Geothermal heat pumps, whole-building, residential	% of carbon load switched	0.4%	0.4%
Dual-fuel heating - furnace/boiler plus HP, residential	% of carbon load switched	N/A	69%
Heat pump water heaters (HPWH), commercial	% of carbon load switched	100%	100%
District water-loop heating and cooling, commercial	% of carbon load switched	0.4%	0.4%
ASHP, Whole-building, commercial	% of carbon load switched	98%	30%
Geothermal heat pumps, whole-building, commercial	% of carbon load switched	1%	1%
Dual-fuel heating - furnace/boiler plus HP, commercial	% of carbon load switched	N/A	68%
Transport efficiency	Entire Sector Consumption	10%	10%
Industrial efficiency	Entire Sector Consumption	0.4%	0.4%
Residential building efficiency, non-insulation	Entire Sector Consumption (non-space conditioning)	0.4%	0.4%
Commercial building efficiency, non-insulation	Entire Sector Consumption (non-space conditioning)	10%	10%
Residential space conditioning efficiency, retrofit & new	Entire Sector Space Conditioning Load	10%	10%
Commercial space conditioning efficiency, retrofit & new	Entire Sector Space Conditioning Load	10%	10%

* Note: HE stands for High Electrification scenario, and SE stands for Selective Electrification scenario

C.2 Pipeline Gas Mix

Figure C-1 shows the pipeline gas mix for each scenario in terms of energy. The *High Electrification* scenario does not include RNG and hydrogen, so the pipeline gas is composed entirely of fossil gas. In the *Selective Electrification* scenario, RNG and hydrogen are available. The *Selective Electrification* scenario assumes that in 2050, 50% of pipeline gas is composed of non-fossil fuels. The adoption of hydrogen is limited by the expected safety limit of 5% by energy, which is achieved in the *Selective Electrification* scenario. The RNG adoption is limited to 45% of the pipeline gas supply by the absolute RNG potential in the region.

Figure C-1. Pipeline Gas Mix for Each Scenario



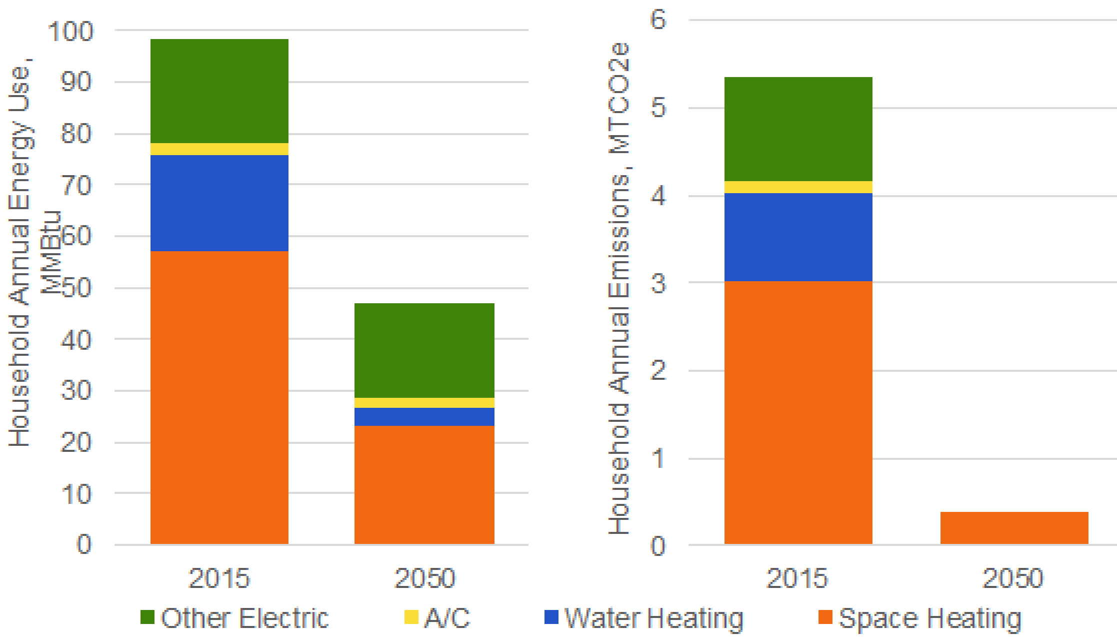
C.3 Reductions in Household Energy Use and Associated Emissions

Guidehouse also modeled the impacts that interventions in the *Selective Electrification* scenario would have on a typical household in New York State. Figure C-2 shows how different residential end uses contribute to household energy consumption and associated GHG emissions in 2015 (prior to intervention) and in 2050 (after intervention). In 2015, the typical single family household consumes natural gas for space heating and water heating.[63] In the *Selective Electrification* scenario, we assume that by 2050, the typical household takes steps to improve building shell and appliance efficiency and switches to electric water heating and dual-fuel space heating.

Similar to our analysis of single-family homes in NFGDC's territory (see Section 3.4), interventions in the *Selective Electrification* scenario can more than halve a typical New York household's energy consumption and reduce household GHG emissions by greater than 90%.

[63] Annual energy use in 2015 from NYSERDA (2019) Patterns and Trends, New York Energy Profiles: 2002–2016, Appendix B, representing single-family homes in New York State. Available at: https://www.eia.gov/consumption/residential/data/2015/

Figure C-2. Reduction in Energy Use and GHG Emissions from Selective Electrification
Example: Average household in New York State



Intervention	Energy Savings	Emissions Reduction
Building Shell Efficiency	15%	15%
End Use Electrification	33%	32%
Appliance Efficiency	4%	4%
Renewable Elec. Generation	n/a	25%
Carbon Capture & Storage	n/a	9%
Low-Carbon Fuels (RNG, Hydrogen)	n/a	7%
Total	**52%**	**93%**

C.4 Figure Data

Table C-2 shows the underlying data for selected figures in this report.

Table C-2. Data for Selected Figures

Variable	Scenario	Data Series	2020	2025	2030	2035	2040	2045	2050
Figure 3-1: GHG Emissions [MMTCO2]	High Electrification	NonEnergy	2.6	2.3	1.9	1.5	1.2	0.8	0.4
		Leakage	0.2	0.1	0.1	0.0	0.0	0.0	0.0
		Power	2.2	2.1	0.5	0.2	0.0	0.0	0.0
		Trans	7.2	5.8	4.5	3.3	2.3	1.4	0.5
		Ind	1.3	1.4	1.5	1.6	1.6	1.7	1.8
		Com	2.1	1.7	1.5	1.2	0.9	0.7	0.4
		Res	3.9	3.1	2.5	1.9	1.4	0.9	0.4
	Selective Electrification	NonEnergy	2.6	2.3	1.9	1.5	1.2	0.8	0.4
		Leakage	0.2	0.1	0.1	0.0	0.0	0.0	0.0
		Power	2.1	2.0	0.4	0.2	0.0	0.0	0.0
		Trans	7.2	5.8	4.6	3.6	2.7	1.9	1.1
		Ind	1.3	1.4	1.5	1.5	1.3	1.2	1.2
		Com	2.1	1.8	1.5	1.2	0.9	0.7	0.4
		Res	3.9	3.1	2.5	1.9	1.4	0.9	0.4
	Reference	Total	19.4	18.6	17.2	16.9	16.9	17.1	17.4
Figure 3-3: Electricity Consumption [TWh/year]	High Electrification	Trans	0.2	1.1	2.4	3.6	4.8	6.1	7.4
		Ind	2.3	2.4	2.6	2.7	2.8	2.9	3.0
		Com	7.1	7.3	7.6	7.9	8.2	8.5	8.9
		Res	6.0	6.8	7.4	7.8	8.1	8.4	8.5
	Selective Electrification	Trans	0.2	1.1	2.1	3.0	3.9	4.9	5.9
		Ind	2.3	2.4	2.6	2.7	2.8	2.9	3.0
		Com	7.1	7.2	7.4	7.7	7.9	8.2	8.6
		Res	6.0	6.7	7.1	7.4	7.7	7.9	8.0
	Reference	Total	15.5	15.2	15.2	15.3	15.5	15.8	16.2
Figure 3-3: Pipeline Gas Consumption [Bcf/year]	High Electrification	Power	16.9	16.9	6.0	6.9	7.8	8.9	10.0
		Trans	4.3	3.9	3.7	3.5	3.4	3.3	3.4
		Ind	11.0	11.8	12.6	13.0	13.5	14.1	14.8
		Com	30.4	25.1	20.7	16.8	13.1	9.4	5.6
		Res	51.2	41.4	33.4	26.2	19.4	13.0	6.9
	Selective Electrification	Power	16.9	16.2	5.6	6.3	7.0	7.8	8.7
		Trans	4.3	4.0	3.8	3.7	3.7	3.7	3.8
		Ind	11.0	11.8	12.6	13.0	10.1	7.1	3.7
		Com	30.4	25.9	22.4	19.3	16.4	13.5	10.7
		Res	51.2	44.0	38.2	31.5	25.4	19.5	13.9
	Reference	Total	110.4	106.7	97.4	97.4	98.3	99.6	101.5
Figure 3-4: Peak Electricity [GW]	High Electrification	Trans	0.0	0.2	0.5	0.8	1.0	1.3	1.6
		Ind	0.5	0.5	0.6	0.6	0.6	0.6	0.7
		Com	1.4	1.4	1.4	1.4	1.4	1.4	1.5
		Res	1.3	1.4	1.7	1.8	2.0	2.0	2.1
	Selective Electrification	Trans	0.0	0.2	0.5	0.6	0.8	1.0	1.3
		Ind	0.5	0.5	0.6	0.6	0.6	0.6	0.7
		Com	1.4	1.4	1.4	1.4	1.4	1.4	1.5
		Res	1.3	1.3	1.5	1.7	1.8	1.8	1.9
	Reference	Total	3.3	3.2	3.2	3.2	3.3	3.3	3.4

Variable	Scenario	Data Series	2020	2025	2030	2035	2040	2045	2050
Figure 3-4: Peak Pipeline Gas Consumption [Bcf/day]	High Electrification	Power	0.18	0.17	0.06	0.06	0.07	0.08	0.09
		Trans	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Ind	0.06	0.06	0.07	0.07	0.07	0.07	0.08
		Com	0.15	0.12	0.10	0.08	0.06	0.04	0.02
		Res	0.44	0.35	0.28	0.22	0.16	0.10	0.05
	Selective Electrification	Power	0.18	0.16	0.05	0.06	0.07	0.07	0.08
		Trans	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Ind	0.06	0.06	0.07	0.07	0.05	0.04	0.02
		Com	0.15	0.13	0.11	0.09	0.07	0.06	0.04
		Res	0.44	0.38	0.33	0.27	0.22	0.17	0.12
	Reference	Total	0.82	0.79	0.68	0.68	0.69	0.69	0.70
Figure 3-5: Residential Space Heating Fuel Consumption [tBtu/year]	High Electrification	Efficiency Gains	0.0	4.9	10.3	15.8	21.4	26.9	32.2
		Hydrogen (HENG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RNG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Fossil Gas	35.2	28.2	22.5	17.3	12.4	7.9	3.6
		Electric	2.6	5.5	7.3	8.6	9.5	10.2	10.6
		Biomass	1.4	1.1	0.9	0.7	0.5	0.3	0.1
		Delivered Fuels	13.7	10.7	8.3	6.0	4.0	2.0	0.2
	Selective Electrification	Efficiency Gains	0.0	4.1	8.6	13.1	17.8	22.3	26.8
		Hydrogen (HENG)	0.0	0.0	0.0	0.3	0.4	0.5	0.5
		RNG	0.0	0.4	1.6	2.7	3.6	4.4	5.0
		Fossil Gas	35.2	30.4	25.5	19.5	14.2	9.3	5.0
		Electric	2.6	4.9	6.3	7.3	8.0	8.5	8.9
		Biomass	1.4	1.1	1.0	0.8	0.6	0.5	0.3
		Delivered Fuels	13.4	9.3	6.1	4.5	3.0	1.6	0.3
	Reference	Total	53.0	50.5	49.3	48.5	47.9	47.3	46.9
Figure 3-6: Commercial Space Heating Fuel Consumption [tBtu/year]	High Electrification	Efficiency Gains	0.0	2.7	5.7	9.0	12.6	16.6	21.0
		Hydrogen HENG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RNG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Fossil Gas	18.9	15.0	11.8	8.8	6.0	3.1	0.1
		Electric	0.5	2.1	3.3	4.1	4.9	5.5	6.2
		Biomass	0.5	0.4	0.3	0.2	0.1	0.1	0.0
		Petroleum	5.5	4.4	3.4	2.6	1.7	0.9	0.0
		District	0.0	0.0	0.0	0.0	0.1	0.1	0.1
	Selective Electrification	Efficiency Gains	0.0	2.2	4.6	7.3	10.3	13.5	17.1
		Hydrogen HENG	0.0	0.0	0.0	0.1	0.2	0.3	0.3
		RNG	0.0	0.2	0.7	1.2	1.6	2.0	2.2
		Fossil Gas	18.9	15.7	12.7	9.9	7.3	4.9	2.6
		Electric	0.5	1.8	2.7	3.3	3.9	4.4	4.9
		Biomass	0.5	0.4	0.3	0.3	0.2	0.2	0.1
		Petroleum	5.5	4.4	3.4	2.6	1.7	0.9	0.0
		District	0.0	0.0	0.0	0.0	0.1	0.1	0.1
	Reference	Total	25.3	24.6	24.5	24.8	25.4	26.3	27.4

Variable	Scenario	Data Series	2020	2025	2030	2035	2040	2045	2050
Figure 3-9: Road Transport Energy Consumption [Trillion Btu/year]	High Electrification	Efficiency Gains	0.0	8.0	16.3	24.0	31.6	39.8	48.6
		Gasoline - All	63.9	49.1	36.6	26.0	16.7	8.3	0.0
		Natural Gas - All	4.2	3.8	3.6	3.4	3.3	3.3	3.3
		Diesel - HD	16.5	15.7	12.3	9.0	5.9	3.0	0.0
		Diesel - MD	4.7	3.9	2.9	2.3	1.8	1.5	1.2
		Electric - HD	0.0	0.0	1.6	3.2	4.7	6.4	8.2
		Electric - MD	0.0	0.0	0.1	0.1	0.1	0.1	0.1
		Electric - LD	0.5	3.7	6.5	9.0	11.5	14.2	17.0
	Selective Electrification	Efficiency Gains	0.0	7.9	15.4	22.2	28.8	36.1	43.9
		Gasoline - All	63.9	49.1	36.6	26.0	16.7	8.3	0.0
		Natural Gas - All	4.2	3.9	3.7	3.6	3.6	3.6	3.7
		Diesel - HD	16.5	15.7	14.1	12.6	11.4	10.4	9.5
		Diesel - MD	4.7	3.9	2.9	2.3	1.8	1.5	1.2
		Electric - HD	0.0	0.0	0.6	1.2	1.7	2.3	3.0
		Electric - MD	0.0	0.0	0.1	0.1	0.1	0.1	0.1
		Electric - LD	0.5	3.7	6.5	9.0	11.5	14.2	17.0
	Reference	Total	89.8	84.3	79.9	76.9	75.7	76.6	78.4
Figure 3-11: Industrial Energy Consumption [Trillion Btu/year]	High Electrification	Electricity	7.7	8.2	8.8	9.1	9.4	9.9	10.3
		Other	17.8	19.0	20.3	21.0	21.8	22.8	23.8
		Local Hydrogen	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Natural Gas	10.7	11.5	12.3	12.7	13.2	13.7	14.4
	Selective Electrification	Electricity	7.7	8.2	8.8	9.1	9.4	9.9	10.3
		Other	17.8	19.0	20.3	21.0	21.8	22.8	23.8
		Local Hydrogen	0.0	0.0	0.0	0.0	3.3	6.9	10.8
		Natural Gas	10.7	11.5	12.3	12.7	9.9	6.9	3.6
	Reference	Total	36.3	38.7	41.4	42.9	44.5	46.5	48.7