Assessment of Energy Efficiency, Electrification, and Decarbonization Potential for the New York State Industrial Sector – Phase One

Final Report

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Glossary of key terms

Btu – British thermal unit. The quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Climate Act – New York Climate Leadership and Community Protection Act. Signed into law on July 18, 2019.

DAC – Disadvantaged communities. Disadvantaged communities are communities identified by state agencies, authorities, and entities to direct funding in a manner designed to achieve a goal of receiving 40% of the overall benefits of spending on clean energy and energy efficiency programs per Climate Act requirements.

Energy consumption. All direct energy used for heat and power at the facility, regardless of where the energy was produced.

Feedstock. Energy sources used for raw material input or any purpose other than the production of heat or power.

Industrial Tiers 1, 2, 3. NYSERDA industrial facility classification where Tier 1 is defined as having greater than $1 million in annual energy expenditures, Tier 2 is $500,000 to $1 million in annual energy expenditures, and Tier 3 is less than $500,000 in annual energy expenditures.

IRR – Internal rate of return. The IRR is a metric used in financial analysis to estimate the profitability of potential capital investment. The IRR for an investment is the percentage rate earned on each dollar invested for each period it is invested A higher IRR means a higher return on investment.

Low-carbon fuels. Alternative fuels that can replace carbon-intense fossil fuels such as natural gas, fuel oil, or coal. This study focuses on hydrogen and renewable natural gas when examining low-carbon fuel decarbonization potential.

Manufacturing facility. A site where the manufacture of products from a raw material to a finished good using industrial production equipment and processes has been determined or is believed to be present.

Manufacturing Energy Consumption Survey (MECS). A national sample survey that collects information on the stock of U.S. manufacturing establishment, their energy-related building characteristics, and their energy consumption and expenditures.[1]

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[1] U.S. Energy Information Administration. “Manufacturing Energy Consumption Survey (MECS).” eia.gov, accessed 8/10/2023. https://www.eia.gov/consumption/manufacturing/about.php

$MTCO_2e$. Metric ton of carbon dioxide equivalent.

North American Industry Classification System (NAICS). A numeric classification system to categorize facilities by processes or production.

North American Product Classification System (NAPCS). A numeric classification system of products (goods and services) that can be linked to a NAICS industry.

Physical unit. The physical unit of an energy source is commonly used to measure a specific type of energy or fuel, e.g., barrels or gallons for liquid fuels, short tons for coal, cubic feet for natural gas, and kWh for electricity.

Retrofit. Refers to an efficiency measure or efficiency program that seeks to encourage the replacement of functional equipment before the end of its operating life with higher-efficiency units (also called "early retirement") or the installation of additional controls, equipment, or materials in existing facilities for purposes of reducing energy consumption (e.g., increased insulation, lighting occupancy controls, economizer ventilation systems). This definition was taken from the Environmental Protection Agency's Guide for Conducting Energy Efficiency Potential Studies.[2]

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[2] United States Environmental Protection Agency. "*Guide for Conducting Energy Efficiency Potential Studies*, A Resource of the National Action Plan for Energy Efficiency." epa.gov, November 2007. https://www.epa.gov/sites/default/files/2015-08/documents/potential_guide_0.pdf

Executive summary

The New York State Public Service Commission (the Commission) directed the New York State Energy Research and Development Authority (NYSERDA) to assess the statewide potential for energy efficiency, electrification, and decarbonization in the industrial sector. DNV conducted this Industrial Potential Study alongside Antares, in consultation with NYSERDA, Department of Public Service staff, and utility representatives.

Study objective

The main objective is to identify and estimate the potential for energy savings and greenhouse gas (GHG) emissions reductions in New York State's industrial manufacturing sector. The team assesses multiple fuels, including electricity, natural gas, and oil, over 3-, 8-, 15-, and 20-year forecast horizons, for the state as a whole, each of the ten Empire State Development Regions, and Disadvantaged Communities (DACs). A secondary study objective is to inform the design and planning of decarbonization interventions in the industrial sector.

This study focuses on New York's manufacturing sector and does not include other sectors that could be considered industrial, such as agriculture, construction, and mining. The primary data source for this study's inputs is the Industrial Facilities Stock Assessment: Phase One.[3] The study addresses energy and decarbonization potential from four categories of industrial technologies: 1) energy efficiency; 2) electrification; 3) low-carbon fuels, feedstocks, and energy sources (referred to as low-carbon fuels); and 4) carbon capture, utilization, and storage (CCUS).

Methodology

The study examines the energy and emissions impacts of the four decarbonization categories and reports results for technical, economic, and achievable potential through adoption scenarios. For each scenario and level of potential, energy, and carbon savings are calculated annually as the sum of savings for new measures implemented that year and rollover savings from measures adopted in prior years.

A "measure" is a particular decarbonization activity or technology investment that creates savings over time relative to the baseline equipment/condition. Measure pairs (baseline activity paired with a decarbonizing measure) are then developed and characterized by the resulting annual energy and

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[3] DNV. *Industrial Facilities Stock Assessment: Phase One Final Report*. Prepared for New York State Energy Research and Development Authority, January 17, 2023. https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/Program-Evaluation/Matter-No-1602180NYSERDAIndustrial-Facilities-Stock-Study-Phase-One-Report-March-2023.pdf

greenhouse gas savings, implementation costs, expected useful life (EUL), proportion of the facility stock the measure could apply to (feasibility), and current stock penetration of the measure.

Technical potential represents the upper limit of energy savings, peak demand reduction, or emissions reduction potential (referred to in total as "decarbonization potential") based on available technologies and measures that can be taken by the facilities.

Economic potential refers to the portion of the technical potential that is cost-effective when compared to supply-side alternatives and business-as-usual investments from facilities. The economic potential is estimated using the benefit-cost analysis (BCA) framework established by the Commission[4] in January 2016. The BCA framework uses the Societal Cost Test (SCT), which calculates the benefit/cost test as the ratio of net present value for the measure's societal benefits and costs, using a societal discount rate. The study team produced two estimates of economic potential based on different forecasts for the societal cost of GHG emissions from the New York Department of Environmental Conservation (DEC).

1. **Low societal cost of carbon scenario**. This scenario uses the DEC's lowest estimate of the social cost of GHG emissions, which was developed using a 3% discount rate.
2. **High societal cost of carbon scenario**. This scenario uses an alternative forecast for the social cost of GHG emissions that is higher than the forecast used in the low case and other scenarios (developed using a 2% discount rate, which the DEC characterizes as their central rate).

Achievable potential is the impact of measures to be adopted under specific scenarios representing real-world factors that can affect customer adoption decisions. These factors include measure availability and awareness, costs, and savings; energy and carbon (if applicable) prices; market barriers; and program interventions. The study examines five adoption scenarios to explore achievable potential, as shown in Table ES-1.

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[4] New York State Department of Public Service. Case 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, Order Establishing the Benefit-Cost Analysis Framework (issued January 21, 2016). https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={F8C835E1-EDB5-47FF-BD78-73EB5B3B177A}

Table ES-1. Achievable potential scenario descriptions and assumptions

Key Assumptions	Base	50% Incentive	IRR Incentive	Carbon Price	Carbon Price + Enabling Investments
Avoided Cost of GHG	Low avoided societal cost of GHG	Base	Base	Base	Base
Renewable Natural Gas (RNG) Price	Base case RNG price forecast from the 2022 New York Climate Scoping Plan[5]	Base	Base	Base	Altered RNG price forecast that assumes New York State steps in and provides a production tax credit funded by carbon prices
Green Hydrogen Price	Hydrogen price forecast that considers Inflation Reduction Act (IRA) production tax credit	Base	Base	Base	Altered hydrogen price forecast that assumes that New York State steps in as the IRA tax credit phases out to keep the hydrogen price low
Carbon Price	No emissions cap set and no carbon price	Base	Base	Carbon price is input from assumptions based on current California price and trends	Carbon price is input from assumptions based on current California price and trends
Incentive Levels (starting in model year 2023)	Set to zero	50% of incremental cost	Incentives bring the IRR for each measure to 10-16%	Incentives bring the IRR for each measure to 10-16%	Incentives bring the IRR for each measure to 10-16%
Program Budgets [a]	Set to zero	Marketing budget: $5,486,555	Marketing budget: $5,486,555	Marketing budget: $5,486,555	Marketing budget from 2023-2024: $5,486,555. From 2025 onwards marketing budget increases 1.5x to $8,229,833.
Market Barriers	Assumptions vary by measure but do not change over time	Base	Base	Base	Base assumptions for Year 1, lowered over time for electrification, low-carbon fuels, and CCUS

a Marketing budget determines how many customers are aware of a measure and is one factor in determining measure uptake.

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[5] New York State Climate Action Council. 2022. "New York State Climate Action Council Scoping Plan." https://climate.ny.gov/resources/scoping-plan/-/media/project/climate/files/IA-Tech-Supplement-Annex-1-Input-Assumptions-2022.xlsx

Key findings

New York's industrial sector has the technical potential to save 28% of its emissions and 14% of its energy use compared to the baseline scenario in 2042, but the economic potential to save only 10 to 11% of emissions and energy, as indicated in Table ES-2. The achievable potential under various scenarios is under 2% of emissions and 3% of energy.

Table ES-2. Technical, economic, and achievable decarbonization and energy savings potential in 2042

		2042 Cumulative Savings			Savings as % of 2042 Baseline		
	2042 Baseline[a]	Technical Potential	Economic Potential	Achievable Potential	Technical Potential	Economic Potential	Achievable Potential
Emissions (thousand $MTCO_2e$)	18,125	5,208	1,882-2,000	229-344	28%	10-11%	1-2%
Energy (million MMBtu)	165	22	17-18	4-5	14%	10-11%	2-3%

a Excludes feedstocks

For sources of the potential savings, energy efficiency accounts for most of the achievable potential, and electrification for about one quarter. The impacts of electric energy efficiency on emissions decline over time as the electric grid decarbonizes.[6] Process heating contributes the greatest potential emissions and energy savings across end uses. These savings come primarily from natural gas efficiency and electrification. More efficient motors and motor systems are the second-largest source of end use savings.

Low-carbon fuels, green hydrogen in particular, have the highest technical potential for emissions savings: about 20% of baseline emissions by 2042. However, these fuels have modest economic potential at 2.6% of 2042 baseline emissions, and minimal adoption even under the Carbon Price + Enabling Investments scenario (0.1% of baseline). The decline in low-carbon fuels accounts for most of the difference between the technical and economic emission potential. Virtually all low-carbon fuel adopted is green hydrogen, most of it replacing petroleum-based fuels. Neither green hydrogen nor RNG is cost effective as a replacement for natural gas as a fuel, although there is some potential for both fuels as a chemical feedstock. Under New York's greenhouse gas accounting rules, renewable natural gas (RNG) is not price competitive with natural gas without substantial price subsidies, but emission reductions achieved by RNG measures do not pass the societal cost test.

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[6] This report assumes that New York State will stay on track with targets set forth in the Community Leadership and Climate Protection Act of 2019, in particular the goal of achieving a zero-emission electric grid by 2040.

CCUS has very limited potential and only applies to a few subsectors. Specifically, CCUS adoption occurs in the Chemicals, Non-Metallic Minerals, Petroleum, and Primary Metals subsectors due to federal price supports form 45Q tax credit applicability. These subsectors have facilities that reach the emissions thresholds required for eligibility.

By subsector, the largest energy consumers contribute most of the potential at all levels. These subsectors are Primary Metals, Paper, Non-Metallic Minerals, and Chemicals. The regions where these subsectors have the strongest presence (particularly Primary Metals) have the largest savings, with Central New York and Western New York contributing the most to savings potential, representing about 30% of total potential. Likewise, potential in relation to Disadvantaged Communities (DACs) depends on the concentration of manufacturing energy use in those communities. In the 50% Incentive scenario, 37% of adoption potential falls within DACs statewide, but in the New York City region 84% does. Other regions in which the majority of potential is within DACs are North Country (59%) and Western New York (58%).

This study incorporates information from a wide range of sources and provides granular estimates over a 20-year analysis horizon. A number of steps have been taken to ensure that the assumptions and results are realistic and consistent with existing information. At the same time, there remains uncertainty as to many details of current and future market conditions and policies, as well as how decisionmakers will respond to those. Limitations of the study include the following:

1. This study is the first phase of a two-phase study. This phase uses the Phase One Industrial Stock Study[7] as the source of 2022 industrial energy use, emissions, and employment by subsector. The Phase One Stock Study developed these estimates from secondary sources. The second phase of this potential study will use results from the Phase Two Industrial Stock Study, which will update these key inputs based on primary data collection. That update will result in updates to corresponding quantities and savings potential and may also change some of the measure characterizations.
2. This study uses fuel price projections from New York State's 2022 Climate Scoping Plan.[8] No detailed economic modeling was conducted feeding back adoption levels of low-carbon fuels to supply-side prices. In particular, the finding that RNG is not cost-effective from a societal perspective (economic potential) is dependent on these price inputs. Other input assumptions might result in RNG passing the societal cost test, which could justify market interventions beyond what was modeled.

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[7] DNV. *Industrial Facilities Stock Assessment: Phase One Final Report*. Prepared for New York State Energy Research and Development Authority, January 17, 2023. https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/Program-Evaluation/Matter-No-1602180NYSERDAIndustrial-Facilities-Stock-Study-Phase-One-Report-March-2023.pdf

[8] New York Climate Action Council, "Scoping Plan: Full Report, Appendix G: Integration Analysis Technical Supplement." Climate.ny.gov, December 2022. https://climate.ny.gov/resources/scoping-plan/-/media/project/climate/files/Appendix-G.pdf

3. Similarly, the study does not use explicit modeling of the effects of particular investments to change particular market barriers and the resulting change in adoption. Rather, generic adoption curve shapes are applied, and investments in barrier reductions are reflected by moving to a curve with higher adoption rates.
4. The modeling for this study identifies the energy consumption associated with individual end uses for each subsector, the decarbonization measures applicable to each end use, and the adoption levels of each of those measures. About a third of industrial energy use has no identified end use in the Phase 1 Industrial Stock Study. For this portion, the only applicable measures are generic ones, such as strategic energy management and control systems. As a result, projected savings for this unidentified component are limited. Actual savings opportunities for this component are likely greater. To the extent the Phase Two Industrial Stock Study can reduce the unidentified end-use component, more specific measures may be identified, and higher savings may be estimated in the second phase of this study.
5. The study explicitly models over 150 individual decarbonization measures applicable to industrial end uses. Each measure’s characteristics are defined based on the best available sources and correspond to typical cases. Prices, impacts, applicability, and availability may vary for individual facilities. The modeling reflects the fact that different facilities will respond differently to the same nominal set of costs and benefits and varies these costs and benefits by industrial subsector and size tier but does not incorporate any assumed distribution of measure costs and benefits.

1 Introduction

In its January 2020 order,[9] the New York State (NYS) Public Service Commission directed NYSERDA to conduct a comprehensive statewide potential study encompassing energy efficiency, electrification, and decarbonization, in consultation with Department of Public Service (DPS) staff and utility representatives. NYSERDA then contracted with DNV to assess the energy efficiency, electrification, and decarbonization potential available in the NYS industrial sector. This initial industrial sector potential study, hereafter referred to as "the study," relies heavily on the baseline data from Phase One of the concurrent NYS Industrial Facilities Stock Study ("the Stock Study"), completed in January 2023.[10] Subsequent updates to the potential study will be based on more detailed information made available under Phase Two of the Stock Study.

1.1 Objectives

The main objective of the study is to identify and estimate potential energy savings and greenhouse gas (GHG) emissions reduction opportunities in New York State's industrial sector. Savings are assessed for multiple fuels, including electricity, natural gas, oil, propane, coal, and gasoline, over 3-, 8-, 15-, and 20-year forecast horizons, starting in 2023. A secondary study objective is to inform the design and planning of decarbonization interventions in the industrial sector, though the scope does not include estimating program potential that any prospective program could attain. Based on the information provided in the Stock Study, this study examines New York's manufacturing sector and does not include other sectors that could be considered industrial, such as construction, agriculture, or mining.

The study focuses on energy and decarbonization potential from four categories of industrial decarbonization technologies as identified in the Department of Energy (DOE) Industrial Decarbonization Roadmap (2022):[11] 1) energy efficiency, 2) electrification, 3) low-carbon fuels, examining renewable natural gas and green hydrogen, and 4) CCUS. The study examines decarbonization potential for all industrial manufacturing segments, with special attention paid to nine high-potential segments, to produce estimates of decarbonization potential per segment and under several scenarios. For each scenario (see

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[9] NYS Public Service Commission Case 18-M-0084, In the Matter of a Comprehensive Energy Efficiency Initiative, Order Authorizing Utility Energy Efficiency and Building Electrification Portfolios Through 2025 (issued January 16, 2020). See pages 76-78. Available at: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B06B0FDEC-62EC-4A97-A7D7-7082F71B68B8%7D

[10] DNV. *Industrial Facilities Stock Assessment: Phase One Final Report*. Prepared for New York State Energy Research and Development Authority, January 17, 2023. https://www.nyserda.ny.gov/-/media/Files/Publications/PPSER/Program-Evaluation/Matter-No-1602180NYSERDAIndustrial-Facilities-Stock-Study-Phase-One-Report-March-2023.pdf

[11] Department of Energy Office of Energy Efficiency & Renewable Energy. "DOE Industrial Decarbonization Roadmap." energy.gov. https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Section 1.2 for descriptions), the study team aggregated results from the sector-level analysis to produce scenario-specific potential estimates for the industrial sector.

Although the primary focus of the analysis is New York's existing industrial facilities, the study also examines the savings potential for new industrial facilities forecast to be built over the analysis' horizons.

1.2 Levels of savings potential and scenarios

This potential study estimates three levels of potential (further defined in later sections).

1. **Technical potential** is the upper limit of energy savings, peak demand reduction, or greenhouse gas reduction potential (referred to as "decarbonization potential"), based on available technologies and measures that can be taken by the facilities with no regard to cost. Measure implementation each year depends on the remaining feasible stock where the measure is not yet applied—that is, on the *feasibility* and on the *not-complete* factor, where the latter is equal to one minus the current stock penetration of the measure. As measures are implemented each year, the remaining stock for additional measure implementation (the not-complete factor) is reduced.[12]
2. **Economic potential** refers to the technical potential that is cost-effective when compared to supply-side alternatives and business-as-usual investments from facilities. Each year's implementation depends also on the societal benefit/cost ratio, which in turn depends on the measure life together with annual measure costs, energy costs, and carbon costs. These costs vary over the time frame of the analysis.
3. **Achievable potential** is the savings potential under specific scenarios representing real-world factors that can affect customer adoption decisions. These factors include measure availability, costs, and savings; energy and carbon (if applicable) prices; market barriers; and program interventions. Achievable potential depends on the benefit/cost ratio *from the customer perspective*. For a given benefit/cost ratio, higher market barriers result in less adoption.

For each scenario and level of potential, energy and carbon savings are calculated annually as the sum of savings for measures that would be implemented that year. A "measure" is a particular decarbonization activity or technology investment that creates savings over time depending on the baseline equipment/condition. *Measure pairs* are then developed, matching existing industrial activity in the state, with energy- or carbon-saving measures, and characterized in terms of the resulting annual savings, implementation costs, expected useful life, proportion of the facility stock the measure could apply to (feasibility), and current stock penetration of the measure. Lastly, cumulative savings are calculated based on each annual savings level and rollover savings from measures implemented in prior years.

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[12] Stock may become available for new adoption of previously implemented measures, as those measures reach the end of their effective useful life. In this study, the majority of measures have measure lives that exceed the study time frame, so there was minimal retirement and replacement of measures.

1.2.1 Technical and economic potential

Technical potential assumes that customers adopt all feasible[13] decarbonization measures regardless of their cost or any market barriers. At the time of existing equipment failure, customers replace their equipment with the lowest emitting option available. Retrofit measures are installed at the maximum feasible rate the market can support. Some of the modeled measures, particularly low carbon fuels and CCUS, may face supply or infrastructure barriers that are not fully accounted for in the model. This analysis focuses on demand for these measures by the industrial sector at forecasted prices and the results should not be viewed as a prediction for the level of deployable green hydrogen, RNG, or CCUS. A detailed description of the technical potential analysis is provided in Appendix A. This case is provided primarily for planning and informational purposes.

Economic potential represents a subset of technical potential and consists only of measures that are cost-effective according to the NYS Public Service Commission's Benefit/Cost Analysis (BCA) Framework.[14] The BCA Framework includes the energy-related costs and benefits experienced by the utility system, the incremental costs of decarbonization measures, and the value of benefits associated with avoided emissions of greenhouse gases and air pollutants. For each measure, the study structured the benefit/cost test as the ratio of net present value for the measure's societal benefits and costs, using a societal discount rate of 3% (real). This study considered measures with a societal benefit/cost ratio of 1.0 or greater to be cost-effective in the economic potential estimates. Section 4 and Appendix A include a description of the benefits and costs elements.

The study team produced two estimates of economic potential based on different forecasts for the societal cost of GHG emissions from the New York DEC agency. The DEC's forecasts differ in the discount rate applied to the future impacts of GHG.[15] The two economic potential scenarios are:

1. **Low societal cost of carbon scenario**. This scenario used the DEC's lowest estimate of the social cost of GHG emissions, which was developed using a 3% discount rate.
2. **High societal cost of carbon scenario**. This scenario uses an alternative forecast for the social cost of GHG emissions that is higher than the forecast used in the low case and other scenarios (developed using a 2% discount rate, which the DEC characterizes as their central rate).

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[13] Feasibility refers to the fraction of baseline equipment for which the carbon reduction measure is technically feasible from an engineering perspective. Since the study team will not be able to characterize every industrial process with precision, the study team may find, for example, that infrared drying is not feasible for all drying applications in the food industry. This factor is designed to capture factors that limit measure installation, beyond what is captured in the other factors.

[14] New York State Department of Public Service. Case 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, Order Establishing the Benefit-Cost Analysis Framework (issued January 21, 2016). https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={F8C835E1-EDB5-47FF-BD78-73EB5B3B177A}

[15] While the avoided cost of carbon forecasts represents different discount rates, and the DEC identifies the forecasts by their discount rate, this is independent of the discount rate used for this study. The study team uses a 3% real discount rate for all scenarios, regardless of the forecast used for the avoided cost of GHG emissions.

A higher avoided cost of GHG emission increases the societal cost test for carbon-saving measures, resulting in more measures passing the economic screening in the higher societal cost of carbon scenario and higher economic potential. Since adoption modeling is based on consumer factors, not the SCT, these values of carbon do not impact adoption scenarios and are only used to calculate economic potential.

1.2.2 Achievable potential scenarios

Achievable potential is expressed through the development of illustrative adoption scenarios that reflect possible futures with different market or policy conditions. These scenarios analyze the potential for the adoption of measures given real-world customer motivations and constraints, such as the impact of cost considerations, customer awareness, equipment replacement cycles, supply chain, workforce barriers, and the extent to which government programs overcome such barriers and constraints. This study determines achievable potential as a subset of technical potential; it does not require that measures pass a societal benefit/cost screen (as is applied to estimate economic potential) to be included in achievable potential estimates.

Depending on the scenario to be modeled, the study team changes the trajectory of certain inputs, including fuel prices, energy, demand cost savings, emissions costs, measure awareness, or reducing the share of the measure cost paid by customers through incentives. Table 1-1 lists the five adoption scenarios to explore achievable potential.

Table 1-1. Achievable potential scenario descriptions and assumptions

Key Assumptions	Base	50% Incentive	IRR Incentive	Carbon Price	Carbon Price + Enabling Investments
Avoided Cost of GHG	Low avoided societal cost of GHG	Base	Base	Base	Base
Renewable Natural Gas (RNG) Price	Base case RNG price forecast from the 2022 New York Climate Scoping Plan[16]	Base	Base	Base	Altered RNG price forecast that assumes New York State steps in and provides a production tax credit funded by carbon prices
Green Hydrogen Price	Hydrogen price forecast that considers Inflation Reduction Act (IRA) production tax credit	Base	Base	Base	Altered hydrogen price forecast that assumes that New York State steps in as the IRA tax credit phases out to keep the hydrogen price low
Carbon Price	No emissions cap or carbon price set	Base	Base	Emissions cap is set, and carbon price is input from assumptions based on current California prices and trends	Emissions cap is set, and carbon price is input from assumptions based on current California prices and trends
Incentive Levels (starting in model year 2023)	Set to zero	50% of incremental cost	Incentives bring the IRR for each measure to 10-16%	Incentives bring the IRR for each measure to 10-16%	Incentives bring the IRR for each measure to 10-16%
Program Budgets [a]	Set to zero	Marketing budget: $5,486,555	Marketing budget: $5,486,555	Marketing budget: $5,486,555	Marketing budget from 2023-2024: $5,486,555. From 2025 onwards marketing budget increases 1.5x to $8,229,833.
Market Barriers	Assumptions vary by measure but do not change over time	Base	Base	Base	Base assumptions in Year 1 of study, lowered over time for electrification, low-carbon fuels, and CCUS

a Marketing budget determines how many customers are aware of a measure and is one factor in determining measure uptake.

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[16] New York State Climate Action Council. 2022. "New York State Climate Action Council Scoping Plan." https://climate.ny.gov/resources/scoping-plan/-/media/project/climate/files/IA-Tech-Supplement-Annex-1-Input-Assumptions-2022.xlsx

2 New York State's industrial sector

This study examines New York's industrial manufacturing sector, focused the top nine subsectors by energy consumption, plus one more catch-all category labeled Other Manufacturing. Subsector energy consumption and GHG emissions in 2022 are used to represent NYS's existing industrial facilities.

Table 2-1 and Table 2-2 provide the 2022 snapshot of industrial energy consumption and emissions. These were developed using the recently completed Phase One Industrial Facilities Stock Study. GHG emissions accounting follows the requirements of the Climate Leadership and Community Protection Act (CLCPA). This includes the use of a 20-year global warming potential and accounting for in-state and out-of-state emissions that are associated with imported fossil fuels.[17]

Table 2-1. New York industrial sector energy consumption and emissions (fuel and nonfuel)

Energy Type	Energy (million MMBtu)	Emissions (thousand $MTCO_2e$)
Fuel	157.1	17,686
Feedstock (nonfuel)	147.7	N/A
Total, 2022	**304.8**	**17,686**

Table 2-2. Consumption and emissions by subsector (excludes feedstock)

NAICS and Subsector	Energy Consumption (million MMBtu)	Emissions (thousand $MTCO_2e$)
322 - Paper	45.0	5,185
Other Manufacturing[18]	22.2	2,571
331 - Primary Metals	18.9	2,177
327 - Non-Metallic Minerals	18.6	2,120
325 - Chemicals	18.2	1,954
324 – Petroleum	10.8	1,090
311 - Food	8.6	927
332 - Fabricated Metals	5.5	606
336 - Transportation Equipment	5.3	581
334 - Computer and Electronics	4.1	474
Total, 2022	**157.1**	**17,686**

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[17] NYSERDA. Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act. Prepared by Eastern Research Group Inc, Lexington, MA, USA. 2022. https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Technical-Reports-andStudies/Greenhouse-Gas-Emissions

[18] 'Other Manufacturing' includes Beverage and Tobacco Products (312), Machinery (333), Printing and Related Support (323), Plastics and Rubber Products Manufacturing (326), Electrical Equipment, Appliances, and Components (335), Wood Products (321), and Miscellaneous (339).

This study adjusts baseline energy consumption for the Petroleum sector based on unpublished results from the second phase of the Stock Study. Those preliminary results indicate that a large share of customers that had been classified as manufacturing facilities in the Petroleum subsector were not actually manufacturing facilities. While this was true to some extent for all subsectors, misclassification was a particularly large problem for Petroleum, to the extent that it was distorting the results of this study. Although the Phase 2 Stock Study numbers are preliminary, the study team and NYSERDA agreed that Petroleum subsector base consumption should be adjusted to avoid publishing misleading results. A reduction factor of 55% was applied to baseline Petroleum subsector use to rescale it to compensate for the problem.

Table 2-3 further breaks down the estimated number of manufacturing facilities by subsector and energy expenditure tier in NYS after the screening and weighting process conducted in the Stock Study. There are an estimated 11,021 manufacturing facilities in New York State. Over 95% of these facilities are small facilities (Tier 3), with annual energy expenditures of less than $500,000. Apart from the Miscellaneous subsector, Fabricated Metals, Food, and Printing are the three manufacturing subsectors with the greatest number of facilities. The manufacturing subsectors with the largest number of large facilities (Tier 1 and Tier 2) are Paper, Chemicals, Primary Metals, and Non-Metallic Mineral Products. Nearly half of Paper facilities are in either Tier 1 or Tier 2.

Table 2-3. NYS manufacturing facilities by subsector, tier, and energy usage

NAICS and Subsector Manufacturing Type	Facilities (N)	% of total facilities	Facilities per Energy Expenditure Tier			Overall Energy Usage (MMBtu)
			1 [a]	2 [a]	3 [a]	
339 - Miscellaneous	2,087	18.9%	6	11	2,070	4,551,079
332 - Fabricated Metal Products	1,961	17.8%	6	14	1,941	5,490,940
311 - Food	1,228	11.1%	21	19	1,188	8,554,515
323 - Printing and Related Support	1,098	10.0%	2	6	1,090	1,797,903
333 - Machinery	692	6.3%	4	7	681	1,847,799
337 - Furniture and Related Products	688	6.2%	[b]	[b]	688	[b]
312 - Beverage and Tobacco Products	467	4.2%	15	10	442	4,229,735
334 - Computer and Electronic Products	435	3.9%	16	18	401	4,057,729
325 - Chemicals	328	3.0%	26	35	267	18,178,927
327 - Non-Metallic Mineral Products	304	2.8%	32	14	258	18,584,453
326 - Plastics and Rubber Products	239	2.2%	10	22	207	3,307,069
335 - Electrical Equip., Appliances, and Components	234	2.1%	3	7	224	2,405,156
321 - Wood Products	222	2.0%	2	2	218	3,809,557
336 - Transportation Equipment	218	2.0%	14	13	191	5,273,803
322 - Paper	213	1.9%	66	36	110	45,047,478
331 - Primary Metals	150	1.4%	31	24	95	18,861,941
314 - Textile Product Mills	110	1.0%	[b]	[b]	110	[b]
313 - Textile Mills	105	1.0%	[b]	[b]	105	[b]
315 - Apparel	103	0.9%	1	-	102	182,016
324 - Petroleum and Coal Products	24	0.9%	19	3	2	10,770,994
316 - Leather and Allied Products	41	0.4%	[b]	[b]	41	101,121
Total	**11,021**	**100.0%**	**296**	**245**	**10,480**	**157,052,215**

[a] Tier 1: $1,000,000 and above; Tier 2: $500,001-$999,999; Tier 3: less than $500,000

[b] Denotes instances where there was not enough information.

2.1 Energy usage

Figure 2-1 depicts overall energy use by subsector, obtained from NAICS three-digit codes. The nine sectors chosen (Paper, Petroleum, Primary Metals, Non-Metallic Minerals, Chemicals, Food, Fabricated Metals, Transportation Equipment, and Computer and Electronics) equate to 89% of total emissions, with the tenth sector encompassing all other subsectors. These ten subsectors align with the ongoing Phase Two Stock Study. Industrial facilities are estimated to consume 157 trillion Btu of energy overall in New York State, excluding feedstock use. The Paper subsector has the greatest non-feedstock consumption at 29%, followed by Primary Metals, Chemicals, and Non-Metallic Minerals.

The analysis of decarbonization opportunities in this report includes measures to reduce feedstock consumption of fossil fuels, for example, as an ingredient for producing organic chemicals, plastics, or products like asphalt shingles. The total feedstock usage is estimated at 148 trillion Btu, primarily in the petroleum and chemicals subsectors, for a total of 305 trillion Btu of industrial energy consumption.

Figure 2-1. Industry subsector energy use breakdown (total energy use = 157.1 million MMBtu)

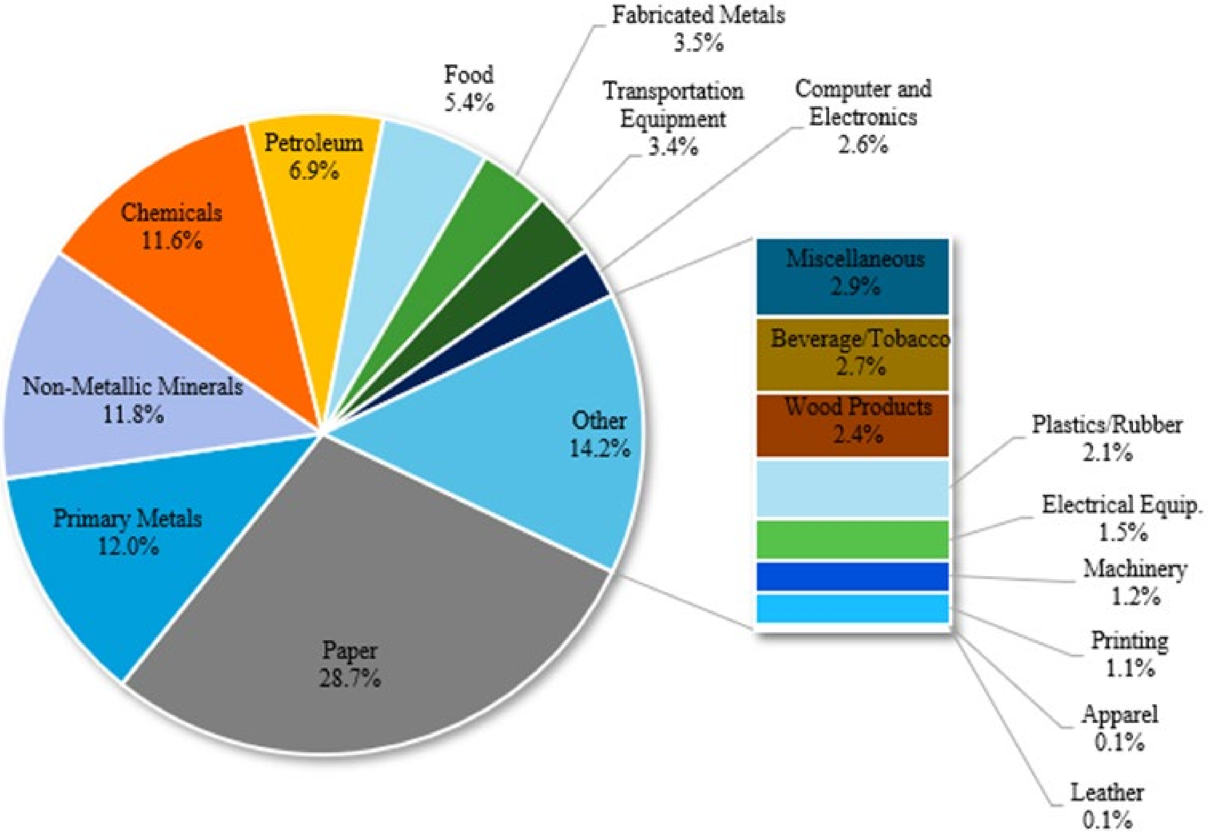


Figure 2-2 indicates the breakdown of New York State non-feedstock industrial energy use by fuel type. Natural gas represents 44% of total non-feedstock industrial energy consumption by fuel type with an estimate of 69 trillion Btu. HGL stands for hydrocarbon gas liquids, including propane.

Figure 2-2. NYS non-feedstock industrial energy consumption by fuel, 2022

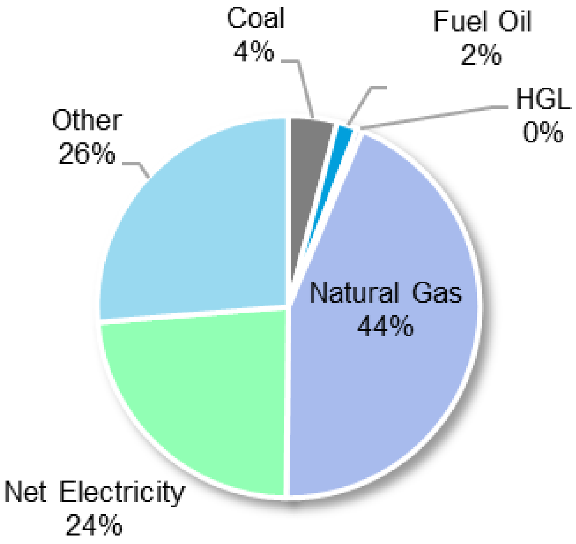


Figure 2-3 shows the fuel composition by fuel type for each subsector. The fuel mix varies by subsector, but natural gas and electricity together dominate all subsectors except Paper.

Figure 2-3. NYS non-feedstock industrial energy consumption by subsector and fuel type, 2022 (million MMBtu)

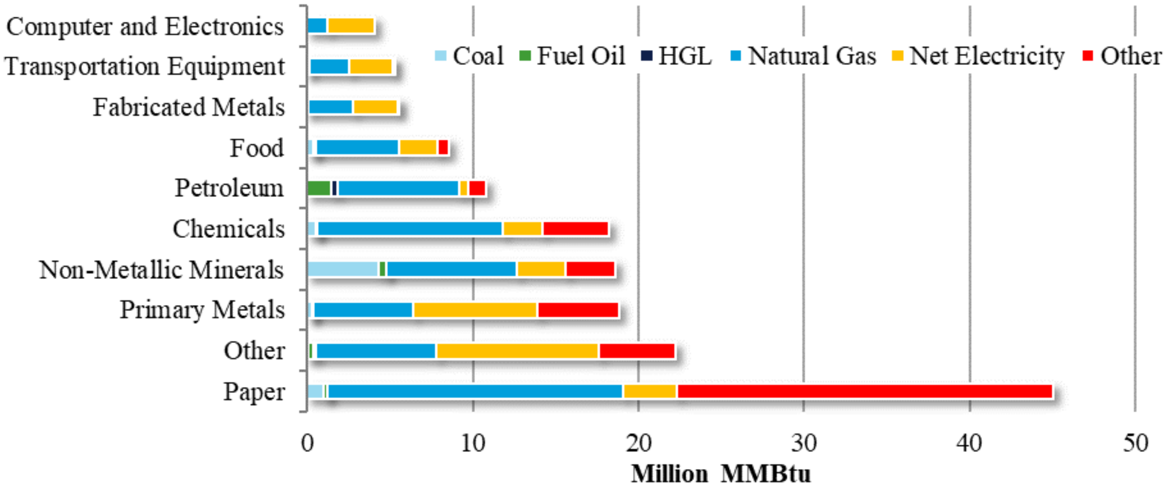
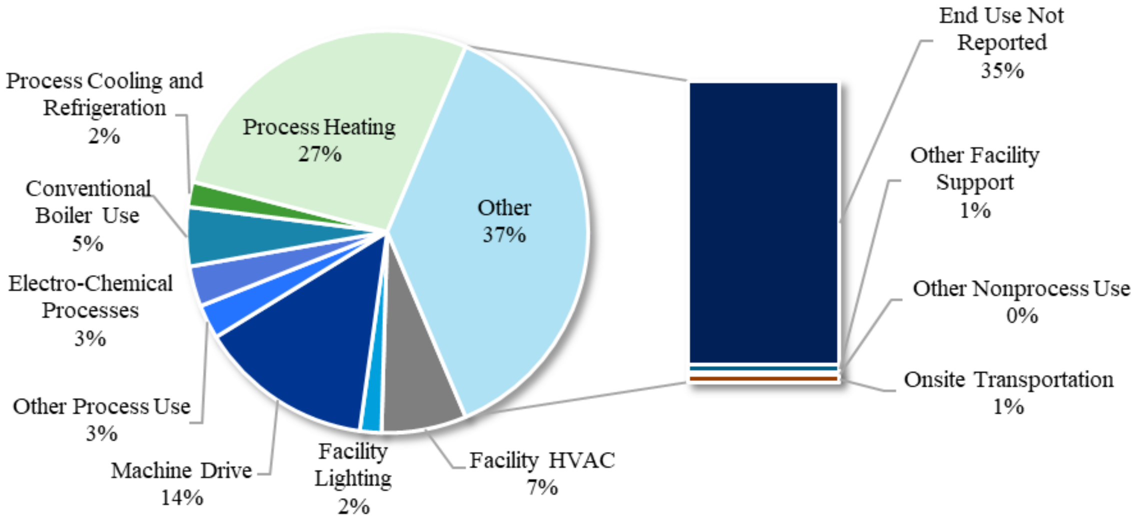


Figure 2-4 shows the breakdown by end use. Process heating and machine drive (motors) are the largest individual end uses, together accounting for over 40% of usage.

The study team made an additional adjustment to Stock Study energy use in developing the end use breakdown. The Petroleum subsector energy use estimates from the Stock Study were not specific to New York and reflected a large share of energy use for petroleum refining. However, a review of facility level data found that the Petroleum subsector in New York is dominated by asphalt paving materials and asphalt shingles, which use petroleum products as both fuel and feedstock. The study team re-estimated the end use breakouts with this information in mind, using results from EIA's Manufacturing End Use Consumption Survey.[19]

Figure 2-4. NYS non-feedstock industrial energy consumption by end use, 2022



Thirty-five percent of non-feedstock energy use does not have end uses identified in the data source used for the analysis (see Section 4.3 for more detail). The data is rooted in manufacturing sector surveys that collected estimated end-use decompositions only for key fuel types (excluding Other) as indicated in Figure 2-3. Other fuel types without reported end use breakdowns include net steam consumption and a variety of waste materials and byproducts. As indicated in Figure 2-3, the largest user of this category of fuels is Paper. Primary Metals, Petroleum, and Chemicals account for the bulk of the remainder.

Much of this energy use is likely addressable by measures included in this study. For example, biomass is used extensively in the paper industry to fuel processes that would otherwise use fossil fuel, such as paper pulping. However, without detail on the types of fuels or end uses, it was not possible to assign specific measure options and estimate their adoption levels for this portion of consumption. The study does address the "End Use Not Reported" component with cross-cutting measures such as strategic energy management. It is likely that some of the use could be addressed with additional measures including electrification. Hence, the study likely understates the savings potential for this category. However, for displacement of waste and byproduct fuels that are essentially free, the facility economics of decarbonization measures is different compared to the economics for the (mostly purchased) primary fuel types addressed directly in this study.

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[19] Energy Information Administration, 2018. Manufacturing End Use Consumptions Survey, 2018 Data Release. https://www.eia.gov/consumption/manufacturing/data/2018/

The Phase Two Stock Study surveys are attempting to collect end-use decompositions for all of the fuels with the greatest consumption at each facility in the survey sample. The Phase Two Potential Study incorporating those results may be able to identify in more detail the opportunities for this "End Use Not Reported" consumption category.

2.2 Emissions

In 2022, emissions for the industrial sector totaled 17.7 $MTCO_2e$. Figure 2-5 shows the breakdown of emissions from energy sources used as fuel in NYS industrial facilities by fuel type, subsector, and end use. In terms of emissions, natural gas and electricity have similar contributions, together about two-thirds of the total. The Paper subsector has the highest emissions of any one subsector at 29% of the total, followed by Primary Metals and Non-Metallic Minerals.

Figure 2-5. NYS non-feedstock industrial energy emissions by fuel and by subsector, 2022

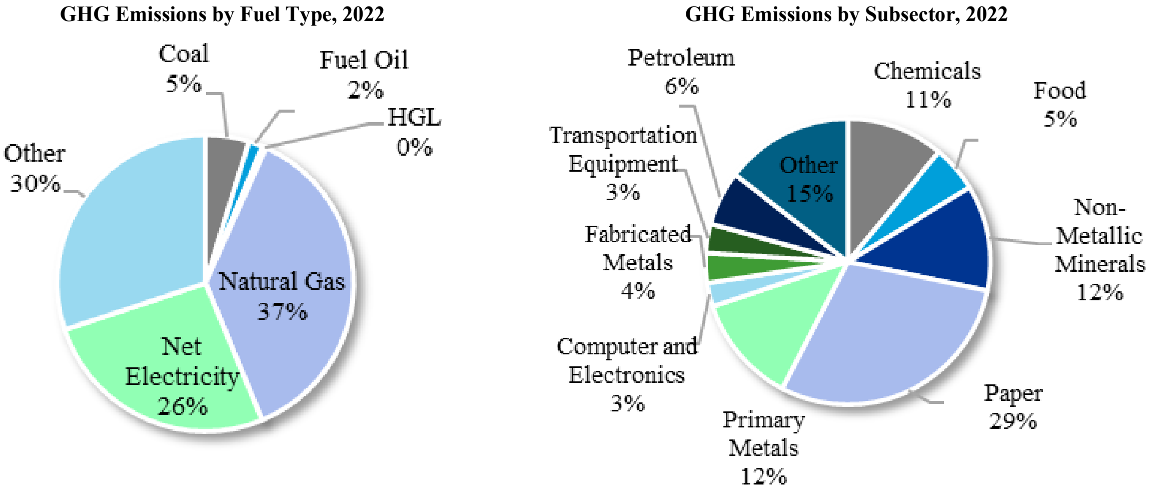
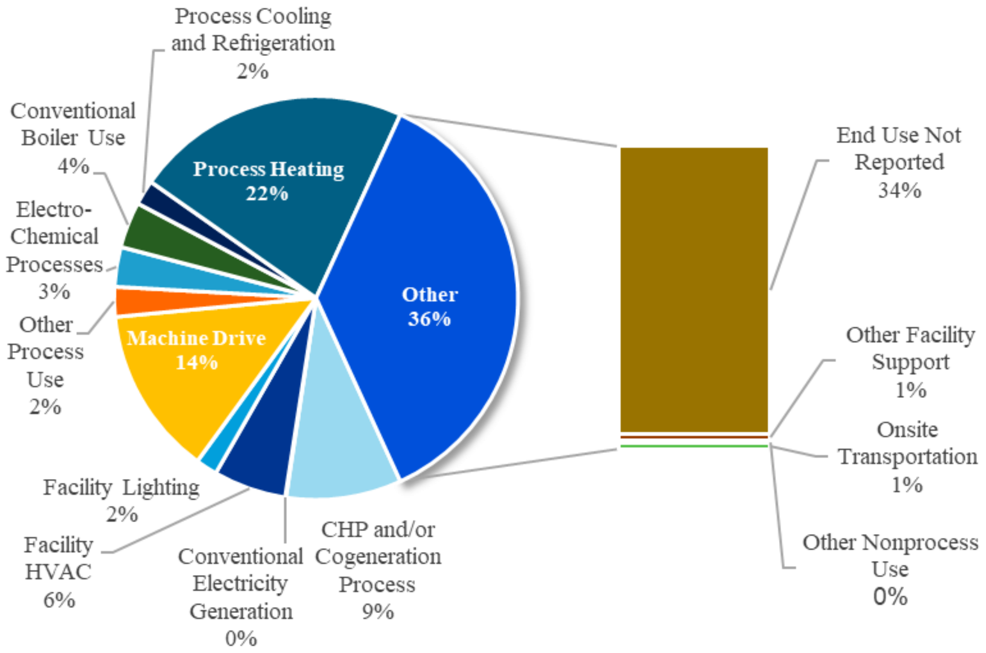


Figure 2-6 shows the industrial emissions breakdown by end use. Like energy use, process heating and machine drive (motors) are the largest individual end uses, together accounting for 40% of emissions.

Figure 2-6. NYS non-feedstock industrial energy emissions by end use, 2022



3 Decarbonization and energy savings potential findings and conclusions

This section summarizes and examines the estimated statewide savings potential for various levels of potential and adoption scenarios. Estimates over time are provided by decarbonization category, by end use, and by Empire State Development Region. Tables of estimates by facility size Tier, Region, and Disadvantaged Community status are provided in Appendix C.

All results in this section address competition between measures. The same base energy use may be addressable through energy efficiency, electrification, and/or low carbon fuels. Some measures are complementary (for example, many energy efficiency measures apply to low carbon fuels as well as base fuels) while others compete against each other (electrification and low carbon fuels). The model's approach to competition is described in Appendix A. To see the potential for each decarbonization category absent competition with the other categories, a set of stand-alone technical and economic decarbonization estimates are provided in Appendix B.

3.1 Technical and economic savings

3.1.1 Technical potential

NYS technical decarbonization potential reaches 5.2 million MTCO$_2$e by 2042, or 28% of estimated baseline 2042 emissions. As shown in Figure 3-1, energy efficiency measures make up most of the early technical potential for decarbonization. In later years, low-carbon fuels, primarily green hydrogen, make up most of the technical potential savings (3.8 million MTCO$_2$e by 2042). In the last half of the study period, electrification technical potential also outpaces energy efficiency savings. CCUS is limited in potential and only applicable to a few subsectors.

These levels of low-carbon fuels and CCUS reflect demand by industrial facilities given our fuel and carbon price forecasts and measure costs. The technical potential is not reflective of supply and infrastructure limitations in these developing markets and should not be viewed as a prediction of deployable low-carbon fuels or CCUS.

The declining emissions reductions over time for energy efficiency is a result of decarbonizing New York's electric grid,[20] which reduces the impacts of electric energy efficiency measures over time. At the same time, decarbonization of the electric grid increases the emissions benefits from electrification.

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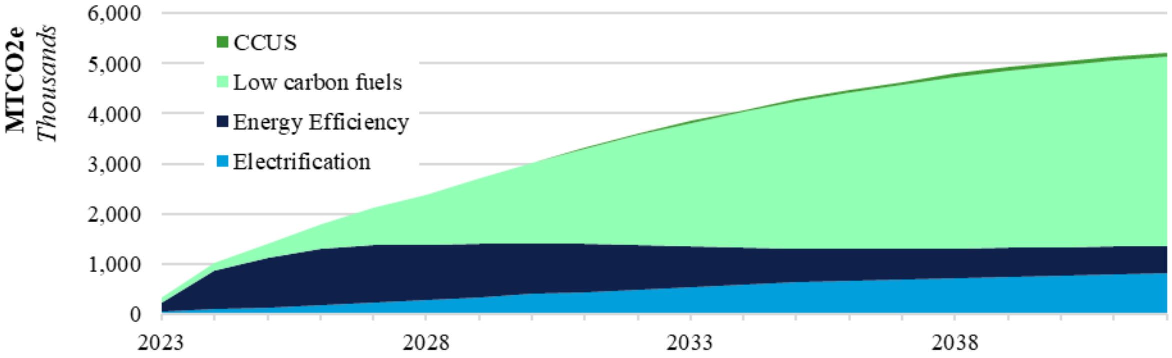
[20] This study assumes that New York State will achieve targets set forth in the Climate Leadership and Community Act of 2019 (the "Climate Act"), specifically a zero-emission electric grid by 2040.

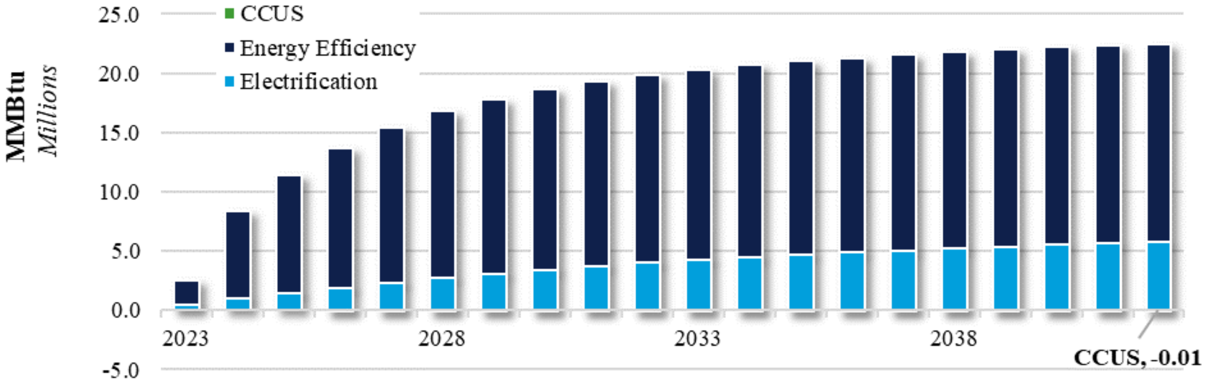
Figure 3-1. Technical potential emissions savings



The decarbonization of electricity generation results in very different patterns for decarbonization potential than for energy potential. Where energy efficiency's decarbonization potential declines over time, its energy potential continues to increase, as shown in Figure 3-2. Electric energy efficiency potential will likely continue to play a role in managing electricity load even as its emissions benefits decline.

By 2042, technical potential energy savings reach 22.5 million MMBtu or 13.6% of baseline 2042 consumption (Figure 3-2). Low-carbon fuels are absent from energy savings because they are energy neutral— savings in fossil fuels are offset by equivalent MMBtu of the low-carbon fuel. CCUS energy savings potential appears as a negative value in Figure 3-2 because these measures reduce emissions but require energy to operate.

Figure 3-2. Technical potential energy savings

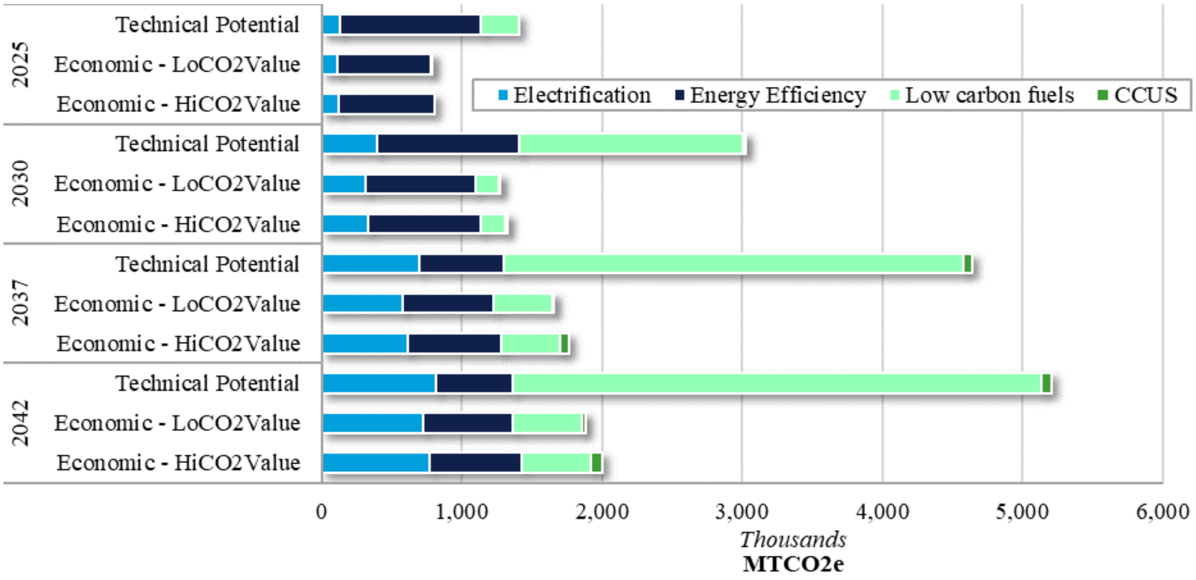


3.1.2 Economic potential

The study developed two economic potential estimates for the study using alternative forecasts for the societal cost of CO_2 (described above). Both forecasts are from the New York Department of Environmental Conservation, but they use different discount rates to estimate the future impacts of greenhouse gases. The low societal cost of carbon scenario is developed using 3% discount rate while the high societal cost of carbon scenario is developed using a 2% discount rate. We discuss the low CO_2 value scenario first, comparing it to technical potential, then present the high CO_2 value economic potential in comparison to low CO_2 value economic potential.

Figure 3-3 compares economic decarbonization potential to technical potential for selected years. Economic potential under the low value of CO_2 goes from 55% of technical potential emissions in 2025, to 36% in 2042, primarily due to the huge jump in technical potential (but not economic potential) in low-carbon fuels over the forecast period. Decarbonization potential in the low CO_2 value case reaches 1.9 million $MTCO_2e$, or 10% of baseline emissions, by 2042.

Figure 3-3. Technical and economic decarbonization potential, selected years

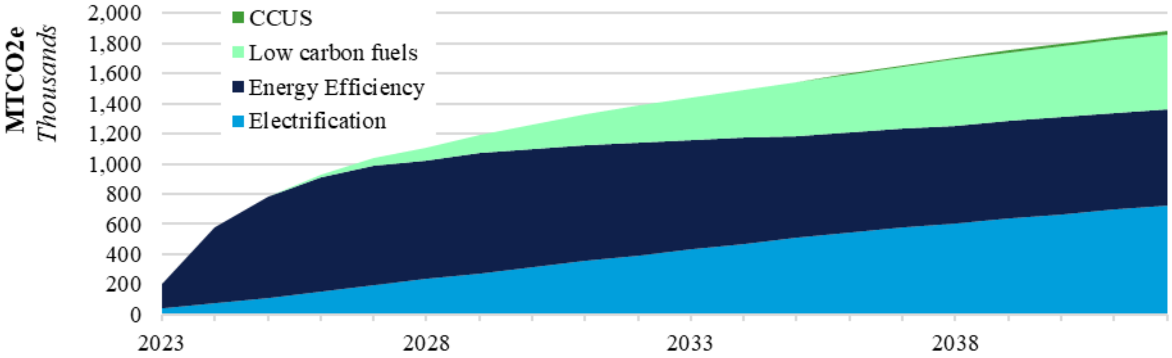


The results do not change substantially under the high value of CO_2: By 2042, the high CO_2 value decarbonization potential is 6% greater than the low CO_2 value case. Economic potential in the high CO_2 value case reaches 2 million $MTCO_2e$ in 2042, equivalent to 11% of baseline emissions. CCUS economic decarbonization potential increases in this scenario, with all technical CCUS potential being economic under the high value case.

While overall economic potential is lower than technical potential, it is not always lower at the category level. Due to the way that measures compete against each other for the same opportunities, economic energy efficiency potential is actually higher than technical energy efficiency potential after 2037. In the technical potential calculation, low-carbon fuel measures that have large technical decarbonization potential but fail the societal cost test will beat out a cost-effective energy efficiency measure that has lower technical potential. In the economic potential calculation, only measures that pass the SCT are placed in competition. That takes most of the low-carbon fuels measures out of the competition allowing energy efficiency to capture a greater share of the total economic potential than it did for technical potential.

The following chart shows economic decarbonization potential by category over time for the low CO_2 value scenario (category results are similar for the high CO_2 value scenario). Early in the forecast, energy efficiency dominates, representing 85% of potential in 2025. Because much energy efficiency affects electricity use, its emissions benefits decline over time. By 2042, energy efficiency represents only 34% of decarbonization potential, compared to 38% for electrification and 26% for low-carbon fuels. Economic decarbonization potential for CCUS is negligible.

Figure 3-4. Low CO_2 value economic decarbonization potential

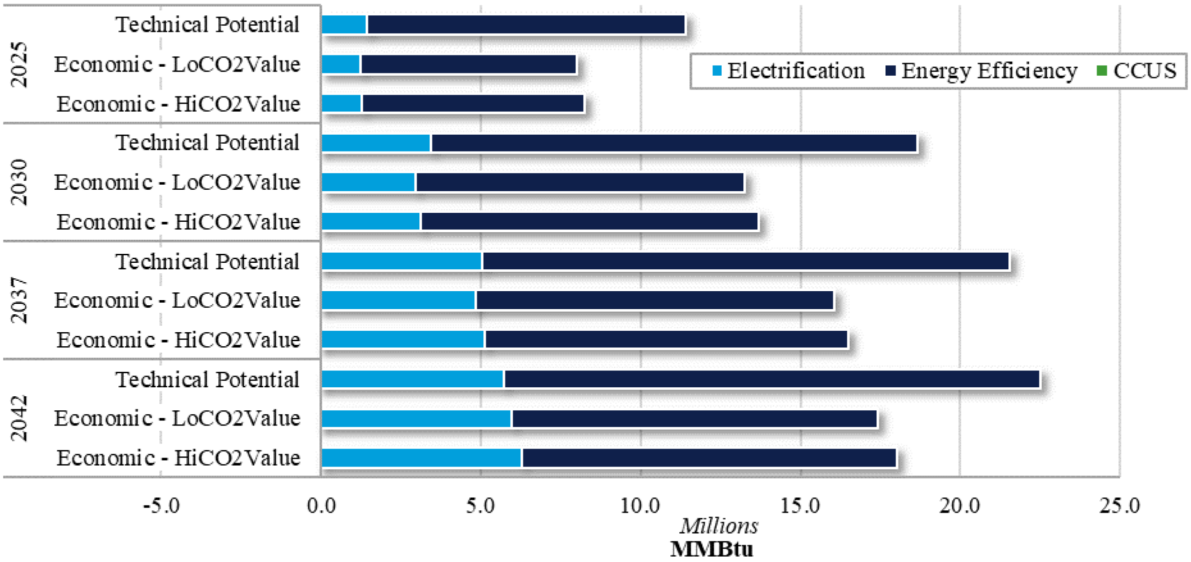


Compared to emissions, economic energy potential represents a much higher share of technical potential (Figure 3-5), ranging from 70% in 2025 to 77% in 2042 for the low CO_2 value scenario. The economic energy savings potential is dominated by energy efficiency, representing 66% of the total 2042 economic potential. CCUS results in negative energy savings (it requires energy to produce emissions savings), and low-carbon fuels do not reduce overall energy use. Economic energy savings potential reaches 17.4 million MMBtu by 2042 in the low CO_2 value scenario, or 10.5% of baseline energy consumption.

Energy savings potential by 2042 is 3% higher in the high CO_2 value scenario than in the low CO_2 value scenario. By 2042, the high CO_2 value economic potential is 18 million MMBtu (equivalent to 11% of baseline energy consumption).

In the later years of the study, electrification economic potential is greater than technical potential for both scenarios. As discussed above for emissions, this is due to competition between electrification, energy efficiency, and low-carbon fuels measures. For example, green hydrogen fuel switching outcompetes induction furnace (an electrification measure) for technical potential as a glass melting furnace replacement, but since green hydrogen fuel switching does not pass the economic screening in that application, induction furnace has no competition in the economic analysis.

Figure 3-5. Technical and economic potential energy savings, selected years



*Negative CCUS energy impacts are included on the chart, but at less than 0.01 million MMBtu the value is not visible

3.2 Adoption

3.2.1 Emissions and energy achievable potential

Achievable decarbonization and energy savings potential across the adoption scenarios vary in magnitude, but the overall mix of potential by end use or subsector remains the same. The incentive-only scenarios' (50% Incentive and IRR Incentive) decarbonization potentials are roughly equivalent as well.

Figure 3-6 and Figure 3-7 show the achievable potential for the adoption scenarios over the forecast period for emissions and energy, respectively. By 2042, the IRR Incentive scenario reaches 1.2% of baseline emissions and 2.3% of non-feedstock energy. The Carbon Price + Enabling Investments scenario saves 2% of baseline emissions and 3% of non-feedstock energy over the same period.

An additional sensitivity was examined, looking at a low RNG cost for the Carbon Price + Enabling Investments scenario. However, this lower price forecast did not impact adoption, and potential remains very small (about 334 thousand MTCO$_2$e by 2042). To get RNG adoption, the study would have to assume a fuel subsidy sufficient to bring RNG into parity with natural gas when both the fuel cost and emissions cost are considered.[21] While this would increase emissions savings, it would not be cost effective from a societal standpoint since the combined fuel, health, and carbon avoided costs do not offset the higher cost of RNG. While a cost-effective portfolio may include some individual measures that

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[21] The study team did not consider the public relations value of carbon reduction measures in the modeling, which could result in some adoption despite costing more than natural gas.

are not cost effective, broadly subsidizing RNG to this level would result in RNG dominating savings potential, and the full suite of interventions would no longer be cost effective.

Figure 3-6. Achievable decarbonization potential, all adoption scenarios

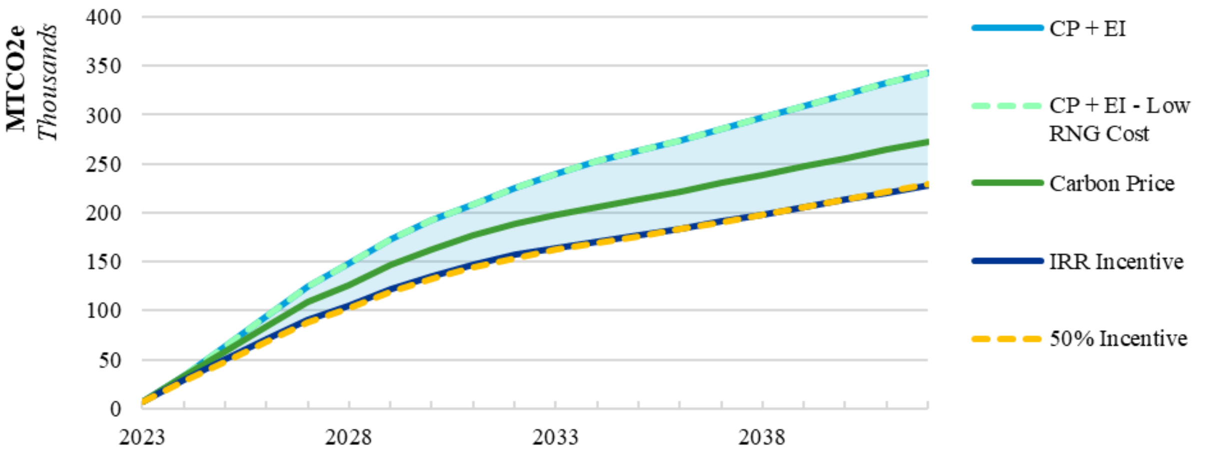


Figure 3-7. Achievable energy savings potential, all adoption scenarios

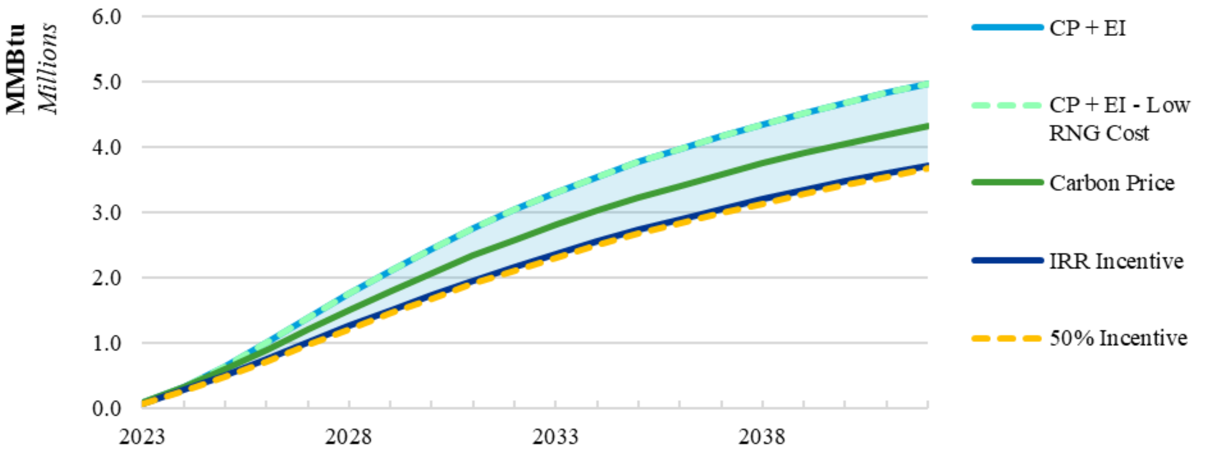
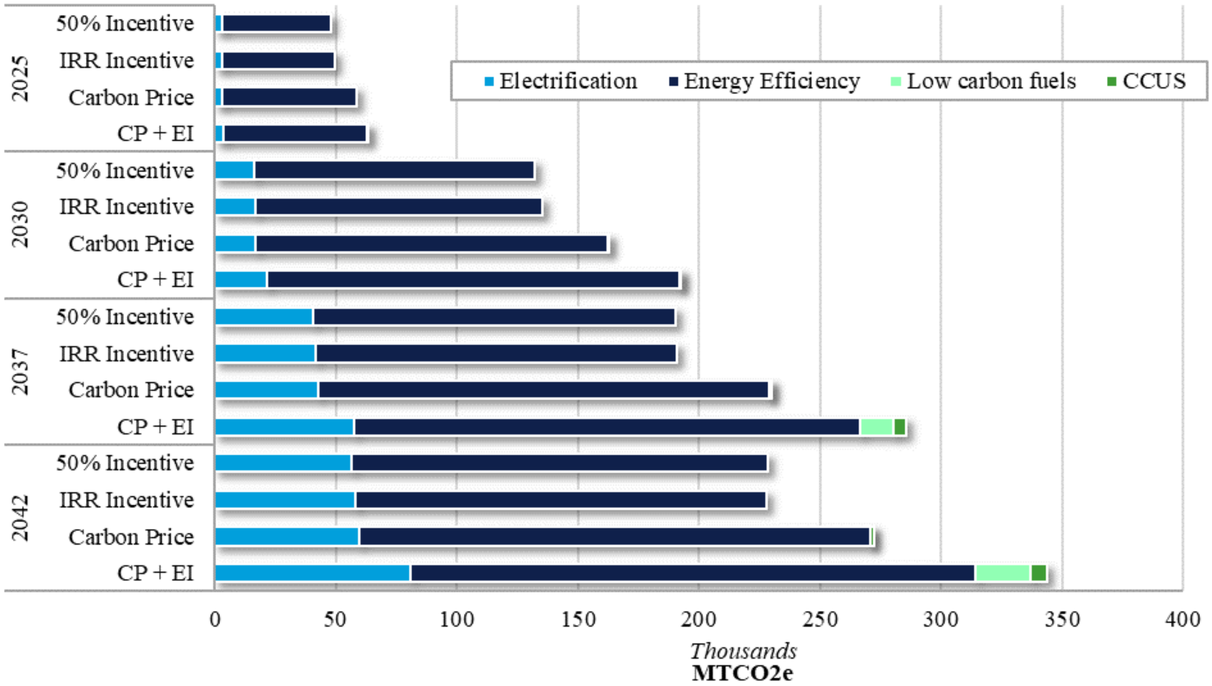


Figure 3-8 breaks out savings by category for the achievable potential scenarios. Achievable potential for the IRR Incentive, 50% Incentive, and Carbon Price scenarios, as shown in Figure 3-8, is split between electrification (22% of the total by 2042) and energy efficiency (78%). There are no low-carbon fuels or CCUS savings in the pure incentive scenarios, and only negligible amounts in the Carbon Price scenario. Results for the Carbon Price + Enabling Investments scenario show a greater share of decarbonization potential in electrification (24% of the total by 2042), low-carbon fuels (7%), and CCUS (2%), compared to the other scenarios.

Figure 3-8. Achievable decarbonization potential by scenario and category, selected years



The Carbon Price + Enabling Investments scenario assesses potential under a future with large investments to reduce barriers to adoption for CCUS, low-carbon fuels, and electrification. This could take the form of public funding for CO_2 and hydrogen pipelines, reducing legal and permitting barriers for pipelines and CO_2 storage, and informational and technical assistance.

The low-carbon fuels adoption is negligible under the Carbon Price scenario, but investments in barriers mitigation provide modest green hydrogen adoption in the Carbon Price + Enabling Investments scenario by 2042. The contribution to decarbonization potential by CCUS is still modest compared to energy efficiency and electrification. Electrification decarbonization potential increased by 43% between the 50% Incentive scenario and the Carbon Price + Enabling Investments scenario by 2042. Still, adoption remains limited by the industrial sector's risk aversion and desire for short pay-back periods for investments. Energy efficiency decarbonization potential increases 23% in the Carbon Price scenario compared to the 50% Incentive scenario; for Carbon Price + Enabling Investments, the increase is 35%.

3.2.2 Energy savings achievable potential by fuel type

In the following results sections, Fuel Oil and HGL fuel savings are combined and represented together as "Oil," because together they only represent about 2% of total baseline energy consumption in the industrial sector. Natural gas and net electricity use represent about 70% of total non-feedstock energy consumption in the industrial sector, a key factor driving the relative energy savings potential by fuel.

Figure 3-9 and Figure 3-10 show the energy savings achievable potential for the 50% Incentive scenario, broken out by fuel switching potential (limited to electrification in the 50% Incentive scenario) and energy efficiency potential. This breakdown shows the increase in electricity consumption that is associated with the energy savings from fuel switching. Almost all fossil fuel savings from fuel switching are in oil and natural gas; coal savings are negligible. The study does not model fuel switching for the other fuels category.

Figure 3-9. Fuel switching (electrification + low-carbon fuels) energy savings potential, 50% Incentive scenario

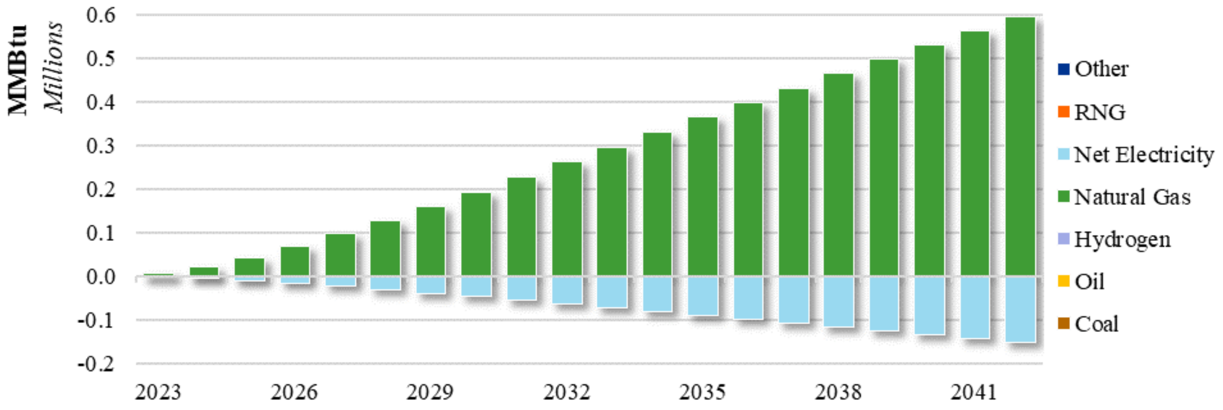


Figure 3-10. Energy efficiency energy savings potential, 50% Incentive scenario

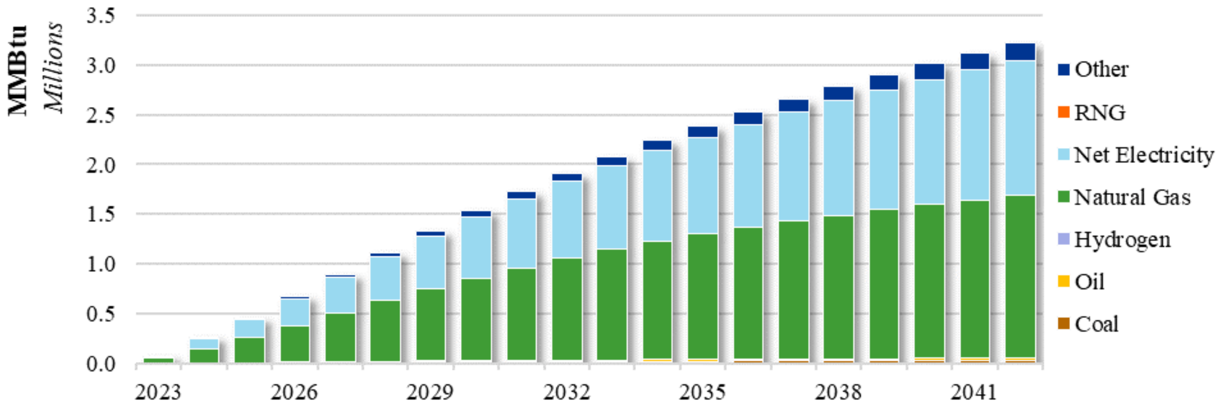
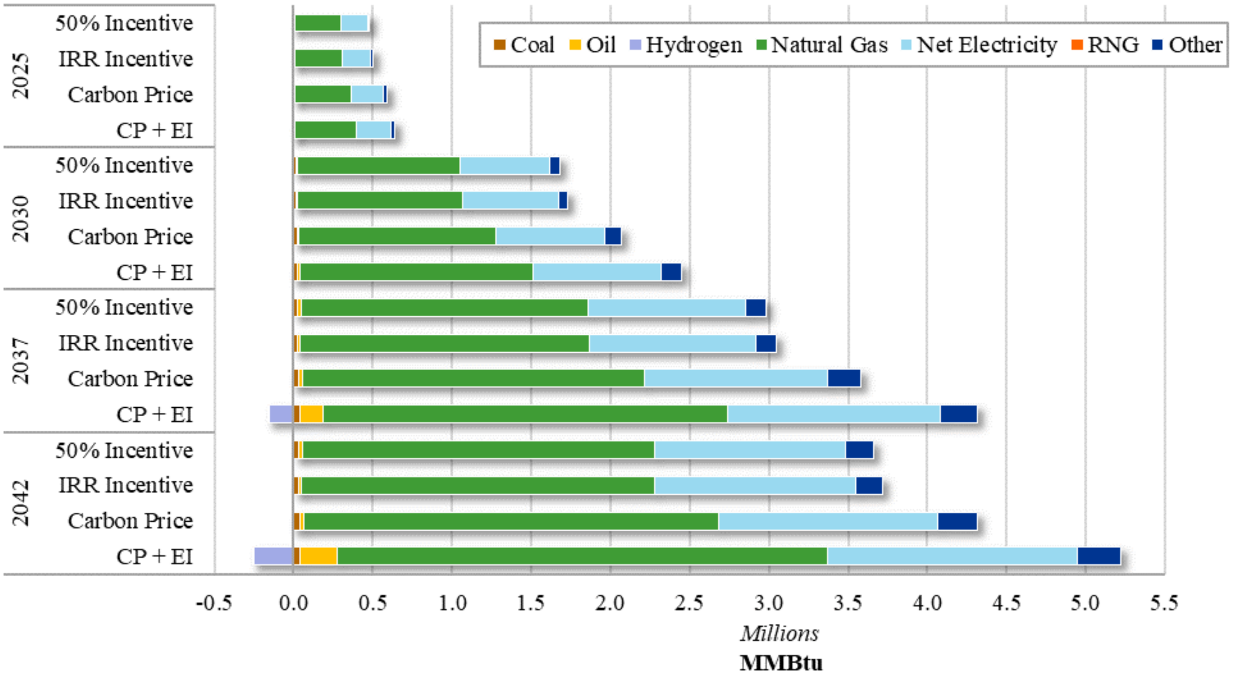


Figure 3-11 shows statewide achievable energy savings potential for all measures by scenario and fuel for 2025, 2030, 2037, and 2042. By 2042, Carbon Price + Enabling Investments potential equals approximately 3% of estimated non-feedstock energy consumption (all fuels) and 4% of fossil fuel (natural gas, oil, and coal) non-feedstock consumption. By 2042, 50% Incentive potential equals approximately 2.2% of estimated non-feedstock energy consumption (all fuels) and 3% of fossil fuel (natural gas, oil, and coal) non-feedstock consumption. In all scenarios, the increase in electricity usage from electrification is offset by energy efficiency savings.

Figure 3-11. Achievable potential energy savings by scenario and fuel, selected years



3.2.3 Achievable potential by end use

The share of achievable potential by end use does not vary significantly across the adoption scenarios, so this section focuses on the 50% Incentive scenario results. Figure 3-12 and Figure 3-13 show decarbonization and energy potential, respectively, for the 50% Incentive scenario.

Process heating measures make up the largest share of savings for both emissions (83% of total in 2042) and energy (52%). These include a broad range of measures: measures such as process controls are broadly applicable across industries and equipment types; other measures are industry-specific or have limited applicability, such as electric resistance melting in the glass industry or efficient ladle preheating in Primary Metals. Decarbonization potential is distributed across a range of measures, with process heat recovery representing the largest share at 17% in 2042.

Motors are the second largest contributor to energy savings but play a decreasing role in decarbonization potential after 2030. More efficient electric motors increase energy savings over the forecast period, but emissions savings tail off as the grid decarbonizes. The motors end use includes compressed air, fans, pumps, and drives. Many motor measures are cost effective, and typically play a large role in industrial efficiency programs.

The Boiler and Cross-Cutting end uses contribute to both emissions and energy savings. Cross-cutting measures include strategic energy management, energy management systems, and high-efficiency transformers (these are the only types of measures applied to the "End Use Not Reported" category).

Savings for these measures are high because they affect a large share of base energy and emissions. Facility Heating Ventilation and Cooling (HVAC) and Process Refrigeration contribute to energy savings but make up only a small share of decarbonization potential by 2042.

Figure 3-12. Decarbonization potential by end use, 50% Incentive scenario

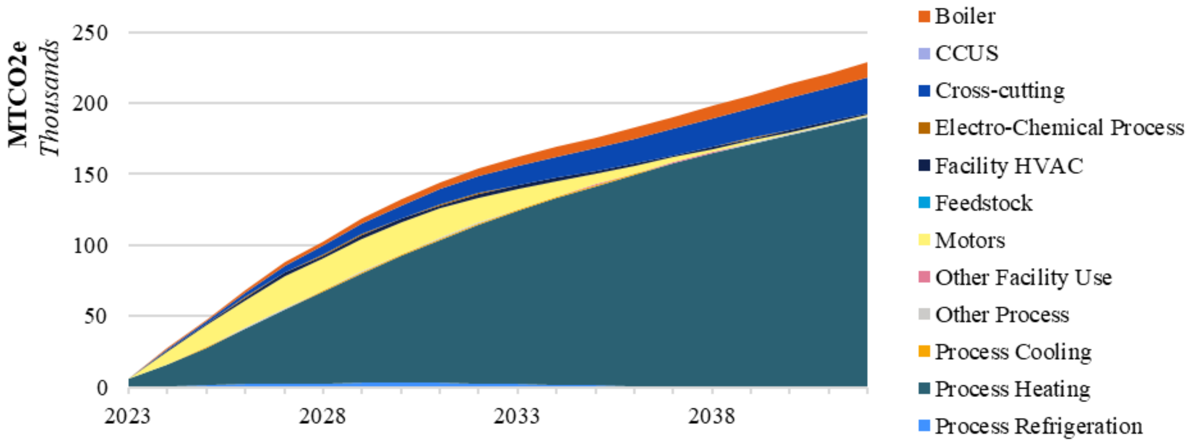


Figure 3-13. Energy savings potential by end use, 50% Incentive scenario

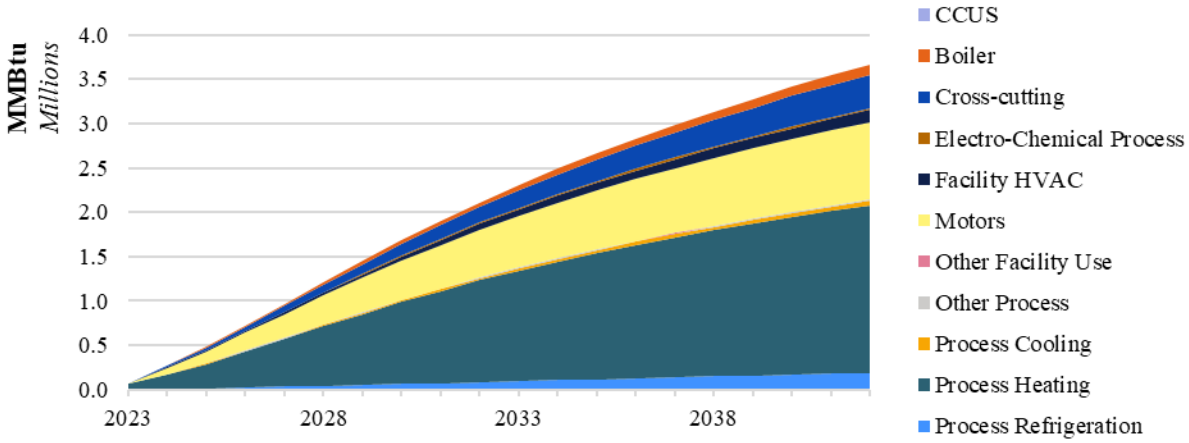
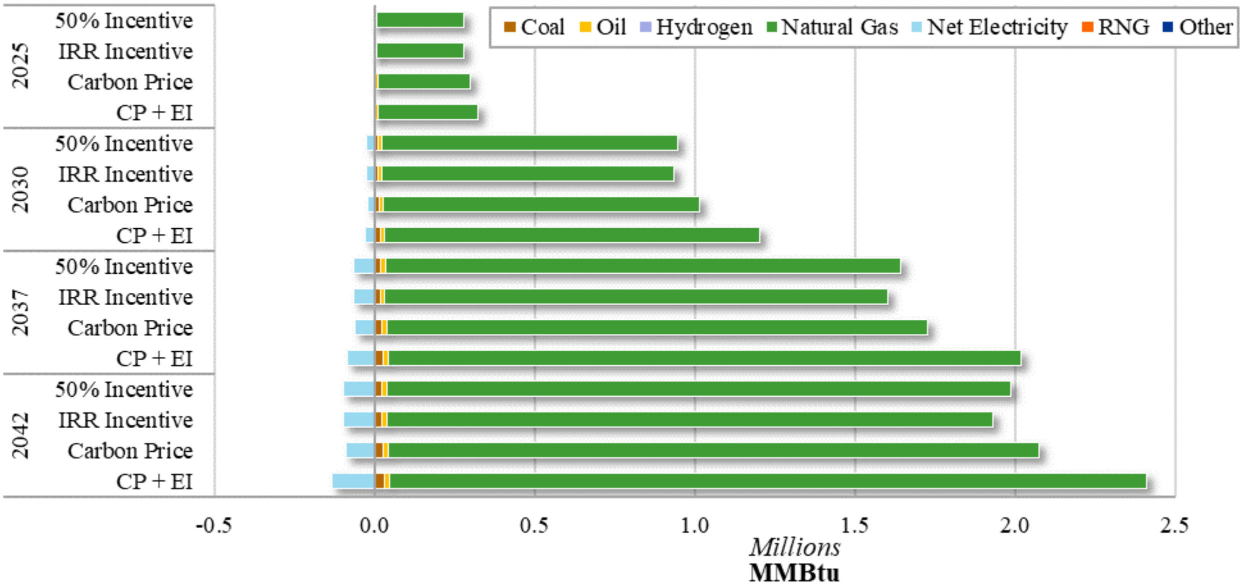


Figure 3-14 highlights the process heating end use energy savings by fuel across the achievable potential scenarios for 2025, 2030, 2037, and 2042. Low-carbon fuels (hydrogen and RNG) are notably absent from the figure, meaning that electrification measures outcompeted the low-carbon fuels measures for potential. Process heating energy savings in the IRR Incentive scenario are lower than 50% Incentive scenario savings, which differs from the total potential comparison between scenarios. The driver of this difference is the process heating energy efficiency potential in the 50% Incentive case, which is about 4% higher than the IRR Incentive case. Across scenarios, total process heating energy savings represent between 5% and 6% of baseline end use consumption by 2042. For natural gas across the scenarios, process heating energy savings account for 6% to 8% of baseline natural gas process heating consumption by 2042.

Figure 3-14. Process heating end use achievable potential energy savings by scenario and fuel, selected years



3.2.4 Achievable potential by subsector

The share of achievable potential by subsector does not change across the adoption scenarios, so the following discussion will focus on the 50% Incentive scenario. The four largest energy consuming subsectors in the New York industrial manufacturing sector are Paper, Primary Metals, Non-Metallic Minerals, and Chemicals. The Paper subsector has the largest share of "other" fuels baseline consumption, for which limited measures were identified in this study compared to gas or electricity.

The Primary Metals subsector has the highest CO_2e and energy savings, representing over 40% of total carbon savings—followed by Paper, Non-Metallic Minerals, Other, and Chemicals. Energy savings potential by subsector follows roughly the same pattern as emissions savings, but there is a larger share of savings in the Chemicals and Other subsectors. Primary Metals represents about one third of total energy savings in 2042.

Induction process heating technologies for the Primary Metals and Paper subsectors and induction and resistance melting in the glass industry (part of the Non-Metallic Minerals subsector) represent 52% of the electrification decarbonization potential by 2042. Induction heating and melting technologies are considered mature in the Primary Metals subsector. From an energy efficiency point of view, induction heating of metal is usually faster and more efficient than convection or radiant heat because the heat is generated directly in the material. Induction heating also offers greater operational control, which provides additional non-energy benefits. Resistance heating is the simplest and oldest heating electrotechnology. Direct resistance heating for melting is a widely used, mature technology in the glass industry. Non-energy benefits for resistance heating technology includes precise control and low maintenance costs.

Figure 3-15. Decarbonization potential by subsector, 50% Incentive scenario

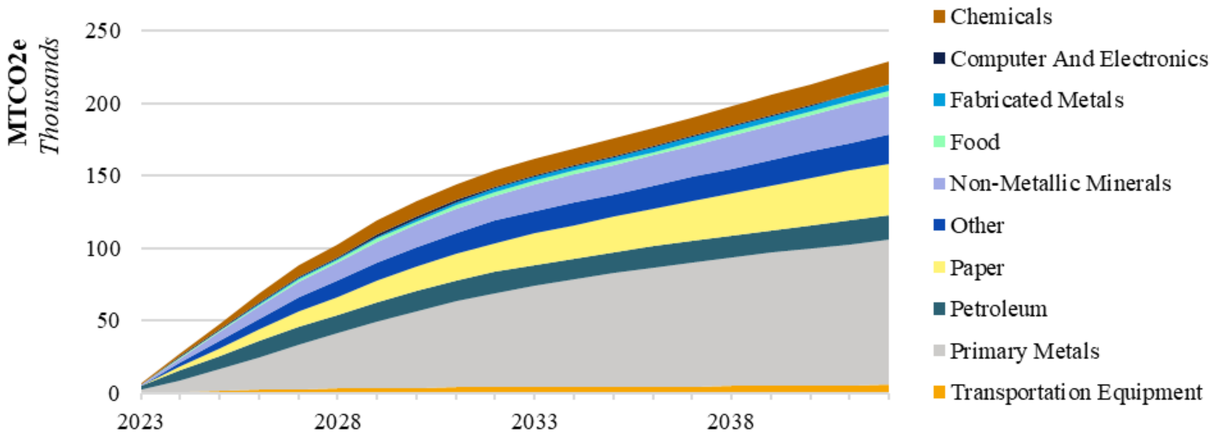
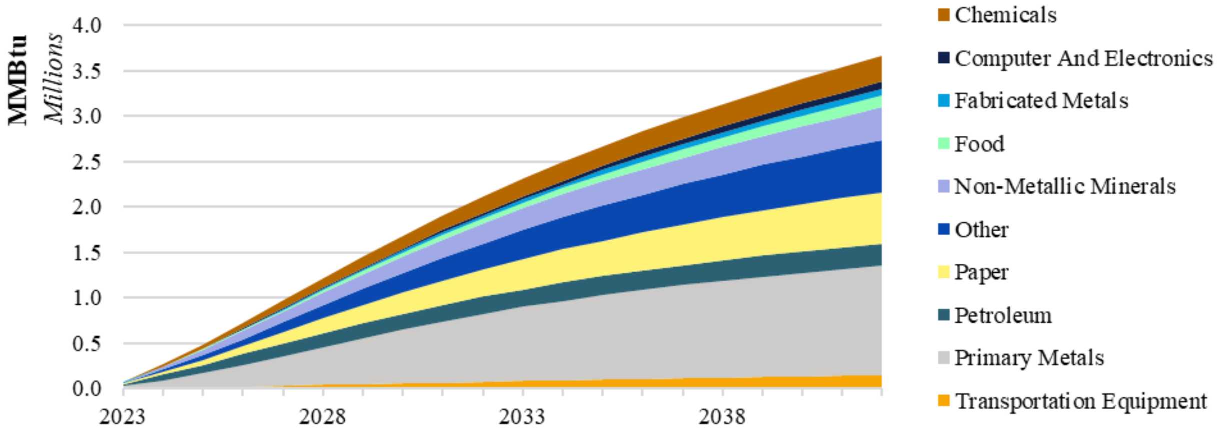


Figure 3-16. Energy savings potential by subsector, 50% Incentive scenario

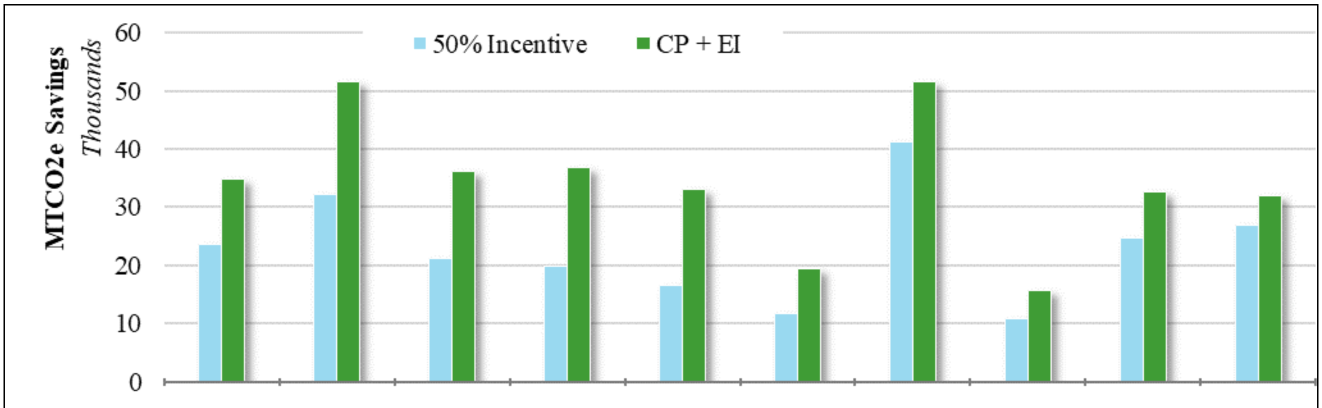


3.2.5 Achievable potential by region

This section provides potential broken out by ten geographic regions in New York state: Capital Region, Central New York, Finger Lakes, Long Island, Mid-Hudson, Mohawk Valley, New York City, North Country, Southern Tier, and Western New York. It provides results for achievable potentials, focusing on 2042 potential in the lowest and highest adoption scenarios—50% Incentive and Carbon Price + Enabling Investments. Additional results by region and DAC are provided in Appendix C.

The following figures present the carbon and energy savings results by region in 2042 for the 50% Incentive and Carbon Price + Enabling Investments scenarios. The regions on the x-axis are sorted by 2042 baseline emissions and energy consumption, respectively, from largest to smallest. Unlike the end use and subsector-level results, share of potential by region does not mirror the share of baseline emissions or energy by region. In either scenario, the region with the highest decarbonization potential in 2042 is Central New York, saving between 2.5%-3.2% of regional emissions. Mohawk Valley represents the smallest share of regional baseline emissions, but has the greatest regional percent savings in 2042 (4.1% saved in CP + EI). The Mid-Hudson and Capital Region have the largest increase in decarbonization potential between the two scenarios, almost doubling in the CP + EI scenario. New York City has the largest share of decarbonization potential within DACs, over 80% in either scenario. In the 50% Incentive scenario, New York City DAC emissions savings reach about 20,000 $MTCO_2e$ by 2042; this represents the largest share of 2042 DAC potential in the scenario. However, Western New York's DAC emissions savings outpace New York City in the CP + EI scenario by 2042, reaching 30,000 $MTCO_2e$ saved (compared to 28 thousand $MTCO_2e$ saved in New York City).

Figure 3-17. 2042 achievable decarbonization potential by region compared to baseline emissions, 50% Incentive and Carbon Price + Enabling Investments scenarios



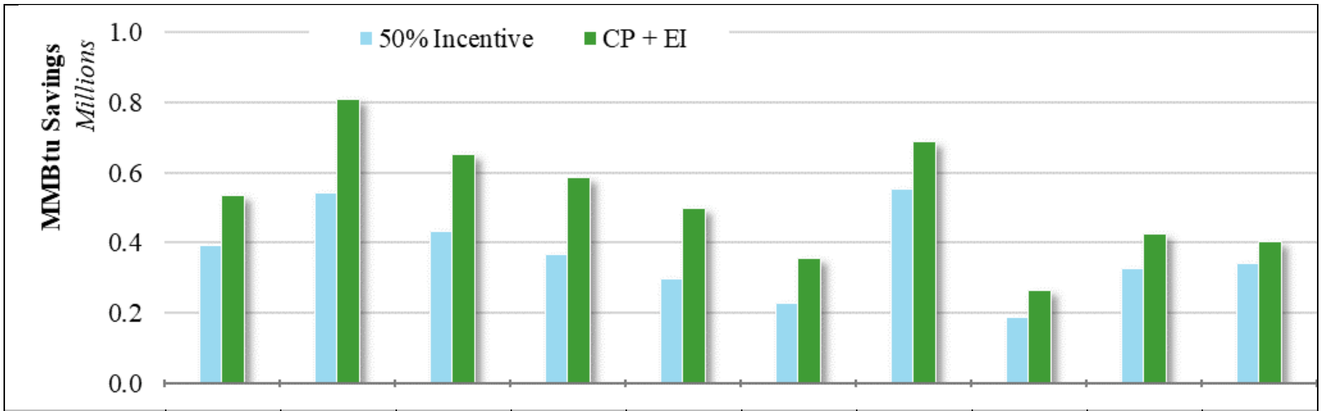
2042 Baseline* (thousand MTCO2e)	New York City	Western New York	Long Island	Capital Region	Mid-Hudson	Finger Lakes	Central New York	Southern Tier	North Country	Mohawk Valley
	2,588	2,540	2,388	2,126	1,767	1,720	1,632	1,595	1,384	788

*excludes feedstocks

Variation across regions reflects differences in the mix of industries in each region and their relative savings potential. For example, Mohawk Valley has the highest share of primary metals of all the subsectors at 27%. Its energy savings potential reaches 5%-6% of regional consumption by 2042. Central New York, despite representing only 10% of base energy use, accounts for 15% of energy savings potential and 18% of decarbonization potential in the 50% Incentive scenario (13% and 15%, respectively, in the Carbon Price + Enabling Investments scenario). Like Mohawk Valley, it has a high share of Primary Metals, at 16% of baseline energy use, along with a higher-than-average share of Petroleum. Areas with less heavy industry, and in particular less Primary Metals, have lower potential relative to their share of base use. For example, although Long Island ranks third in baseline emissions and energy, it ranks sixth for emissions savings in the 50% Incentive scenario and fourth in the Carbon Price + Enabling Investments scenario. Despite representing 17% of New York's industrial energy use in

2022 and 13% by 2042, Long Island accounts for only 12% of energy potential and 9% of decarbonization potential in the 50% Incentive scenario (10% and 12%, respectively in the Carbon Price + Enabling Investments scenario).

Figure 3-18. 2042 achievable energy savings potential by region compared to baseline consumption, 50% Incentive and Carbon Price + Enabling Investments scenarios



2042 Baseline* (million MMBtu)	New York City	Western New York	Long Island	Capital Region	Mid-Hudson	Finger Lakes	Central New York	Southern Tier	North Country	Mohawk Valley
	22.9	22.7	21.5	18.8	15.9	15.3	14.5	14.1	12.3	7.0

*excludes feedstocks

3.3 Peak demand potential results

In addition to carbon and energy savings, the study estimated peak demand impacts for electricity and natural gas. Industrial demand is relatively flat with respect to time of day and season compared to other sectors, since process energy use is not weather sensitive. HVAC is only 7% of baseline use, and correlates less with outdoor temperature than in the residential or commercial sector. Heavy industries typically have two- or three-shift operations, which minimizes intraday variation for the sector.

Table 3-1 shows the 2042 statewide demand impact potential by fuel from energy efficiency, electrification, low-carbon fuels, and CCUS measures modeled in this analysis. Electricity results represent net impacts, taking into account both electricity savings from energy efficiency and changes to electricity use due to electrification. For all scenarios modeled there is a net reduction in electricity demand.

Table 3-1. 2042 statewide electricity and gas demand impact potential

Fuel Type	Units	Estimated 2042 Peak	Demand Reduction Potential				
			Technical Potential	CP + EI	Carbon Price	IRR Incentive	50% Incentive
Net Electricity	Summer Peak MW	1,591	334	61	54	49	46
Natural Gas	Winter Peak MMBtu-Day	224,076	38,578	8,768	7,385	6,218	6,235

Figure 3-19 and Figure 3-20 break out demand savings by category for natural gas and electricity, respectively. Energy efficiency savings dominate, accounting for 70% to 75% of natural gas demand reduction in 2042 across the various scenarios. Electricity demand reductions due to energy efficiency savings are 9 to 10 times higher than the increases due to electrification.

Figure 3-19. Achievable natural gas demand impact potential by scenario and category, selected years

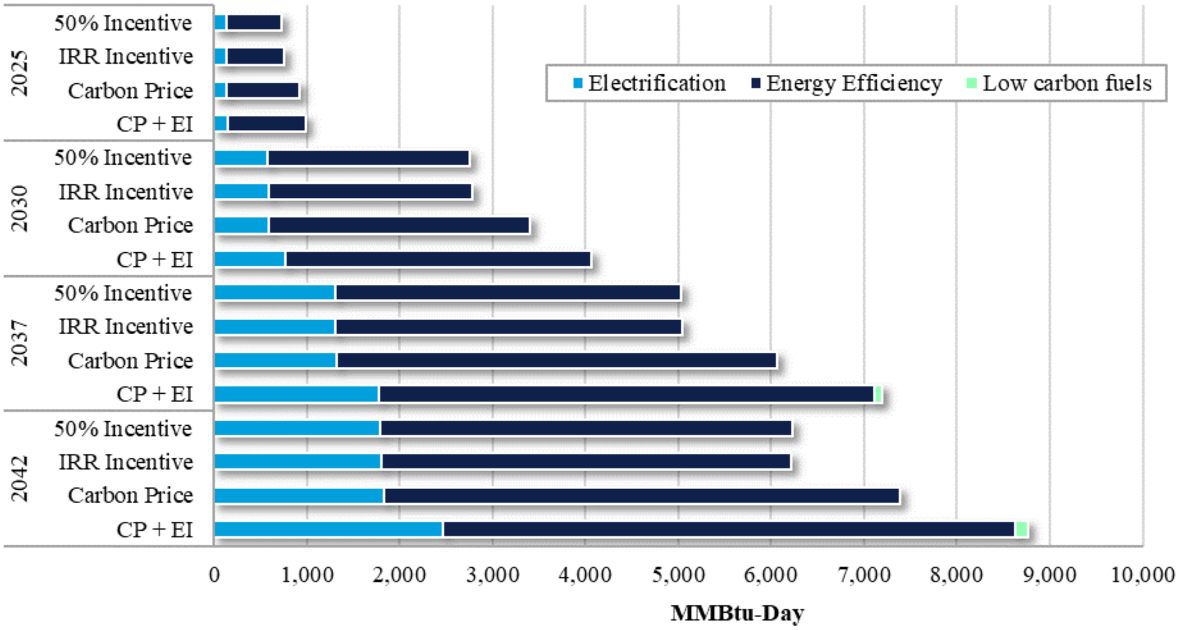
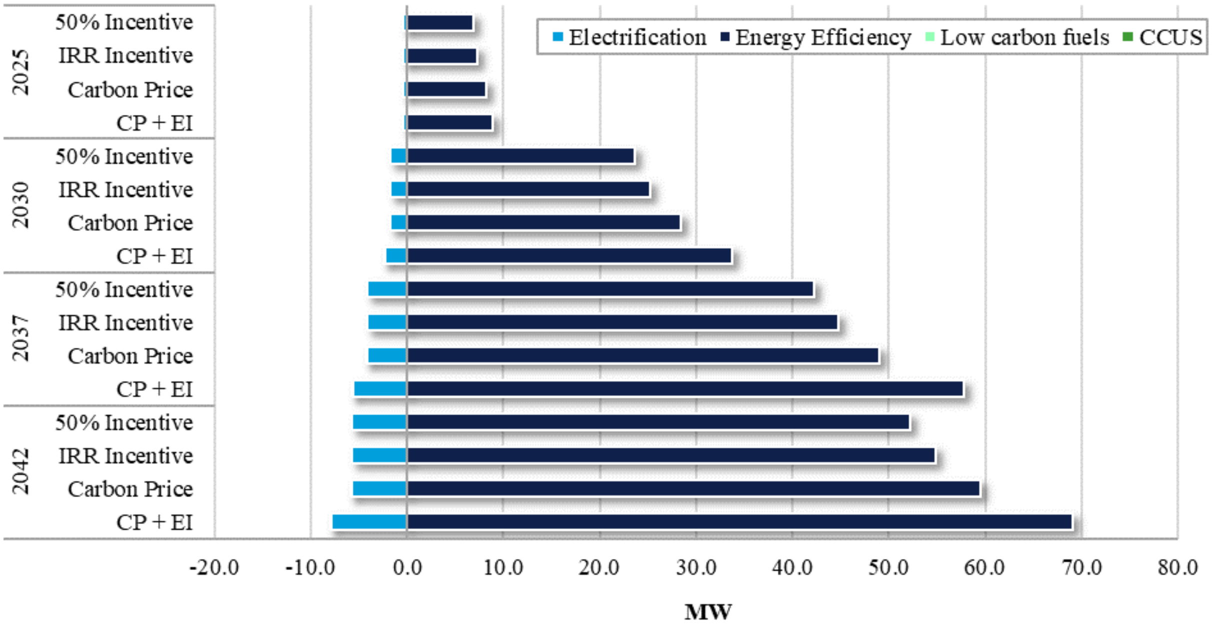


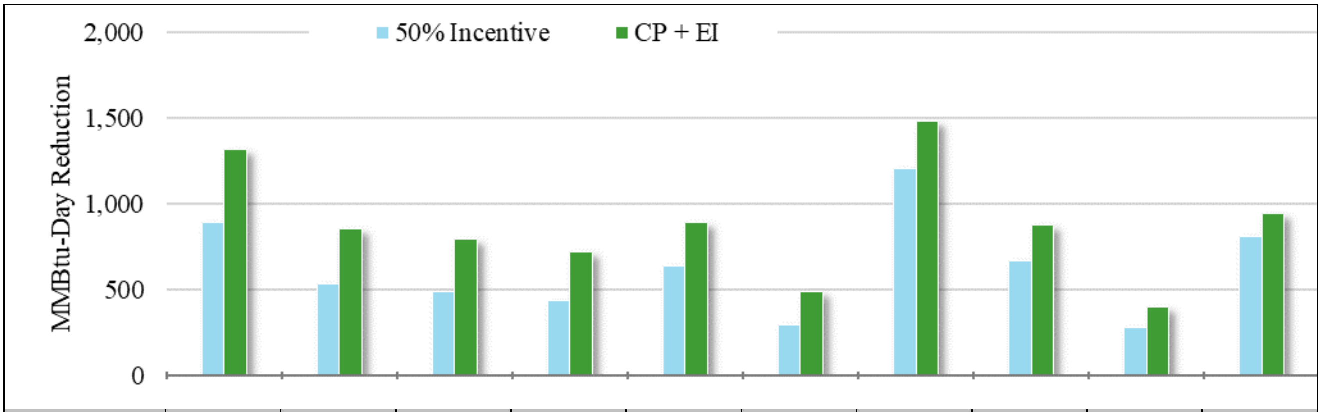
Figure 3-20. Achievable electric demand impact potential by scenario and category, selected years



3.3.1 Peak demand potential by region

The following figures present the demand potential results by region and fuel in 2042 for the 50% Incentive and Carbon Price + Enabling Investments scenarios. The x-axis is sorted by 2042 regional baseline peak demand, for each respective fuel, from largest to smallest. Demand potential by region does not follow the same pattern as baseline demand. While the Central New York region has the largest share of regional natural gas demand reduction potential in 2042, it ranks seventh by baseline natural gas demand. Mohawk Valley also has a disproportionately large share of natural gas demand savings potential, compared to the region's baseline natural gas demand. Mohawk Valley and Central New York have the largest shares of Primary Metals by baseline energy use (27% and 16%, respectively), and Primary Metals had the highest percent savings potential of all the subsectors.

Figure 3-21. 2042 achievable natural gas demand impact potential by region compared to baseline demand, 50% Incentive and Carbon Price + Enabling Investments scenarios

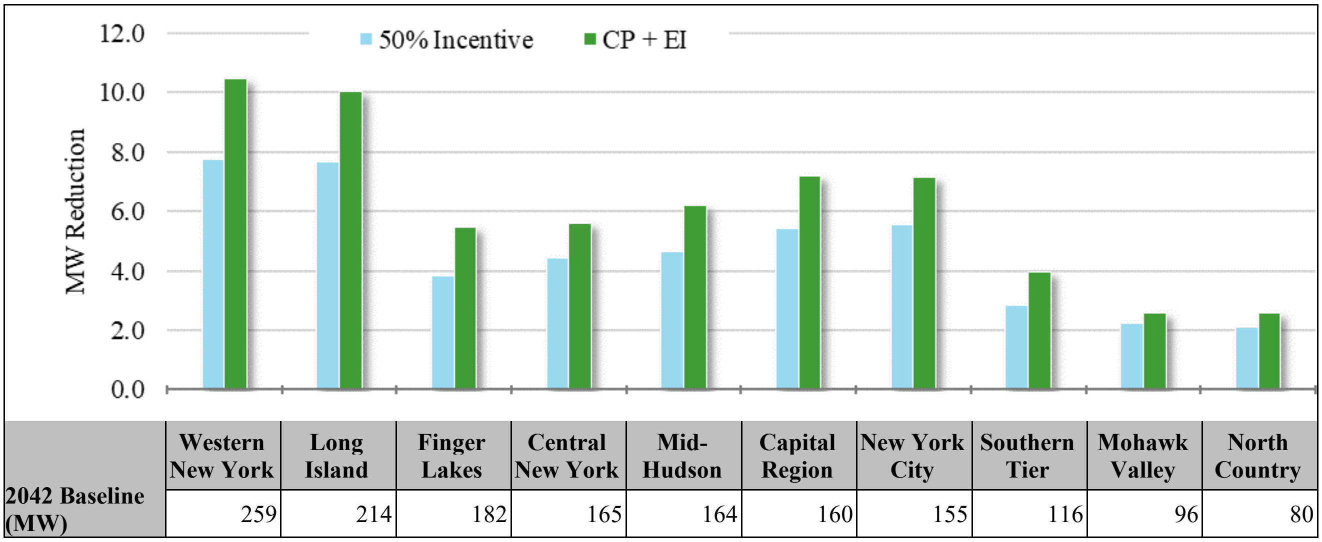


	Western New York	Long Island	Capital Region	Mid-Hudson	New York City	Finger Lakes	Central New York	North Country	Southern Tier	Mohawk Valley
2042 Baseline* (MMBtu-Day)	33,355	32,372	27,652	25,759	23,691	22,294	19,255	16,223	14,116	9,359

*excludes feedstocks

Regional electric demand potential follows the trends seen in the baseline by region, more so than natural gas demand and energy savings potential. Western New York and Long Island represent the largest about a third of electric demand potential and baseline electric demand in New York state by 2042.

Figure 3-22. 2042 achievable electric demand impact potential by region compared to baseline demand, 50% Incentive and Carbon Price + Enabling Investments scenarios



	Western New York	Long Island	Finger Lakes	Central New York	Mid-Hudson	Capital Region	New York City	Southern Tier	Mohawk Valley	North Country
2042 Baseline (MW)	259	214	182	165	164	160	155	116	96	80

Table 3-2 illustrates the pattern of demand savings potential over time by region, in this case for the 50% Incentive scenario. Other scenarios have similar time trajectories.

Table 3-2. Achievable peak demand impact potential by fuel and region, 50% Incentive scenario

	2025	2030	2037	2042
Electric Peak Demand Reduction (MW)				
Capital Region	0.9	2.9	4.6	5.4
Central New York	0.6	2.1	3.7	4.4
Finger Lakes	0.4	1.4	2.9	3.8
Long Island	1.1	3.6	6.3	7.7
Mid-Hudson	0.5	2.0	3.7	4.7
Mohawk Valley	0.3	1.2	1.9	2.2
New York City	1.0	2.9	4.6	5.6
North Country	0.5	1.4	1.9	2.1
Southern Tier	0.4	1.2	2.3	2.8
Western New York	0.8	3.3	6.2	7.7
Total Peak Demand Reduction (MW)	**6.4**	**21.9**	**38.2**	**46.5**
Natural Gas Peak Demand Reduction (MMBtu-Day)				
Capital Region	47	197	379	487
Central New York	155	585	1,020	1,207
Finger Lakes	23	98	216	293
Long Island	55	204	409	531
Mid-Hudson	41	166	338	436
Mohawk Valley	125	446	712	812
New York City	88	284	499	633
North Country	77	297	546	670
Southern Tier	33	118	219	279
Western New York	85	352	698	887
Total Peak Demand Reduction (MMBtu-Day)	**728**	**2,747**	**5,035**	**6,235**

3.4 Highest savings measures

Table 3-3 and Table 3-4 report the top-saving measures in 2030, and their 2042 potential, for the 50% Incentive and Carbon Price + Enabling Investments scenarios, the lowest and highest adoption scenarios modeled. The measures included in the tables and their ordering are based on 2030 savings, and the list may exclude some of 2042's top 10 measures. Focusing on the top measures in 2030 highlights measures that are feasible and have high potential in the near term. While the 2042 forecast may identify higher potential for emerging technologies, the longer time horizon makes that forecast more uncertain. Table 3-3 shows the results for energy savings for the two scenarios, and Table 3-4 shows emissions results. For both energy and decarbonization in both scenarios, the top 10 measures' potential represents about three-quarters of the total potential.

The majority of the top measures are process heating end use measures, with Process Heat Recovery as a top measure for both energy and emission savings in both scenarios. Only in the Carbon Price + Enabling Investments scenario does process heat recovery fall to second place, with strategic energy management taking the top spot (strategic energy management ranks from fourth to sixth for the other cases). Process heat recovery systems differ by subsector, but generally include technology options such as preheating combustion air, heat pumps, and mechanical vapor recompression.

The only measure included on the energy list but not on the emissions list is Compressed Air – Maintenance. Compressed air end use measures save electricity, and as the electricity supply decarbonizes, the emissions impact of the measure decreases, reducing its emissions impact relative to its energy impact. On the emissions list, it is replaced by Steam Distribution System – Reduce Steam Pressure.

Nine out of the 10 top measures are energy efficiency measures. The only electrification measure that made the 2030 top 10 lists was Electric Infrared Processing, which replaces fossil fuels for heating and drying with electric infrared heating. By 2042, two other process heating electrification measures are included in the top 10 measures, both induction process heating technologies.

Efficient ladle preheating is an energy efficiency measure for both integrated iron and steel and electric arc furnace plants that reduces the fuel consumption required to bring ladles up to steel handling temperatures. The measure includes several forms of intervention, including low-cost options such as installing temperature controls and scheduling of ladle heating to ensure that ladles are not kept on heat for longer than necessary.[22]

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[22] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. "Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Iron and Steel Industry," September 2012. https://www.epa.gov/sites/default/files/2015-12/documents/ironsteel.pdf

Pumps system maintenance and optimization is an energy efficiency measure that models savings recommendations from a pump systems optimization analysis. The measure savings represent interventions such as, right-sizing pumps, trimming or replacing the impeller, slowing the pump, and replacing the pump. The costliest portion of this measure is usually the systems analysis, but major energy and demand savings are possible in large systems.[23]

Process integration typically involves conducting a total site pinch analysis to identify and exploit potential synergies between systems, linking them in a thermodynamically optimal way to increase energy efficiency.

Table 3-3. Top 10 measures ranked by 2030 energy savings in 50% Incentive and Carbon Price + Enabling Investments scenarios

Scenario	Measure	2030 Potential (million MMBtu)	2042 Potential (million MMBtu)
50% Incentive	Process Heat Recovery	0.23	0.34
	Pumps - System Maintenance and Optimization	0.20	0.33
	Efficient Ladle Preheating	0.16	0.28
	Process Integration	0.16	0.30
	Compressed Air - End Use Optimization	0.14	0.30
	Strategic Energy Management	0.13	0.37
	Hot Rolling - Install Recuperative Burners	0.10	0.23
	EMS - Process Control Systems	0.08	0.20
	Electric IR Processing	0.06	0.16
	Compressed Air - Maintenance	0.06	0.14
	% of Total Potential	**79%**	**73%**
Carbon Price + Enabling Investments	Strategic Energy Management	0.26	0.56
	Process Heat Recovery	0.25	0.37
	Pumps - System Maintenance and Optimization	0.23	0.35
	Process Integration	0.21	0.36
	Efficient Ladle Preheating	0.21	0.31
	Compressed Air - End Use Optimization	0.17	0.34
	Hot Rolling - Install Recuperative Burners	0.16	0.30
	EMS - Process Control Systems	0.10	0.24
	Electric IR Processing	0.08	0.19
	Compressed Air - Maintenance	0.08	0.17
	% of Total Potential	**72%**	**64%**

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[23] Xu, Tengfang, Slaa, Jan Willem, Sathaye, Jayant. (Lawrence Berkeley National Laboratory). 2010. “Characterizing Costs, Savings and Benefits of a Selection of Energy Efficient Emerging Technologies in the United States.” California Energy Commission. Publication number: BOA-99-205-P.

Table 3-4. Top 10 measures ranked by 2030 decarbonization potential in 50% Incentive and Carbon Price + Enabling Investments scenarios

Scenario	Measure	2030 Potential (thousand MTCO$_2$e)	2042 Potential (thousand MTCO$_2$e)
50% Incentive	Process Heat Recovery	22.0	32.8
	Efficient Ladle Preheating	15.5	26.9
	Process Integration	15.3	29.0
	Pumps - System Maintenance and Optimization	9.9	0.2
	Hot Rolling - Install Recuperative Burners	9.8	22.2
	Strategic Energy Management	9.0	24.4
	EMS - Process Control Systems	7.7	16.8
	Compressed Air - End Use Optimization	7.0	0.1
	Electric IR Processing	6.7	19.0
	Steam Distribution System - Reduce Steam Pressure	4.0	10.4
	% of Total Potential	**81%**	**80%**
Carbon Price + Enabling Investments	Process Heat Recovery	24.2	35.3
	Process Integration	20.4	34.4
	Efficient Ladle Preheating	20.0	29.9
	Strategic Energy Management	18.7	37.1
	Hot Rolling - Install Recuperative Burners	15.4	28.7
	Pumps - System Maintenance and Optimization	11.3	0.2
	EMS - Process Control Systems	9.5	19.7
	Compressed Air - End Use Optimization	8.4	0.2
	Electric IR Processing	8.3	22.6
	Process Boiler - Maintenance and Tune Up	6.4	10.7
	% of Total Potential	**74%**	**64%**

3.5 Potential estimates in context

Table 3-5 summarizes the decarbonization potential for the technical, economic, and four adoption scenarios and compares them to baseline emission in select years. The highest adoption scenario saves only 1.9% of baseline emission by 2042, about 18% of the economic potential.

Table 3-5. Summary of potential estimates, statewide MTCO$_2$e decarbonization potential

	2025	2030	2037	2042
Baseline Emissions [a] (thousand MTCO$_2$e)	**18,125**	**18,124**	**18,094**	**18,528**
Cumulative Savings (thousand MTCO$_2$e)				
Technical Potential	1,409	3,022	4,638	5,208
Economic Potential – HiCO2Value	806	1,326	1,763	2,000
Economic Potential – LoCO2Value	780	1,263	1,654	1,882
Carbon Price + Enabling Investments Scenario	63	192	285	344
Carbon Price Scenario	58	162	230	272
IRR Incentive Scenario	50	135	191	228
50% Incentive Scenario	48	132	190	229

	2025	2030	2037	2042
Savings as % of Baseline				
Technical Potential	7.8%	16.7%	25.6%	28.1%
Economic Potential – HiCO2Value	4.4%	7.3%	9.7%	10.8%
Economic Potential – LoCO2Value	4.3%	7.0%	9.1%	10.2%
Carbon Price + Enabling Investments Scenario	0.3%	1.1%	1.6%	1.9%
Carbon Price Scenario	0.3%	0.9%	1.3%	1.5%
IRR Incentive Scenario	0.3%	0.7%	1.1%	1.2%
50% Incentive Scenario	0.3%	0.7%	1.1%	1.2%

a Excludes feedstocks

Technical potential is lower as a percent of baseline for energy than for emissions, lacking the boost that decarbonization potential gets from low-carbon fuels and CCUS, shown in Table 3-6. Energy savings is higher as a percent of baseline, though still modest at 3% of baseline for the Carbon Price + Enabling Investments scenario in 2042 (29% of economic potential).

Table 3-6. Summary of potential estimates, statewide MMBtu energy savings potential

	2025	2030	2037	2042
Baseline Consumption [a] (million MMBtu)	**161.0**	**161.2**	**161.1**	**164.9**
Cumulative Savings (million MMBtu)				
Technical Potential	11.4	18.7	21.6	22.5
Economic Potential – HiCO2Value	8.3	13.7	16.5	18.0
Economic Potential – LoCO2Value	8.0	13.3	16.0	17.4
Carbon Price + Enabling Investments Scenario	0.6	2.4	4.2	5.0
Carbon Price Scenario	0.6	2.1	3.6	4.3
IRR Incentive Scenario	0.5	1.7	3.0	3.7
50% Incentive Scenario	0.5	1.7	3.0	3.7
Savings as % of Baseline				
Technical Potential	7.1%	11.6%	13.4%	13.6%
Economic Potential – HiCO2Value	5.1%	8.5%	10.2%	10.9%
Economic Potential – LoCO2Value	5.0%	8.2%	10.0%	10.5%
Carbon Price + Enabling Investments Scenario	0.4%	1.5%	2.6%	3.0%
Carbon Price Scenario	0.4%	1.3%	2.2%	2.6%
IRR Incentive Scenario	0.3%	1.1%	1.9%	2.3%
50% Incentive Scenario	0.3%	1.0%	1.9%	2.2%

a Excludes feedstocks

3.6 Conclusions

The industrial sector has the potential for targeted reductions to energy use and carbon emissions. New York's industrial sector has the technical potential to save 28% of its emissions and 14% of its energy use in 2042, but the economic potential to save only 10% of emissions and 11% of energy. The achievable potential under various scenarios is under 2% of emissions and 3% of energy.

Energy efficiency is the largest source of economic and achievable potential energy savings in the New York industrial sector. Energy efficiency accounts for at least two thirds of decarbonization potential across all adoption scenarios. In 2030, nine of the top ten measures by either energy or emissions savings are energy efficiency measures, and by 2042 they still make up seven of the top ten.

Electrification has an important role in decarbonizing the industrial sector. Decarbonization potential from electrification measures makes up more than 20% of total potential in 2042 in all scenarios. The Carbon Price + Enabling Investments scenario increases electrification by 36% over the Carbon Price scenario, and 43% over the 50% Incentive scenario. These findings suggest that instituting a carbon price provides some boost to electrification, but combining the carbon price with strategic investment in barrier reduction can provide a greater boost.

The majority of the electrification potential lies in the Primary Metals, Paper, and Non-Metallic Minerals subsectors. Induction process heating technologies for the Primary Metals and Paper subsectors and resistance melting in the Non-Metallic Minerals subsector represent most of the electrification measure potential. Induction heating and melting technologies are considered mature in the Primary Metals subsector. From an energy efficiency point of view, induction heating of metal is usually faster and more efficient than convection or radiant heat because the heat is generated directly in the material. Induction heating also offers greater operational control, which provides additional non-energy benefits. Resistance heating is the simplest and oldest heating electrotechnology. Direct resistance heating for melting is a widely used, mature technology in the glass industry, which falls under the Non-Metallic Minerals subsector. Non-energy benefits for resistance heating technology includes precise control and low maintenance costs.

While the emission reductions of electricity energy-efficiency measures decline over time as the grid decarbonizes, these measures continue to contribute significantly to energy savings potential. With increased electrification across all sectors in New York, these measures will likely continue to be important for managing electrical load.

Low-carbon fuels lead technical decarbonization potential in 2042 but have modest economic potential. The technical potential exists for green hydrogen to replace fuel oils and act as a chemical feedstock, but only 13% of this potential is economic under the societal cost test, the lowest of the four categories of measures. The absence of low-carbon fuels accounts for most of the difference between the technical and economic emission potential. As noted in the methodology section, measures assume small gains in cost effectiveness over time, but there is still the potential for breakthrough technologies and other advancements, which could change the trajectory or energy savings and decarbonization measures.

Virtually all low-carbon fuel adopted is green hydrogen, almost all of which replaces base petroleum use. Neither green hydrogen nor RNG is cost effective from a societal standpoint as a replacement for natural gas as a fuel, although there is some potential for both fuels as a chemical feedstock. The study team did not model RNG as a replacement for coal or oil (except as a replacement for chemical feedstocks), since in concept it was intended to be a direct replacement for natural gas without a change in equipment. As a replacement for oil, green hydrogen's benefits include substantial health benefits from replacing oil, which along with coal has dramatically higher health impacts than natural gas.

CCUS has very limited potential and only applies to a few subsectors. There is very little technical potential for CCUS compared to the other categories of intervention, due to its applicability being limited to a small number of very large facilities in only some subsectors. CCUS adoption occurs in industries that can benefit from federal tax credits for CCUS installations at large-emitting industrial facilities, due to improved customer economics for the CCUS measures assessed. Only the Chemicals, Non-Metallic Minerals, Petroleum, and Primary Metals subsectors had facilities that reached the emissions thresholds required for eligibility for federal 45Q tax credit. Of the CCUS technical decarbonization potential in 2042, over a quarter of it is economic.

By end use, process heating contributes the greatest decarbonization and energy savings potential. These savings come primarily from natural gas efficiency and electrification.

By subsector, the largest energy consumers contribute most of the potential at all levels. These subsectors are Primary Metals, Paper, Non-Metallic Minerals, and Chemicals.

Key measures for near-term energy and emissions savings include strategic energy management, process heat recovery, and process heat electrification measures. Strategic energy management and energy management system savings are high (together savings 17% of decarbonization potential in the Carbon Price + Enabling Investments scenario) because they affect a large share of base energy and emissions, applying across all subsectors, fuels, and end uses. Process heat recovery accounts for an additional 10% of potential in the Carbon Price + Enabling Investments scenario. Process heat electrification offers promising savings on the emissions front that will increase as the grid decarbonizes. These measures include induction heating measures in Primary Metals, resistance heat in Non-Metallic Minerals (glass), and a variety of technologies for curing and drying. Infrared, microwave, and ultraviolet technologies did not show up as large savers due to narrow applicability, but they are highly cost effective in many applications, in part due to non-energy benefits, including scheduling, cycling, and smaller footprint.

By region, the regions with greatest presence of high-consuming subsectors have the greatest decarbonization and energy savings potential. Central New York and Western New York take the top two spots for both energy and emissions savings across all scenarios, trading off for number one. Together they represent about 30% of savings potential. Central New York's savings potential is disproportionate to its share of base energy consumption, representing 10% of base use but 13% to 15% of energy savings and up to 18% of decarbonization potential, due to a high concentration of facilities in Paper, Chemicals, and Petroleum. In contrast, Long Island has the largest share of base use at 17%, but only 9% to 12% of savings potential. These differences reflect the mix of industries in each region. In the Carbon Price + Enabling Investments scenario, Central New York, Western New York, Capital Region, and Long Island together account for 47% of the manufacturing energy consumption and over half the achievable decarbonization and energy savings potential.

By disadvantaged community, savings potential depends on the concentration of manufacturing energy use in those communities and the specific types of industries. Statewide, 63% of adoption potential in the 50% Incentive scenario falls outside of DACs. In the densely populated New York City region, only 16% does.

4 Overview of methods

This section provides an overview of the methodology used to estimate the energy and decarbonization potential in the industrial sector in New York. Additional details are included in Appendix A.

4.1 Segmentation approach

The study team examined the energy and decarbonization potential by industrial segments defined by the combination of industry subsector (three-digit NAICS code), energy expenditure tier, presence of DACs, and Empire State Development Regions (see Table 4-1). The first three characteristics are defined following the recently completed Phase One Industrial Facilities Stock Assessment. This study explicitly breaks out nine manufacturing NAICS groups individually and assesses measures specific to each of these. The remaining manufacturing NAICS groups are modeled as a single subsector, the “Other” category. The study team assessed the potential in the “Other” category for broadly applicable industrial measures but not for industry-specific process measures.

Table 4-1. Study segmentation

Industrial subsector (three-digit NAICS [a])	Annual Energy Expenditure Tier	Empire State Development Region		DAC
Paper Petroleum Primary Metals Non-metallic Minerals Chemicals Food Fabricated Metals Transportation Equipment Computers and Electronics Other [b]	Tier 1: $1,000,000 and above Tier 2: $500,001-$999,999 Tier 3: less than $500,000	Capital Region Central New York Finger Lakes Long Island Mid-Hudson Mohawk Valley New York North Country Southern Tier Western New York	Inside and outside of a DAC	Inside and outside of a DAC

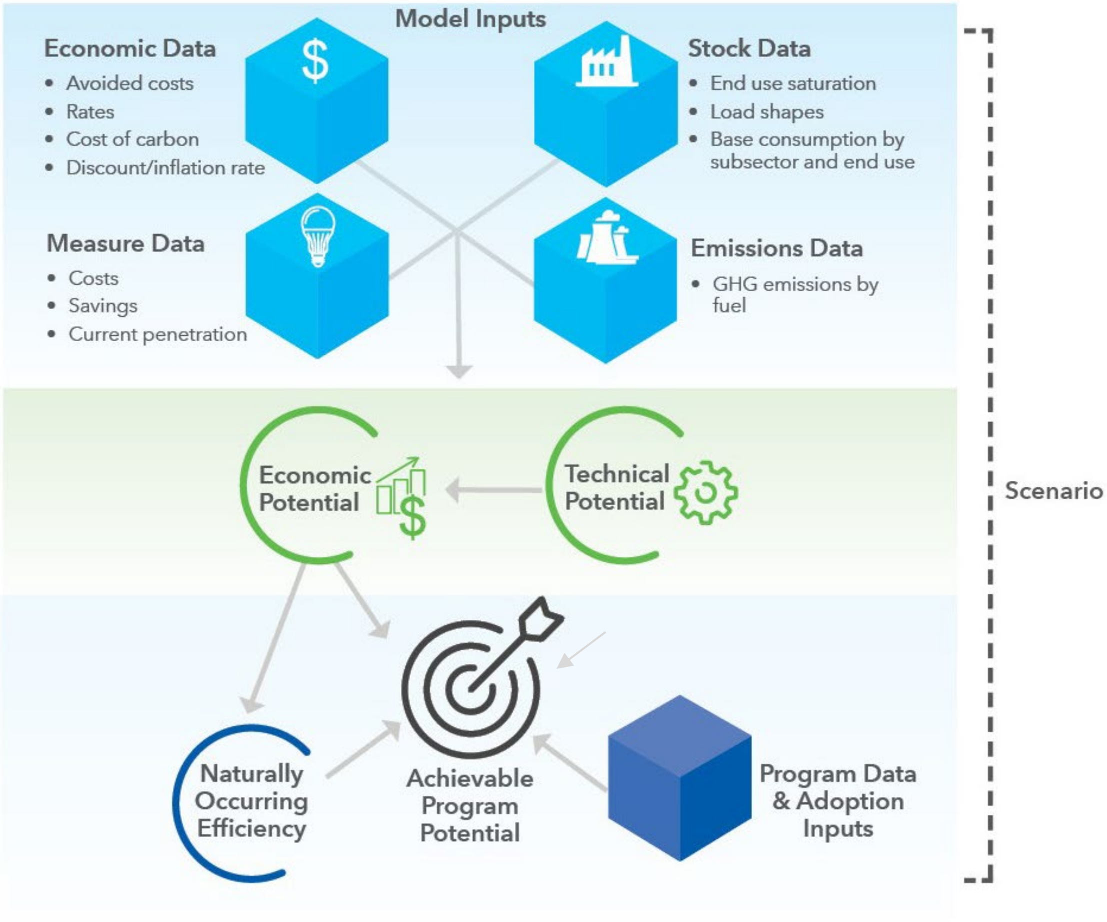
[a] NAICS is the North American Industry Classification System, a widely used system for classifying of business establishments.

[b] The following sub-sectors are bundled into a single “Other” category for the Potential Study: Beverage/Tobacco, Wood Products, Plastics/Rubber, Electrical Equipment, Machinery, Printing, Apparel, Leather, and Miscellaneous Manufacturing

4.2 Modeling overview

An energy and decarbonization potential modeling system entails a number of systematic analytical steps to produce accurate estimates of the effects of energy efficiency, electrification, low-carbon fuels, and CCUS measures on system load and greenhouse gas emissions. These potential estimates are built from the bottom up, matching energy-intensive industrial processes or equipment with alternative, low-emission technologies, and enacting these investments when it makes sense for the facility owner financially (the latter applicable only for economic and achievable potential). A simplified overview of these basic analytical steps and key inputs is shown in Figure 4-1.

Figure 4-1. Simplified conceptual overview of modeling process for estimating potentials



The first stage in the process (indicated in the top section of the figure) is the development of the inputs necessary to model energy and decarbonization potential. This stage includes the critical step of developing the list of measures to be modeled. Data development for the four categories of inputs shown in Figure 4-1 is discussed in detail in Section 4.3. Once the data is developed, the study team uses it to populate the energy and decarbonization potential model itself.

The model consists of a series of Microsoft Excel spreadsheets containing inputs or performing calculations to estimate potential. The model and its analytical steps are discussed in detail in Appendix A. The initial modeling uses inputs reflecting the team's best forecasts of the future trajectory of technology costs, rates, avoided costs, fuel availability, carbon emissions from electricity, programs, and policy. Subsequent model runs explore alternative scenarios, for example, developing savings potential under different future cost trajectories or policies.

4.3 Data development

Developing input data is a key step implemented in this study, including:

1. Develop a list of industrial decarbonization measure opportunities to include in then model. In this step, an initial draft **measure list** was developed and provided to NYSERDA and stakeholders. The final measure list was developed after incorporating comments.
2. Review industrial **stock and baseline equipment data** from NYS Industrial Stock Study, then analyze and develop information on industry characteristics by market segment, including market size (represented as total all-fuels energy consumption in this study), energy consumption and intensity by end use, end-use consumption load patterns by time of day and year (i.e., load shapes), market shares of key energy consuming equipment, and market shares of energy efficiency technologies and practices. Segmentation captures consumption by industry subsector, expenditure tier, geography, and DAC proximity. Appendix A of this report further describes the baseline data developed for this study.
3. Gather and develop **measure data** to characterize the measure and the baseline equipment (or condition) to which it applies and includes the parameters of savings (as a percent of baseline equipment consumption), costs, and expected useful life. Data on measures were gathered from a variety of sources; descriptions and details on measure inputs are provided in Appendix A.
4. Collect **economic data**: including avoided costs, cost of carbon, electric rates, forecasted fuel prices, discount rates (societal and customer), inflation rate, and line losses and leakage rates. These inputs are provided in Appendix A of this report. To the extent possible these values were matched with other New York State analyses, such as the residential and commercial buildings decarbonization potential study[24] and New York's Climate Scoping Plan.
5. Gather and develop **emissions data** to account for in-state and upstream greenhouse gas emissions from fuel combustion within New York state's industrial sector. Data includes CO_2, N_2O, and CH_4 emissions factors by fuel, with emissions factors for electricity varying over time.

Measure list. The study team looked at measures and interventions across a range of industrial end uses. The Energy Information Administration's MECS identifies 13 broad industrial end uses (shown in Table 4-2). This study uses the MECS list of end uses as a starting point for specifying industrial decarbonization measures. It is important to note that these are self-reported by facilities, and thus more than a third of reported energy use is reported as end use not defined.

Table 4-2. Industrial end uses defined by the Manufacturing Energy Consumption Survey (MECS)

Process	Non-Process	Generation/Cogeneration
Conventional Boiler Use Process Heating Process Cooling and Refrigeration	Facility HVAC Facility Lighting Other Facility Support Onsite Transportation	Combined Heat and Power and/or Cogeneration Process Conventional Electricity Generation

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[24] NYSERDA, prepared by Cadmus, Energy + Environmental Economics, and Industrial Economics Incorporated, "Assessment of Energy Efficiency and Electrification Potential in New York State Residential and Commercial Buildings," April 2023. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/building-stock-potential-studies/NYSEEandElectrificationPotentialStudyApril2023-acc.pdf

Process	Non-Process	Generation/Cogeneration
Machine Drive Electro-Chemical Processes Other Process Use	Other Non-process Use	

Source: MECS (https://www.eia.gov/consumption/manufacturing/)

The study team categorizes existing and emerging measures across the study sectors, end uses, and the decarbonization categories listed above. The four decarbonization categories are defined in the DOE Industrial Decarbonization Roadmap (2022)[25] as follows:

- **Energy efficiency**: Specific activities or technology investments a facility might undertake, or have the availability to use, improve, or manage facility or system energy consumption, including improving the performance of industrial processes, optimizing thermal heat from manufacturing processes, and using advanced data analytics to increase energy productivity in manufacturing processes. Reducing the energy consumption of the industrial sector directly reduces greenhouse gas (GHG) emissions associated with fossil fuel combustion.
- **Electrification**: Switching fossil-fuel-consuming equipment to an equivalent, efficient electrotechnology. Includes electrification of process heat, electrification of facility space heating, or replacing thermally driven processes with electrochemical ones to reduce industrial emissions from onsite combustion of fossil fuels.
- **Low-carbon fuels**: Substitution of low-carbon fuels, feedstocks, and energy sources such as hydrogen or biofuels, can further reduce combustion-associated GHG emissions for industrial processes. Low-carbon fuels are especially relevant decarbonization measures for high-temperature process heating that is challenging to electrify. This study focuses on green hydrogen and renewable natural gas when examining low-carbon fuels' decarbonization potential. Upper bounds for RNG adoption were defined by the recent RNG Potential Study[26] but no scenario approached this limit.
- **Carbon capture, utilization, and storage (CCUS)**: Capturing generated CO_2 before it can enter the atmosphere, utilizing captured CO_2 wherever possible, and storing captured CO_2 long-term. CCUS is the strategy for mitigating hard-to-abate emissions sources.

Measure data elements are discussed in further detail in Appendix A.

4.4 Data application

This section discusses how the data types described above are used for each step of the study.

4.4.1 Data application for baseline characterization

To estimate the savings potential from energy and decarbonization measures, it is necessary to understand how much energy and what equipment are currently being used. This baseline characterization begins

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[25] Department of Energy Office of Energy Efficiency & Renewable Energy, 2022, DOE Industrial Decarbonization Roadmap. https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

[26] NYSERDA prepared by ICF Resources, LLC. "Potential of Renewable Natural Gas in New York State." April 2022.

with a segmentation of NYSERDA's industrial sector for which the concurrent NYS Industrial Stock Study provided the basis. That study assesses industrial facility firmographics, location, whether the facility lies within a DAC, energy use, and clean energy opportunities to characterize New York's industrial sector. Table 4-3 shows the industrial sector segmentation in this potential study.

Table 4-3. Overview of industrial analysis segmentation

Dimension	Segmentation Variable	Description
1	Subsector	Industry classification obtained from three-digit NAICS code: Chemicals, Computer and Electronics, Food, Non-Metallic Minerals, Paper, Petroleum, Transportation Equipment, Fabricated Metals, Primary Metals, and Other
2	Expenditure Tier	Annual energy expenditure range - Tier 1 ($1,000,000+), Tier 2 ($500,001-$999,999), Tier 3 (less than $500,000)
3	Geography	Empire State Development Regions: Capital region, Central NY, Finger Lakes, Long Island, Mid-Hudson, Mohawk Valley, New York, North Country, Southern Tier, Western NY
4	DAC	Whether an industrial facility is located with a disadvantaged community
5	Vintage	Existing or new construction

To develop the baseline characterization for each segment, the study team performed the following steps:

1. Developed base year (2022) market size (defined as all-fuels MMBtu consumption by segment) and annual energy use for each market segment using the Stock Study data.
2. Used the Stock Study and secondary sources[27] to develop base equipment saturations, equipment characteristics, and process characteristics (e.g., average temperature of a process heating process) – these values are used to further break out baseline consumption by fuel type, end use, and base equipment.
3. Ensured calibration to base year values described in step 1 for annual energy use in each segment.
4. Compared and cross-checked with other recent DNV studies and internal subject matter experts.
5. Worked with NYSERDA and stakeholders to vet the data against their knowledge and experience.

The results of the baseline characterization allow the team to identify the market size, segment-level annual energy use, and annual energy intensity for each market segment.

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[27] The Stock Study breaks out consumption by end use or fuel type. While this breakout represents a useful first cut at describing how energy is being used, the study team has refined these into more granular processes or equipment so as to identify specific opportunities for savings using secondary sources. Further details on the secondary sources used are provided in Appendix A.

4.4.2 Data application for estimating measure potential impacts

The study team calculated measure potential for each subset of the industrial sector (based on the segmentation described above) and aggregated these results to estimate statewide potentials.

In this bottom-up modeling approach, first the technical potential for energy savings is estimated by integrating the market segment parameters developed in the baseline characterization and the following decarbonization measure data inputs:

1. **Equipment lifetime** is the estimate in years of a measure or equipment's useful life. Equipment is replaced according to their measure life.
2. **Not-complete factor** is the fraction of baseline equipment that has not yet been converted to the decarbonization measure; that is, 1 minus the fraction of base all-fuels energy use that already has the carbon reduction measure installed. Depending on the characteristics and specificity of the baseline equipment, the not-complete factor could be 100%. This is the case for all electrification measures, for example.
3. **Feasibility factor** is the fraction of baseline equipment for which the carbon reduction measure is technically feasible from an engineering perspective. Because our industrial analysis is not able to characterize every industrial process with precision, the study team may find, for example, that infrared drying is not feasible for all drying applications in the food industry. This factor is designed to capture factors that limit measure installation, beyond what is captured in the other factors.
4. **Savings factor** is the percent reduction in baseline end-use energy consumption or GHG emissions for the fuel impact being calculated resulting from application of the measure. In the case of energy efficiency measures, the savings factor is the percent reduction in baseline equipment energy consumption for the fuel savings being calculated resulting from the application of the efficient technology.
5. **CO_2 emissions factor** is the carbon dioxide emissions per unit of energy savings (MMBtu or kWh). If electricity emissions are modeled hourly, this factor incorporates the savings load shape for the measure.

Economic:

1. **Incremental measure costs** of each decarbonization measure are compared to the energy and carbon savings delivered by the measure over its lifetime to produce estimates of decarbonization impacts per unit of additional cost.

Appendix A: Detailed methodology

Stock and baseline data development

The concurrent NYS Industrial Stock Study provides the foundation for estimating savings potential. That study examines industrial facility firmographics, location, proximity to DACs, energy use, and clean energy opportunities to characterize New York's industrial sector. The study's geographic analysis geocodes[28] the majority (97.5%) of manufacturing facilities in the state.

The Stock Study data were adapted to align with the segmentation in this study.

- The nine specific subsectors map directly from the Stock Study to this study. The remaining 12 subsectors broken out in the Stock Study are aggregated into a single "other" category for this study.
- The Stock Study assesses facilities by three expenditure tiers, which the study team incorporated into the potential analysis without changes.
- Empire State Development Regions align with county boundaries. The existing Stock Study geocoding enables facilities and associated data to be readily mapped to these regions.
- The Stock Study assesses facilities for proximity to a DAC using a three-mile radius, which the study team has adopted for this study, so no additional analysis is required.

The Stock Study breaks out consumption into end uses using 2018 MECS results (see Table 4-2). While this breakout represents a useful first cut at describing how energy is being used, the study team has refined these into more granular processes or equipment to identify specific opportunities for savings. Since the measure list includes specific technologies (induction, infrared) that can replace conventional drying technologies. For example, the study team split out drying from the broad process heating category.

There is a large body of research on process energy use within specific industries, and the study team pulled from these secondary sources to create the breakouts necessary to support the study analysis.

A key element of this data development step was to ensure that the disaggregated (end use/equipment type) consumption adds up to top-line consumption by subsector, tier, region, and DAC proximity.

The final step in developing baseline equipment inputs was to incorporate end use load shapes and estimate demand impacts for both electricity and natural gas.

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[28] Geocoding converts a text string representing a physical location into latitude and longitude coordinates that can be visualized in geographic space, along with its associated data.

Measure data

Measure data required to estimate savings potential included:

- Measure cost (equipment, labor)
- Non-energy impacts (NEIs), including operations and maintenance (O&M) expenses
- Factors to convert costs to cost per unit of base consumption (e.g., if chiller costs are entered per ton, the factor will convert them to $/baseline all-fuels MMBtu)
- Expected useful life (EUL)
- Implementation type (retrofit, replace-on-burnout, new)
- Measure savings (% of baseline equipment consumption)
- Current measure market penetration
- Codes and standards information to inform changes to baseline efficiency over time

These inputs varied by measure and by subsector, region, or forecast year. Table A-1 summarizes how inputs vary across these model elements.

Table A-1. Input variation by measure, subsector, region, and forecast year

Measure Input	Varies by:			
	Measure	Subsector	Region	Forecast Year
Measure cost	X			
NEIs	X	X		
Cost conversion factor	X	X		
EUL	X			
Implementation type	X			
Measure savings	X		HVAC only	
Current measure market penetration	X	X		see note
Codes & standards	X			X

Note: Measure market penetration varies over the forecast horizon as an element of the stock turnover and adoption modeling. Only initial market penetration is an input to the model.

Secondary research and leveraging data sources

The study team leveraged multiple data sources. In the cases where similar data was available from two sources, they prioritized the source that is most representative of New York. Table A-2 presents the hierarchy used to systematically inventory data sources in the development of the measure list. The same protocol was followed for measure parameter development.

Table A-2. Potential study measure data source hierarchy

Priority	Source	Details
1	NYSERDA	Project information, studies, and baseline studies
2	Regional Technical Resource Manual (TRM) and Site-Specific Data	DNV and Antares internal site-specific data from regional audits and site studies, New York State TRM
3	National DOE Sources	White papers from LBNL, ENERGY STAR Industry Guides
4	DNV Industrial Practice Data and Technical Research	Internal subject matter expertise, literature review, non-regional site-specific data
5	Well-Vetted Sources Outside of Region	Illinois TRM, Northwest Power, and Conservation Council

Table A-3 contains an initial list of sources that the team has leveraged in developing the measure list and/or identified as a data source to develop measure parameters. The data sources were organized by priority, following the hierarchy described in Table A-2. Key measure parameters required for characterization in the model include savings, costs, equipment lifetime, and baseline definition. Sources with an “x” in the parameter column indicate that the source has data for that respective parameter.

Table A-3. Initial list of measure data sources

Source Name	Savings	Costs	Lifetime	Baseline
Priority 1				
New York State Energy Research and Development Authority Industrial Facilities Stock Assessment: Phase One	x			x
NYSERDA Improving Industrial Efficiency, Computer & Electronics, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Fabricated Metals, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Plastics, and Rubber Products, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Chemical Manufacturing, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Food Manufacturing, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Primary Metals, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Non-Metallic Minerals, Info Sheet	x			x
NYSERDA Improving Industrial Efficiency, Pulp and Paper, Info Sheet	x			x
Priority 2				
Antares New York On-Site or Site-Specific Data NYSERDA DOE ITP Save Energy Now, NYSERDA IPE Non-Natural Gas Fossil Fuel ECM Identification	x	x		x
DNV New York On-Site or Site-Specific Data	x	x		x

Source Name	Savings	Costs	Lifetime	Baseline
New York State Technical Resource Manual V9	x		x	x
Priority 3				
Worrell, E., P. Blinde, M. Neelis, E. Blomen, E. Masanet. 2010. Energy Efficiency Improvement and Cost Saving Opportunities for the U.S. Iron and Steel Industry: An ENERGY STAR Guide for Energy and Plant Managers. US DOE.	x	x		x
Hasanbeigi, Ali, Arens, Marlene, and Price, Lynn. 2013. Emerging Energy-efficiency and Carbon Dioxide Emissions-reduction Technologies for the Iron and Steel Industry. US DOE.	x	x		X
U.S. Department of Energy (US DOE). 2022. Industrial Decarbonization Roadmap. US DOE.	x			X
U.S. Department of Energy (US DOE). 2015. Bandwidth Study on Energy Use and Potential Energy Saving Opportunities in U.S. Pulp and Paper Manufacturing. US DOE.	x			X
Priority 4				
Thirumaran, Kiran, Nimbalkar, Sachin U., Thekdi, Arvind, and Cresko, Joe. 2019. Energy Implications of Electrotechnologies in Industrial Process Heating Systems. ACEEE Summer Study on Energy Efficiency in Industry.	x			X
Schoeneberger, Carrie, Zhang, Jingyi, McMillan, Colin, Dunn, Jennifer B., and Masanet, Eric. 2022. Electrification Potential of U.S. Industrial Boilers and Assessment of the GHG Emissions Impact. NREL.	x	x		X
DNV Industrial Agricultural Market Saturation Study for California Public Utilities Commission (CPUC)				X
Priority 5				
Illinois Technical Reference Manual Version 11	x	x	x	
Northwest Power and Conservation Council, RTF UES Workbooks	x	x		X

The study team uses the term "measure" to refer to activities and technology investments undertaken to save energy and/or reduce carbon emissions, regardless of the decarbonization category. Measures are defined and parameterized relative to a defined baseline equipment type. The measure and its baseline equipment together make up a measure pair. Table A-4 summarizes the number of measure pairs in the measure list by MECS end use category and by decarbonization category. The list is a compilation of measure pairs from the DNV measure library supplemented with additional measures that were identified in the Phase One Stock Study or by the industrial sector subject matter experts. The measure pair table identifies the set of measure pairs that the study team included in this study. Certain measures were dropped during the modeling process when the team could not find data to support the analysis.

Table A-4. Summary of measures by MECS end use and decarbonization category

MECS End Use	CCUS	Electrification	Energy Efficiency	Low-Carbon Fuels	Total by End Use
Process Heating	0	27	36	120	183
Facility HVAC	0	5	55	0	60
Machine Drive	0	0	46	0	46
Conventional Boiler Use	0	1	16	7	24
Process Cooling and Refrigeration	1	0	21	0	22
N/A (Measure relates to nonfuel energy use, feedstocks)	3	0	0	14	17
All [a]	6	0	3	0	9
Facility Lighting	0	0	8	0	8
Electro-Chemical Processes	0	0	6	0	6
Onsite Transportation	0	4	1	0	5
Other Process Use	0	0	4	0	4
Other Facility Support	0	0	1	0	1
Other Non-process Use	0	0	1	0	1
Total by Resource	**10**	**37**	**198**	**141**	**386**

[a] Measure is applied to all end uses e.g., Strategic Energy Management, Pre-Combustion Carbon Capture for Storage.

Baseline equipment was defined in broad categories. For example, the “Water Cooled Chiller” (electric) includes all chilled water-producing technologies, including centrifugal, scroll, and screw. Any of these technologies have the same function and the same types of measures apply. The use of broad categories is necessary because in most cases insufficient data is available to support a more granular analysis in the industrial sector.

A high degree of granularity is more important for end uses and equipment that make up a larger share of industrial energy use, while end uses contributing less merit more general treatment. For example, due to the importance of process heat in the Primary Metals subsector, the study team modeled electric arc furnaces as an electrification measure for blast furnaces and basic oxygen furnaces (high granularity). In contrast, lighting energy use was only a small share of industrial use, so “Lighting Controls” was included as a measure category, and there is no distinction among the types of controls.

Adjustments to old measure cost data

The study team used trends in Industrial Assessment Centers (IAC) database total cost data to adjust measure cost-per-savings information to reflect NYS costs in 2022. IAC database costs were first adjusted for inflation to represent 2022 dollars. All savings numbers were converted to MMBtu and the top ten percent of costs per savings unit were dropped to remove outliers. Additionally, measure categories not needed for this analysis and those with only one data point were dropped. The team then ran a linear model predicting cost-per-savings as a function of state, measure type, year, and the interaction of measure type and year. This allows different states and measure types to be more or less expensive overall over years. It includes an overall linear time trend for costs over time, and also a separate linear time trend for each measure type.

For most measures, the costs used are simply the prediction of this model for New York in 2022. However, in certain cases, we used this model to adjust cost data from other sources.

Notably, cost trends included increased efficiency in measure installation, which reduced costs, but increasing difficulty of saving energy, which increased costs. These trends, combined, yielded relatively flat trends in cost-per-savings.

Economic data

NYSERDA provided data to inform most of the categories of economic data required for this study or knew of sources for data that satisfy New York's regulatory oversight for studies like this one. If data did not already exist, the study team has identified the following sources to fill in any gaps:

- Inflation—Federal Reserve Bank short- and long-term inflation forecasts, Consumer Price Index
- Program costs—program filings with DPS
- Avoided cost of energy (electricity)—Locational-based marginal price (LBMP) of electricity ($/kWh) from NYISO combined with hourly impact shape
- Avoided cost of generation capacity—Installed Capacity Model based on NYISO-published data
- Avoided cost of carbon (electricity and natural gas)—New York State Department of Environmental Conservation[29]
- Regional Greenhouse Gas Initiative (RGGI) price adders—NYISO System and Resource Outlook Appendix E Data

Depending on the economic input, values may vary by region, forecast year, and hour of year (Table A-5).

Table A-5. Economic input variation by region, forecast year, and hour of year

	Region	Tier	Year of Forecast	Hour of Year
Avoided cost of GHG			X	
Electricity avoided costs				
Energy (kWh)	X		X	X
Generation capacity (kW)	X		X	
Transmission (kW)	X		X	
Distribution (kW)	X			
Natural gas avoided costs	X		X	X
Electricity rates	X	X	X	X

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[29] New York State Department of Environmental Conservation. "Establishing a Value of Carbon Guidelines for Use by State Agencies." June 2021 update. https://www.dec.ny.gov/docs/administration_pdf/vocguid22.pdf

	Region	Tier	Year of Forecast	Hour of Year
Natural gas rates		X	X	X
Other fossil fuel prices			X	
RGGI Price Adder			X	
Electricity CO_2 emissions factors	X [a]		X	X

a Electricity CO_2 emissions factors vary between upstate and downstate only, not specific regions.

Emissions data

The model can accommodate but does not require hourly CO_2 emissions factors. The study team aligned its carbon and other GHG emissions factors with the Climate Act. Emissions factors for electricity were pulled from NYSERDA's projected emissions factor for New York State grid electricity.[30]

Decarbonization potential model

Model overview

The study team used a spreadsheet-based, macro-assisted model to estimate decarbonization potential. The model consists of six workbooks. Five of these contain model inputs, broken out into load shapes and building stock inputs, measure inputs, avoided cost inputs, rate and price inputs, and emissions inputs. The sixth workbook is where the inputs are integrated, and potential is calculated. The model uses macros to assist the data integration, particularly in integrating hourly inputs (load shapes, avoided costs, and rates), as those calculations are cumbersome and slow when calculated as Excel formulas. Macros are used again in the adoption modeling, to cycle measure/segment combinations through a spreadsheet calculation engine and save the results to an output file.

The modeling consists of four key steps:

Step 1: Estimate technical potential

- Incorporate stock, baseline equipment, measure, load shape, and emissions data into the model.
- Match and integrate the various types of data to produce independent estimates of technical potential energy and carbon reduction for each measure.
- Remove double counting of potential between competing measures to create a combined estimate of technical potential.

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[30] NYSERDA. "The Projected Emission Factors for New York State Grid Electricity", annexed spreadsheet. NYSERDA,2023. Greenhouse Gas Emissions Studies - NYSERDA

Step 2: Estimate economic potential

- Incorporate economic input data including current and forecasted retail electric energy rates, current and forecasted avoided costs of energy and capacity, and the societal value of carbon reductions.
- Apply economic factors to measure savings, costs, and measure lives to calculate benefit/cost ratios from the societal and participant perspectives.
- Screen measures with independent technical potential for societal cost effectiveness.
- Remove double counting of potential between competing cost-effective measures to create a combined estimate of economic potential.

Step 3: Estimate achievable program and naturally occurring potentials

- Gather and develop estimates of program costs (e.g., for administration and marketing) and historic program participation and savings.
- Develop estimates of customer adoption of carbon reduction measures as a function of the economic attractiveness of the measures, barriers to their adoption, and the effects of program intervention.
- Estimate achievable program and naturally occurring potentials; calibrate achievable and naturally occurring potentials to recent program and market data.

Step 4: Scenario analyses and resource planning inputs

- Develop parameters for alternative scenarios of interest.
- Recalculate potentials under alternate scenarios.

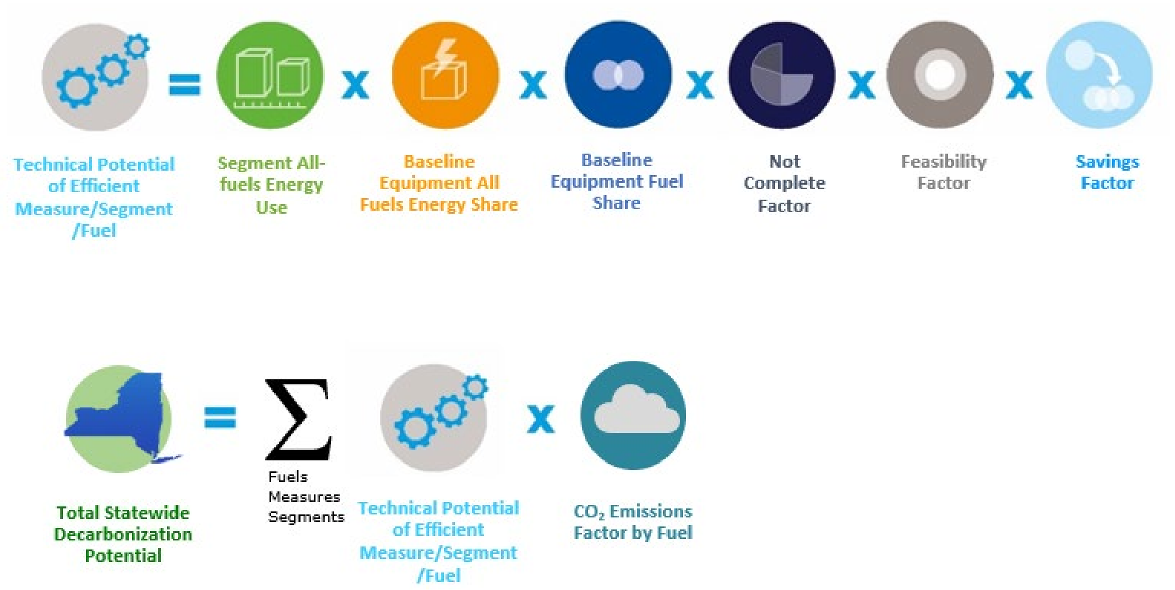
The discussion below provides further detail on the study team's modeling approaches for technical, economic, and achievable decarbonization forecasts.

Estimate technical potential

Technical potential refers to the amount of energy savings, peak demand reduction, or carbon reduction that would occur with the complete penetration of all measures analyzed in each application where they were deemed technically feasible from an engineering perspective. Total technical potential is developed from estimates of the technical potential of individual measures as they are applied to discrete market segments (defined by subsector, expenditure tier, region, and DAC proximity).

The core of the analysis is to estimate energy savings potential by fuel. Peak demand impacts and carbon impacts flow from the energy calculation through the application of load shapes and carbon emissions profiles. The core equation used to calculate the energy technical potential for each individual efficiency measure, by market segment and fuel, is shown in Figure A-1. This simplified formula does not capture the element of time in technical potential or competition between measures (these are addressed below). Energy savings potential was calculated separately for each fuel type, measure, and market segment. To estimate statewide decarbonization potential, the study team first estimated the carbon emissions associated with each calculated energy savings value, then add up the carbon savings across fuels, measures, and segments.

Figure A-1. Core equations for calculating technical potential



In the figure:

- **Segment all-fuels energy use** is the normalizing unit for the study. This is the total energy consumption in million Btu for all fuels considered in the study for a particular market segment (subsector, tier, region, DAC proximity). The study team abbreviated all-fuels energy use in MMBtu as AFMMBtu.
- **Baseline equipment all-fuels energy share** is the fraction of the base all-fuels energy use that is used by the baseline equipment; for example, the share of AFMMBtu used by electric water-cooled chillers.
- **Baseline equipment fuel** shares allocate AFMMBtu for the baseline equipment to specific fuels. If the calculation is for electricity impacts, the units are kWh per AFMMBtu. For fuels measured in MMBtu, the units are fuel MMBtu per AFMMBtu, equivalent to the share of AFMMBtu for that fuel (if the equipment uses only one fuel and is measured in Btu, the value is 1). For the water-cooled chiller example, the equipment fuel share for electricity would be the annual kWh per base all-fuels MMBtu for a standard efficiency electric water-cooled chiller, with shares for other fuels set to zero.
- **Not-complete factor** is the fraction of baseline equipment that has not yet been converted to the decarbonization measure; that is, 1 minus (the fraction of base all-fuels energy use that already has the carbon reduction measure installed). In the chiller example, this is the share of electric water-cooled chillers that are not high efficiency. Depending on the characteristics and specificity of the baseline equipment, the incomplete factor could be 100%. This is the case for all electrification measures, for example.

- **Feasibility factor** is the fraction of baseline equipment for which the carbon reduction measure is technically feasible from an engineering perspective. Because our industrial analysis will not be able to characterize every industrial process with precision, the study team may find, for example, that infrared drying is not feasible for all drying applications in the food industry. This factor is designed to capture factors that limit measure installation, beyond what is captured in the other factors.
- **Savings factor** is the percent reduction in baseline end use energy consumption or GHG emissions for the fuel impact being calculated resulting from application of the measure. In the case of energy efficiency measures, the savings factor is the percent reduction in baseline equipment energy consumption for the fuel savings being calculated resulting from application of the efficient technology.
- **CO_2 emissions factor** is the carbon dioxide emissions per unit of energy savings (MMBtu or kWh). If electricity emissions are modeled hourly, this factor incorporates the savings load shape for the measure.

For fuel switching measures, the study team has an additional factor representing the new usage of the new fuel (electricity or low-carbon fuel) as a result of the switch (not shown in Figure 4-2). New fuel energy use is calculated from old fuel savings by applying a ratio, for example, the new equipment uses 260 kWh per 1 MMBtu of natural gas used by the old equipment.

Technical potential over time

The equation in Figure A-1 represents the calculation in Year 1. For subsequent years, an internal stock accounting replaces the first five elements of the formula, which represent the energy use of the base equipment eligible for replacement by the measure. As equipment turns over or add-on measures are installed, the amount of base energy use available for replacement decreases.

The stock accounting algorithm handles capital turnover and stock decay over a period of up to 20 years. The model begins in Year 1 with the fraction of base all-fuels energy use for which each measure will apply. The input to this calculation is the total base all-fuels energy use available for the measure from the technical potential analysis, i.e., the segment all-fuels energy use multiplied by the not complete and feasibility factors described previously. The study team calls this the eligible stock. The stock algorithm keeps track of the amount of base all-fuels consumption available for each efficiency measure in each year based on the total eligible stock and whether the application is new construction, retrofit, or replace-on-failure.

Retrofit measures are available for implementation by the entire eligible stock. The eligible stock is reduced over time as a function of adoptions and facility decay. Replace-on-burnout measures are available on an annual basis, approximated at an annual rate of turnover equal to the inverse of the service life. The annual portion of the eligible market that does not accept the replace-on-burnout measure does not have an opportunity again until the end of the service life of the baseline replacement adopted instead.

New construction applications are available for implementation in the first year. The proportion of energy use that does not adopt the measure is given subsequent opportunities corresponding to whether the measure is a replacement or retrofit-type measure.

Measure competition and double counting

The study team applied the following methodology from the New York Buildings Potential Study[31] for cases where competing measures were considered, to both avoid double counting and allow some adoption of measures other than the one with the highest individual adoption rate:

1. Use the adoption model to determine the proportion p_j of base use adopting each competing measure j individually.
2. Define p_1 as the largest of the individual proportions p_j.
3. Calculate the "no-measures" proportion p0 as the complement of the maximum of the individual measures. That is, $p_0 = 1- p_1$.
4. Calculate the sum S of the individual competing measures proportions, and the sum D including the no-measures proportion. That is, for a total of m competing measures.

$$S = \sum_{i=1}^{m} p_i$$

$$D = \sum_{i=0}^{m} p_i \ = S + 1 - p_1$$

5. Calculate the adjusted proportion as

$$p'_j = p_j / D$$

The authors of the Buildings Potential Study did not address how they applied this approach when a mix of replace-on-burnout (ROB) and retrofit measures compete for the same base measure. The study team believes the above calculations must be done separately for ROB and retrofit measures to obtain sensible results in the model (since the ROB adoption percent is applied only to the share of base equipment that is turning over in a given year while retrofits are not limited in this way). Essentially ROB measures will compete only for the ROB portion of the use, while the retrofit measures compete without that restriction.

Technical potential addressing measure interaction

Where measures are not in competition, calculating technical potential is straightforward. One of the parameters of the model's adoption curves is maximum annual adoption. That parameter determines the

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[31] Assessment of Energy Efficiency and Electrification Potential in New York State Residential and Commercial Buildings. February 2023. Study available at: https://www.nyserda.ny.gov/About/Publications/Evaluation-Reports/Building-Stock-and-Potential-Studies/Assessment-of-Energy-Efficiency-and-Electrification-Potential

annual share of the remaining technically eligible building stock that will adopt each year until there are no more installation opportunities.

Where different measures compete for the same opportunities, the model determines which of the competing measures has the highest savings potential (as assessed independently, without considering competing measures). If there is a single measure with the highest potential, we calculate its potential as described above and the remaining competing measures are assigned zero technical potential. If multiple competing measures tie for the highest potential, each measure's potential is weighted by 1/n, where n is the number of tied measures within the competition group.

Estimation of economic potential

Economic potential refers to the technical potential of those energy conservation measures that are cost effective. For this study, cost effectiveness is measured by the societal cost test (SCT). The test and its application in estimating economic potential are described in the following sections. Economic potential considers that many of the modeled measures cost more to purchase initially than their standard-efficiency counterparts. The incremental costs of each decarbonization measure are compared to the energy and carbon savings delivered by the measure over its lifetime to produce estimates of decarbonization impacts per unit of additional cost.

Cost-effectiveness tests

To estimate economic potential, it is necessary to develop a method by which it can be determined that a measure or market intervention is economic. New York uses the SCT for energy efficiency program filings, and the study team uses the SCT as our primary cost effectiveness test for this study.

The SCT measures the net costs of a market intervention based on its total costs and benefits, including both the participants' and the program administrator's costs and benefits, as well as externalities (such as the cost of carbon, other environmental impacts, and public health impacts). Table A-6 summarizes the costs and benefits included in the test. The SCT uses a societal discount rate and applies to conservation, load management, and fuel substitution programs. For fuel substitution measures, the test measures the net effect of the impacts from the fuel not chosen versus the impacts from the fuel that is chosen because of the switching measure. SCT test results for fuel substitution should be viewed as a measure of the economic efficiency of a measure considering the total energy supply system, greenhouse gas impacts, and non-energy impacts.

Table A-6. Societal cost test included benefits and costs

Benefits	Costs
Generation, transmission, and distribution avoided costs Participants avoided equipment costs (fuel switching only) Value of carbon and other GHG reduction Non-energy impacts (net)	Program costs paid by the administrator Net participant measure costs [a]

[a] The increase in participant measure costs due to the market intervention, compared to the no-intervention case.

Generation, transmission, and distribution savings (hereafter, energy benefits) are defined as the economic value of the energy and demand savings stimulated by the interventions being assessed. These benefits are typically measured as induced changes in energy consumption, valued using some mix of avoided costs. Electricity benefits are valued using three types of avoided electricity costs: avoided distribution costs, avoided transmission costs, and avoided electricity generation costs. The latter include both capacity costs ($ per kW) and energy costs ($ per kWh generated).

Participant costs are composed primarily of incremental measure costs. Incremental measure costs are essentially the costs of obtaining the measure, relative to the baseline costs. In the case of an add-on device (say, an adjustable-speed drive), the incremental cost is simply the installed cost of the measure itself. In the case of equipment that is available in various levels of efficiency (e.g., a rooftop unit), the incremental cost is the excess of the cost of the high-efficiency unit over the cost of the base (reference) unit.

Administrative costs encompass the real resource costs of program administration, including the costs of administrative personnel, program promotions, overhead, measurement and study, and shareholder incentives. In this context, administrative costs are not defined to include the costs of various incentives (e.g., customer rebates and salesperson incentives) that may be offered to encourage certain types of behavior. The exclusion of these incentive costs reflects the fact that they are essentially transfer payments. That is, from a societal perspective they involve offsetting costs (to the program administrator) and benefits (to the recipient).

In addition to the SCT, the study team calculated the participant benefit-cost ratio for each measure. This B-C ratio looks at costs and benefits from the perspective of the facility, comparing life cycle costs to life cycle benefits. On the benefits side, the ratio includes bill impacts and any non-energy impacts (including O&M cost decreases). This is compared to measure costs net of any incentives. The model uses the participant benefit-cost ratio to drive its adoption algorithm since a measure with a high benefit-cost ratio is a more attractive investment than one with a low ratio.

Use of the societal cost test to estimate economic potential

The study team developed an estimate of economic potential by calculating the SCT of individual measures and applying the methodology described below.

Economic potential can be defined either inclusively or exclusively by the costs of programs that are designed to increase the adoption rate of energy efficiency, electrification, low-carbon fuels, and CCUS measures. The study team defined economic potential to exclude program costs. The team did so primarily because economic potential is meant to be unrelated to programs that aim to encourage adoption. Thus, the study team's definition of economic potential is that portion of the technical potential that passes the economic screening test (described below) exclusive of program costs. Economic potential, like technical potential, is a theoretical quantity that will exceed the amount of potential estimated to be achievable through current or more aggressive program activities.

The SCT focuses on resource savings and counts benefits as avoided supply costs and the value of carbon mitigated, and costs as measure costs and program costs (excluding incentives). The test ignores any impact on rates. The SCT also treats financial incentives and rebates as transfer payments, i.e., the SCT is not affected by incentives. The somewhat simplified benefit and cost formulas for the SCT are presented in Equations 1 and 2.

Equation 1. Societal cost test benefits calculation

$$\text{Benefits} = \sum_{t=1}^{N} \frac{Avoided\ Costs\ of\ Supply_t + Avoided\ Cost\ of\ Carbon_t + Value\ of\ Non{-}energy\ benefits_t}{(1 + \mathrm{d})^{\mathrm{t-1}}}$$

Equation 2. Societal cost test cost calculation

$$\text{Costs} = \sum_{t=1}^{N} \frac{Program\ Cost_t + Participant\ Cost_t + Non{-}energy\ Costs_t}{(1 + \mathrm{d})^{\mathrm{t-1}}}$$

Where:

d = the nominal discount rate
p = the costing period
t = time (in years)
n = 20 years

The model uses a nominal rather than real discount rate, as inflation is accounted for separately.

The avoided costs of supply are calculated by multiplying measured energy savings and peak demand impacts by per-unit avoided costs on an hourly (8760) basis. Energy savings are allocated hourly and peak impacts are estimated using load shape factors.

As noted previously, in the measure-level SCT calculation used to estimate economic potential, program costs are excluded from Equation 2.

Measure interaction and competition is modeled in the same way as for technical potential (discussed above), except that only measures passing the SCT are in competition.

Estimation of achievable and naturally occurring potentials

This section presents the method employed to estimate the fraction of the market that adopts each measure in the presence and absence of programs. The study team defines:

- *Achievable potential* as the savings potential under specific scenarios representing real-world factors that can affect customer adoption decisions.
- *Naturally occurring potential* as the amount of impact estimated to occur as a result of normal market forces, that is, in the absence of any utility or governmental intervention.

The estimates of achievable potential are typically the most important results of the modeling process. Estimating technical and economic potentials are necessary steps in the process from which important information can be obtained. However, the end goal of the process is to better understand how much of the remaining potential can be captured via programs, whether it would be cost-effective to increase program spending, and how program costs may be expected to change in response to measure adoption over time.

Adoption method overview

We use a method of estimating measure adoption that applies equally to our program and naturally occurring analyses. While some adoption modeling frameworks (for example, the Bass diffusion model) explicitly model market penetration as a function of time, this adoption model predicts annual measure adoption among available aware customers as a function of the customer's benefit/cost ratio, given specific market barriers. The absolute level of adoption, and ultimately market penetration, change over time due to changes in each of the four factors below.

- **The availability** of the adoption opportunity relative to the total base consumption a measure targets. This is a function of capital equipment turnover rates, the measure implementation type (retrofit or replace-on-failure), and changes in facility stock over time. The availability of a replace-on-failure measure is limited by the rate at which existing equipment reaches its end of life, while the entire stock of baseline equipment is available for a retrofit measure. Availability decreases over time as measures saturate the market. The more facilities adopt as a measure, the fewer remain yet to adopt. All else equal, this leads to decreased annual adoption over time as fewer and fewer facilities are left that have not yet adopted the measure.

- **Customer awareness** of the measure. Awareness of a measure increases over time both through naturally occurring channels and program interventions. All else equal, higher awareness results in higher adoption over time.
- **The cost-effectiveness** of the measure to potential adopters
    - Measure costs for some measures may be projected to fall over time, which will result in a higher **benefit-cost ratio** and higher annual adoption over time (all else equal).
    - Certain measures that are not cost effective early in the forecast may become cost effective in later years. This may be due to decreasing measure costs, but for fuel-switching measures relative fuel costs could also be a factor. For low-carbon fuels, both fuel costs and availability will come into play.
    - Program interventions may be modeled to change over time, which could increase or decrease the customer's benefit-cost ratio and, with it, adoption.
- **Market barriers** associated with the measure. Market barriers can also be modeled to decrease over time, resulting in higher annual adoption.

Modeling adoption through the channels of stock turnover, awareness, cost-effectiveness, and market barriers allows the study team to explicitly model a variety of market interventions. The market penetration forecast is the end result of the interplay between these factors as they change over time.

The stock accounting for the achievable analysis is the same as for technical potential, described above.

In our modeling framework, customers cannot adopt a measure merely because there is stock available for conversion. Before they can make the adoption choice, they must be aware and informed about the measure. Thus, in the second stage of the process, the model calculates the portion of the available market that is informed. An initial user-specified parameter sets the initial level of awareness for each measure (individually or categorically). Incremental awareness occurs in the model as a function of the amount of money spent on awareness/information building and how costly it is to reach each customer.

The model also controls for information retention. An information decay parameter in the model is used to control for the percentage of customers that will retain program information from one year to the next. Information retention is based on the target audience and the effectiveness of the marketing techniques employed.

The portion of the total market that is available and aware can now face the choice of whether or not to adopt a particular measure. Only customers for whom a measure is available for implementation (stage 1) and, of those customers, only those who have been informed about the program/measure (stage 2), are in a position to make the implementation decision.

In the third stage of the penetration process, the model calculates the fraction of the market that adopts each measure annually as a function of the participant test. The participant test is a benefit-cost ratio that is generally calculated as follows:

Equation 3. Participant cost test benefit calculation

$$\text{Benefits} = \sum_{t=1}^{N} \frac{Customer\ Bill\ Savings_t + Customer\ Non{-}energy\ Benefits_t}{(1 + \mathrm{d})^{\mathrm{t}-1}}$$

Equation 4. Participant cost test cost calculation

$$\text{Costs} = \sum_{t=1}^{N} \frac{Incremental\ Participant\ Measure\ and\ O\&M\ Costs_t - Incentives_t}{(1 + \mathrm{d})^{\mathrm{t}-1}}$$

Where:

d = the discount rate

t = time (in years)

N = measure lifetime

The bill reductions are calculated by multiplying measure energy savings and customer peak demand impacts by retail energy and demand rates.

The model uses measure implementation curves to estimate the percentage of the informed market that will accept each measure based on the participant's benefit-cost ratio. The model provides enough flexibility so that each measure in each market segment can have a separate implementation rate curve. The functional form used for the implementation curves is:

Equation 5. Implementation curve calculation

$$y = \frac{a}{1 + (4/x) \times (1 + (bx)^{-c})}$$

where:

y = the fraction of the market that installs a measure in a given year from the pool of available aware customers;

x = the customer's benefit-cost ratio for the measure;

a = the maximum annual adoption rate for the technology;

b = the inflection point of the curve. It is generally 1 over the benefit-cost ratio that will give a value of 1/2 the maximum value; and

c = the parameter that determines the general shape (slope) of the curve.

Examples of the curves utilized in the model are shown in Figure A-2. Different curves are used to reflect different levels of market barriers for different efficiency measures. The range of benefit-cost ratios shown in the chart extends beyond the level where program intervention is typically used to increase measure adoption (measures with a B/C of 30 are rapidly adopted by the market without intervention). The study team included the extended range to show how the *a* parameter (maximum annual adoption) influences the curves: Annual adoption asymptotically approaches the specified maximum as the benefit-cost ratio increases.

A list of classic market barriers is shown in Table A-7. It is the existence of these barriers that necessitates program interventions to increase the adoption of conservation measures.

Figure A-2. Primary measure implementation curves used in adoption model

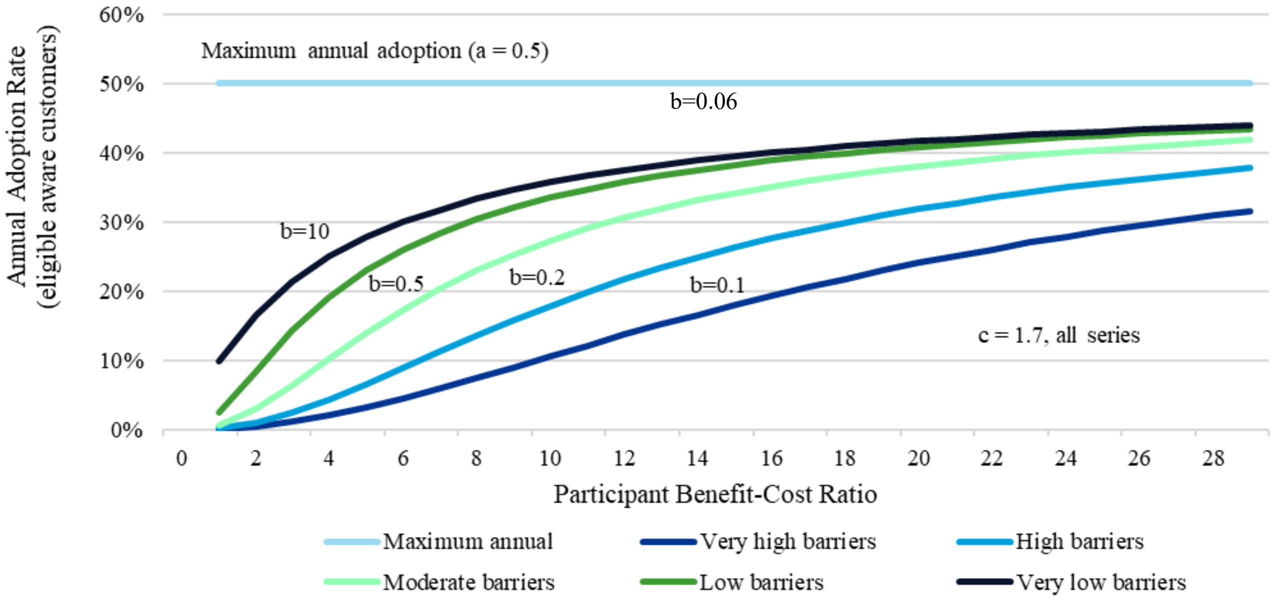

Table A-7. Summary description of market barriers from Eto, Prahl, Schlegel 1996[32]

Barrier	Description
Information or Search Costs	The costs of identifying energy-efficient products or services or of learning about energy-efficient practices, including the value of time spent finding out about or locating a product or service or hiring someone else to do so.

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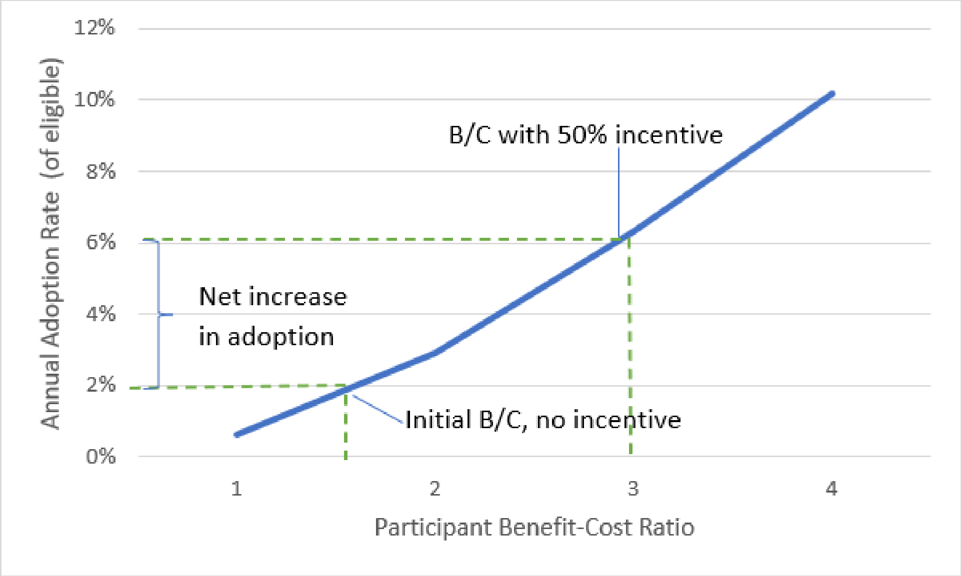
[32] Eto, Joseph H, Ralph Prahl, and Jeff Schlegel, 1996. "A Scoping Study on Energy-Efficiency Market Transformation by California Utility DSM Programs." Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA. https://eta.lbl.gov/publications/scoping-study-energy-efficiency

Barrier	Description
Performance Uncertainties	The difficulties consumers face in evaluating claims about future benefits. Closely related to high search costs, in that acquiring the information needed to evaluate claims regarding future performance is rarely costless.
Asymmetric Information and Opportunism	The tendency of sellers of energy-efficient products or services to have more and better information about their offerings than do consumers, which, combined with potential incentives to mislead, can lead to sub-optimal purchasing behavior.
Hassle or Transaction Costs	The indirect costs of acquiring energy efficiency, including the time, materials, and labor involved in obtaining or contracting for an energy-efficient product or service. (Distinct from search costs in that it refers to what happens once a product has been located.)
Hidden Costs	Unexpected costs associated with reliance on or operation of energy-efficient products or services - for example, extra operating and maintenance costs.
Access to Financing	The difficulties associated with the lending industry's historic inability to account for the unique features of loans for energy savings products (i.e., that future reductions in utility bills increase the borrower's ability to repay a loan) in underwriting procedures.
Bounded Rationality	The behavior of an individual during the decision-making process that either seems or actually is inconsistent with the individual's goals.
Organization Practices or Customs	Organizational behavior or systems of practice that discourage or inhibit cost-effective energy efficiency decisions, for example, procurement rules that make it difficult to act on energy efficiency decisions based on economic merit.
Misplaced or Split Incentives	Cases in which the incentives of an agent charged with purchasing energy efficiency are not aligned with those of the persons who would benefit from the purchase.
Product or Service Unavailability	The failure of manufacturers, distributors, or vendors to make a product or service available in a given area or market. May result from collusion, bounded rationality, or supply constraints.
Externalities	Costs that are associated with transactions, but which are not reflected in the price paid in the transaction.
Non-Externality Pricing	Factors other than externalities that move prices away from marginal cost. An example arises when utility commodity prices are set using ratemaking practices based on average (rather than marginal) costs.
Inseparability of Product Features	The difficulties consumers sometimes face in acquiring desirable energy efficiency features in products without also acquiring (and paying for) additional undesired features that increase the total cost of the product beyond what the consumer is willing to pay.
Irreversibility	The difficulty of reversing a purchase decision in light of new information that may become available, which may deter the initial purchase, for example, if energy prices decline, one cannot resell insulation that has been blown into a wall.

The model estimates adoption under both naturally occurring and program intervention situations. There are only two differences between the naturally occurring and program analyses. First, awareness differs between the two cases due to program marketing and outreach activities that increase awareness compared to the naturally occurring case. Starting naturally occurring awareness and awareness growth are tied to measure cost effectiveness. Second, in any program intervention case in which measure incentives are provided, the participant benefit-cost ratios are adjusted based on the incentives. Thus, if an incentive that pays 50% of the incremental measure cost is applied in the program analysis, the participant benefit-cost ratio for that measure will double (since the costs have been halved). The effect on the amount of adoption estimated will depend on where the pre- and post-incentive benefit-cost ratios fall on the curve. This effect is illustrated in Figure A-3.

Figure A-3. Illustration of effect of incentives on adoption level as characterized in implementation curves



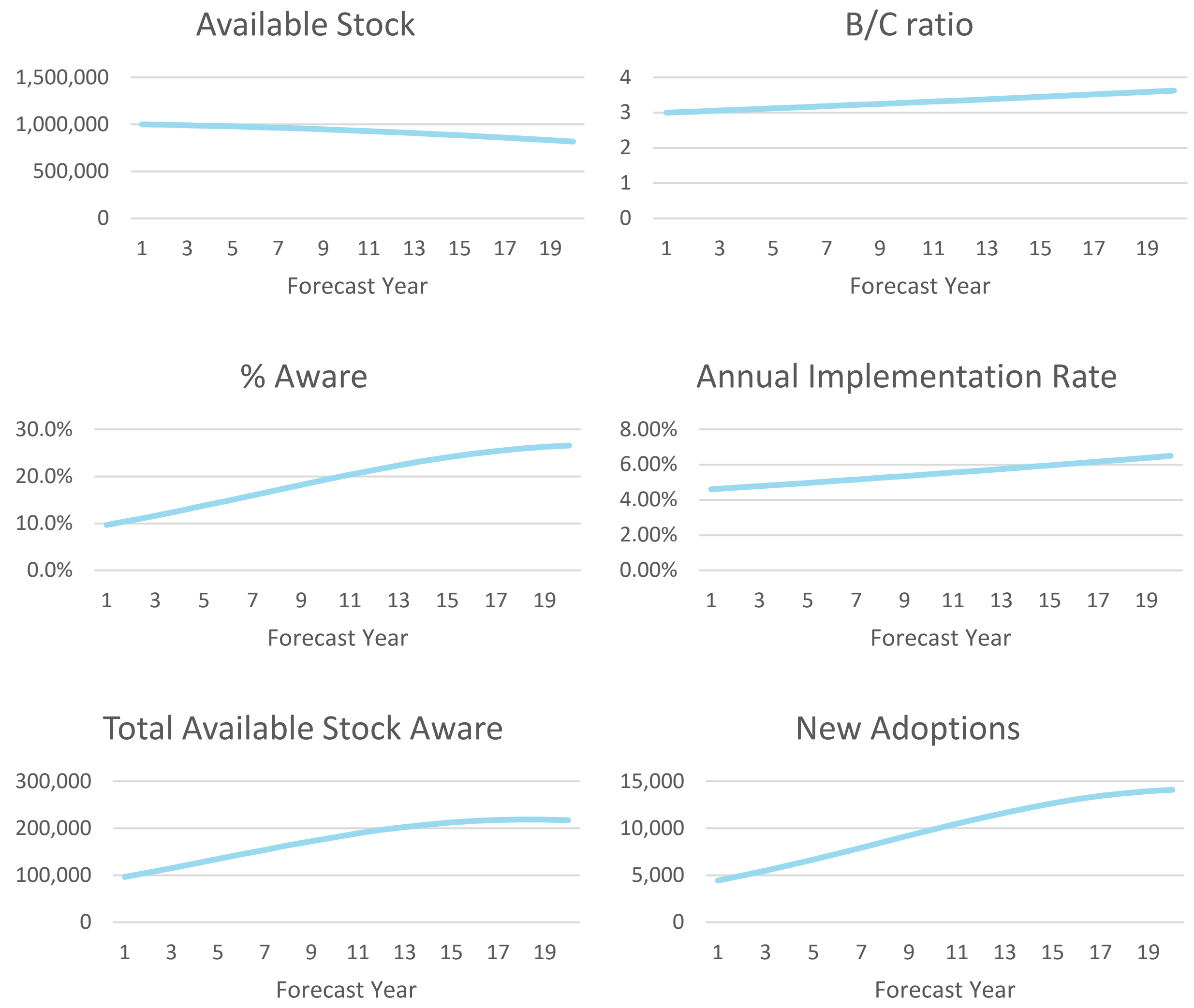
Adoption over time

Figure A-4 provides a graphical example of how the various elements of the adoption modeling process interact. The numbers are for illustration only and don’t represent a specific subsector. The left column shows the available stock, percent aware, and the total available aware stock.

- Available stock declines over time as customers adopt the measure and are therefore no longer available to install the measure.
- Percent awareness grows over time due to a combination of naturally occurring increases in awareness and the effects of program marketing

- The total available awareness stock combines these two factors. Because in this example increases in awareness aren't large enough to offset the decreases in the available stock, this curve flattens over time and the available aware stock starts to decline in years 19 and 20 of the forecast.

Figure A-4. Adoption modeling example



The right-hand column shows the customer benefit-cost ratio, the annual implementation rate, and finally, the overall new adoptions.

- The study team assumed that the benefit-cost ratio increases over the forecast period due to declining measure costs.
- The annual implementation rate increases, driven by improving measure economics.
- Applying the annual implementation rate to the total available stock awareness results in a forecast of new adoptions that have a modest S shape. At first, adoptions increase at an increasing rate, but the curve hits an inflection point, in year 9 in the example. Adoption continues to increase but at a

decreasing rate. With a longer forecast horizon (or with higher rates of adoption), annual adoption would eventually start to decline.

Scenarios

Once the model is set up with the base modeling assumptions, the study team reran the model to estimate potential under different scenarios. The scenarios are described in Section 1.2.

Disadvantaged communities

The study team included DAC (in or out) as one element of the facility segmentation. Facilities located within a DAC are analyzed separately from those located outside of any DAC, allowing easy reporting of overall savings or decarbonization potential that impact one or more DACs. This approach is focused on facilities and does not capture the additive impacts on a DAC that is near multiple industrial facilities.

Assessing the savings potential of a particular DAC requires a geographic analysis. Fortunately, the Phase One Stock Study included a GIS analysis that includes an assessment of which facilities are within each DAC, their aggregate emissions affecting the DAC, and the emissions share for each facility. That analysis is not intended to be accurate at the individual facility level but is meaningful in aggregate. This study analysis will use the geographic analysis from the Stock Study to identify potential reductions to emissions within a DAC, in aggregate.

To use this rich analysis for the potential study, the study team needed to map the segment level (combined subsector, expenditure tier, Empire State Development Region, and DAC proximity) results of the potential analysis back to the facility level. The Stock Study and this study's baseline analysis break out base energy use by segment based on facility-level analysis. Based on that mapping, the study team allocated savings potential for each segment to facilities within that segment in proportion to their base energy consumption. Due to the segment-level resolution of this study, this approach will not accurately capture differences in potential at the facility level and may therefore over- or understate DAC-level savings potential.

Fuel subsidy assumptions for the Carbon Price + Enabling Investments scenario

Under the Carbon Price + Enabling Investments scenario, the analysis assumes the same carbon price as in the Carbon Price scenario, and assumes substantial investments in incentives, infrastructure, and informational programs. For low carbon fuels, "incentives" take the form of price subsidies for the fuel. The analysis team considered a few different ways to structure these.

1. **Low subsidies.** Subsidize both hydrogen and RNG up to the lower societal value of the avoided carbon, which is the same societal value as is used to determine the economic potential for this scenario. That is, subsidize both fuels up to the point where each is economic from a societal

perspective. This approach has logical merit, but results in essentially no adoption of either fuel. That is, even with the carbon price and socially economic subsidies, these fuels are not cost-effective for customers.

2. **High subsidies.** Subsidize both hydrogen and RNG up to the higher societal value of the avoided carbon, which is greater than the societal value of carbon used to determine the economic potential for this scenario. Independent of the subsidy, no RNG passes the SCT but some green hydrogen does in cases where it replaces fuels with high societal health impacts. The rationale for subsidies or incentives beyond the level of societal cost-effectiveness is that some portion of the portfolio can be non-cost-effective provided the overall portfolio is cost-effective. The high subsidy approach results in very high levels of RNG adoption, to the point where the overall portfolio would not be cost-effective. Hence, this approach can’t be justified.
3. **Mixed Subsidies.** Subsidize hydrogen at the higher societal value of the avoided carbon, and subsidize RNG at the lower societal value. Hydrogen is modeled as a replacement for coal, oil, and natural gas, and most of its adoption in the high subsidy case is to replace oil, while RNG primarily replaces conventional natural gas. Reducing oil consumption has substantially higher health benefits than reducing natural gas, which could justify the higher incentive basis for hydrogen compared to RNG. In practical terms, the mixed approach results in some low carbon fuel adoption, but not enough to make the overall portfolio non-cost-effective, making the approach a reasonable balance. However, the mixed approach results in green hydrogen adoption, but no RNG. ***This is the approach followed in Carbon Price + Enabling Investments results reported.***

In practice, an actual program to promote low carbon fuels would likely develop an alternative subsidy approach that encourages some adoption of both green hydrogen and RNG, within an overall cost-effective investment portfolio. The scenario using the mixed subsidies is designed to demonstrate that some level of low-carbon-fuel adoption can be achieved within overall cost-effectiveness.

Appendix B: Separate technical and economic potential by decarbonization category

To assess the effect of competition between measures on the relative savings by category, the study team estimated potential for each category in isolation—that is, assuming measures in the other decarbonization categories were not available. Table B-1 presents the technical emissions savings potential for these standalone runs compared to the technical potential developed with all measures in competition. Absent competition from the other categories, energy efficiency is 42% higher, electrification is 27% higher, and low carbon fuels are 12% higher. There was no change to CCUS when run in isolation.

Table B-2 shows the corresponding economic results. The standalone analysis produced only a slight increase in energy efficiency potential (0.7%) and a negligible increase to electrification potential starting in 2038, with no change to low carbon fuels or CCUS.

Table B-1. Comparison of standalone emissions savings technical potential by category to technical potential with competition, MtCO2e

	Competition Results				Standalone Results			
	Energy Efficiency	Electrification	Low carbon fuels	CCUS	Energy Efficiency	Electrification	Low carbon fuels	CCUS
2023	188,348	43,282	84,408	0	200,438	43,368	84,408	0
2024	764,933	87,827	177,089	0	786,831	88,005	177,630	0
2025	1,001,865	131,229	276,299	0	1,032,138	131,506	278,164	0
2026	1,116,753	178,313	481,761	1,912	1,154,428	178,698	488,576	1,912
2027	1,152,590	228,886	726,927	4,705	1,200,900	230,240	742,868	4,705
2028	1,087,908	289,102	1,000,997	8,405	1,149,042	292,855	1,032,028	8,405
2029	1,071,001	339,069	1,294,769	12,768	1,146,333	346,850	1,345,007	12,768
2030	1,016,609	391,491	1,596,517	17,803	1,107,796	405,433	1,671,680	17,803
2031	956,472	442,077	1,897,586	23,357	1,064,228	464,517	2,002,561	23,357
2032	887,706	491,825	2,187,493	29,295	1,012,010	525,241	2,326,502	29,295
2033	813,972	540,116	2,457,813	35,442	955,623	586,970	2,633,864	35,442
2034	743,719	585,379	2,703,312	41,627	902,921	647,905	2,918,078	41,627
2035	684,418	626,127	2,922,073	47,681	860,442	706,164	3,175,121	47,681
2036	639,531	661,814	3,113,857	53,484	830,209	760,860	3,404,402	53,484
2037	606,761	693,087	3,279,027	58,912	809,786	812,093	3,604,006	58,912
2038	583,017	721,006	3,428,509	63,897	797,049	860,123	3,774,310	63,897
2039	567,525	746,516	3,543,143	68,406	788,846	905,883	3,917,026	68,406
2040	558,992	769,962	3,636,136	72,401	784,168	949,510	4,034,060	72,401
2041	553,654	791,644	3,709,638	75,861	782,172	991,070	4,127,862	75,861
2042	549,513	812,092	3,767,393	78,828	781,592	1,031,210	4,202,090	78,828

Table B-2. Comparison of standalone emissions savings economic potential by category to economic potential with competition, MtCO2e

	Competition Results				Standalone Results			
	Energy Efficiency	Electrification	Low carbon fuels	CCUS	Energy Efficiency	Electrification	Low carbon fuels	CCUS
2023	168,170	37,696	1	0	168,170	37,696	1	0
2024	503,209	76,330	3	0	503,195	76,330	3	0
2025	666,452	113,208	4	0	666,427	113,208	4	0
2026	756,247	151,901	20,270	5	756,239	151,901	20,270	5
2027	800,119	191,632	48,162	12	800,175	191,632	48,162	12
2028	789,668	236,177	82,094	20	789,888	236,177	82,094	20
2029	799,167	274,858	120,246	31	799,521	274,858	120,246	31
2030	787,596	314,663	160,827	43	788,145	314,663	160,827	43
2031	771,222	353,959	202,172	56	771,991	353,959	202,172	56
2032	749,258	393,285	242,769	70	750,274	393,285	242,769	70
2033	724,488	432,696	281,179	84	725,840	432,696	281,179	84
2034	699,897	470,963	316,395	98	701,638	470,963	316,395	98
2035	679,415	507,953	352,776	1,731	681,571	507,953	352,776	1,731
2036	664,483	543,233	385,042	6,060	667,035	543,233	385,042	6,060
2037	654,142	576,542	412,865	10,166	657,063	576,542	412,865	10,166
2038	647,467	607,943	436,149	13,984	650,768	607,960	436,149	13,984
2039	643,896	638,037	455,510	17,463	647,543	638,070	455,510	17,463
2040	642,176	666,893	470,919	20,563	646,103	666,926	470,919	20,563
2041	641,712	694,471	484,637	21,557	645,932	694,503	484,637	21,557
2042	642,831	721,262	495,061	22,410	647,427	721,293	495,061	22,410

Appendix C: Results by region, DAC proximity, and expenditure tier

Results by region

Table C-1. Emissions and energy savings by region, 50% Incentive scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
Capital Region	4	12	16	20
Central New York	7	23	35	41
Finger Lakes	2	6	9	12
Long Island	6	14	17	21
Mid-Hudson	3	9	14	17
Mohawk Valley	5	16	24	27
New York City	7	15	19	24
North Country	5	13	20	25
Southern Tier	2	6	9	11
Western New York	6	17	26	32
Total Cumulative Savings (thousand MTCO2e)	**48**	**132**	**190**	**229**
Cumulative Energy Savings (million MMBtu)				
Capital Region	0.05	0.17	0.30	0.37
Central New York	0.07	0.27	0.46	0.55
Finger Lakes	0.02	0.08	0.17	0.23
Long Island	0.06	0.19	0.35	0.43
Mid-Hudson	0.03	0.12	0.24	0.30
Mohawk Valley	0.05	0.19	0.30	0.34
New York City	0.06	0.19	0.32	0.39
North Country	0.05	0.16	0.27	0.33
Southern Tier	0.02	0.08	0.15	0.19
Western New York	0.06	0.22	0.43	0.54
Total Cumulative Savings (million MMBtu)	**0.48**	**1.68**	**2.99**	**3.67**

Table C-2. Emissions and energy savings by region, IRR Incentive scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
Capital Region	5	13	17	21
Central New York	7	23	35	40
Finger Lakes	2	6	9	12
Long Island	7	14	18	21
Mid-Hudson	3	10	14	17
Mohawk Valley	5	16	23	26
New York City	7	15	19	24
North Country	5	13	20	24
Southern Tier	3	6	9	11
Western New York	6	18	26	32
Total Cumulative Savings (thousand MTCO2e)	**50**	**135**	**191**	**228**
Cumulative Energy Savings (million MMBtu)				
Capital Region	0.05	0.18	0.32	0.39
Central New York	0.08	0.27	0.46	0.54
Finger Lakes	0.02	0.09	0.18	0.23
Long Island	0.06	0.20	0.36	0.45

	2025	2030	2037	2042
Mid-Hudson	0.03	0.13	0.24	0.31
Mohawk Valley	0.05	0.19	0.29	0.33
New York City	0.06	0.20	0.33	0.40
North Country	0.05	0.16	0.27	0.33
Southern Tier	0.03	0.08	0.15	0.19
Western New York	0.06	0.23	0.44	0.55
Total Cumulative Savings (million MMBtu)	**0.50**	**1.73**	**3.05**	**3.72**

Table C-3. Emissions and energy savings by region, Carbon Price + Enabling Investments scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
Capital Region	7	20	30	37
Central New York	9	32	45	51
Finger Lakes	3	10	15	19
Long Island	8	21	29	36
Mid-Hudson	4	15	26	33
Mohawk Valley	6	21	28	32
New York City	8	20	28	35
North Country	6	19	28	33
Southern Tier	3	9	13	16
Western New York	7	27	42	52
Total Cumulative Savings (thousand MTCO2e)	**63**	**192**	**285**	**344**
Cumulative Energy Savings (million MMBtu)				
Capital Region	0.08	0.27	0.48	0.59
Central New York	0.09	0.37	0.60	0.69
Finger Lakes	0.03	0.14	0.27	0.35
Long Island	0.08	0.29	0.53	0.65
Mid-Hudson	0.04	0.19	0.39	0.50
Mohawk Valley	0.07	0.24	0.35	0.40
New York City	0.08	0.25	0.43	0.53
North Country	0.07	0.23	0.37	0.43
Southern Tier	0.03	0.12	0.21	0.26
Western New York	0.08	0.35	0.66	0.81
Total Cumulative Savings (million MMBtu)	**0.64**	**2.45**	**4.31**	**5.22**

Results by DAC proximity

Table C-4. Emissions and energy savings by DAC, 50% Incentive scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
DAC	15	46	69	83
NonDAC	32	86	121	145
Total Cumulative Savings (thousand MTCO2e)	**48**	**132**	**190**	**229**
Cumulative Energy Savings (million MMBtu)				
DAC	0.16	0.56	0.98	1.20
NonDAC	0.33	1.12	2.00	2.47
Total Cumulative Savings (million MMBtu)	**0.48**	**1.68**	**2.99**	**3.67**

Table C-5. Emissions and energy savings by DAC, IRR Incentive scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
DAC	16	47	69	83
NonDAC	34	89	122	145
Total Cumulative Savings (thousand MTCO2e)	**50**	**135**	**191**	**228**
Cumulative Energy Savings (million MMBtu)				
DAC	0.16	0.57	1.00	1.21
NonDAC	0.34	1.16	2.05	2.51
Total Cumulative Savings (million MMBtu)	**0.50**	**1.73**	**3.05**	**3.72**

Table C-6. Emissions and energy savings by DAC, Carbon Price + Enabling Investments scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
DAC	20	66	103	124
NonDAC	42	126	182	220
Total Cumulative Savings (thousand MTCO2e)	**63**	**192**	**285**	**344**
Cumulative Energy Savings (million MMBtu)				
DAC	0.21	0.80	1.40	1.68
NonDAC	0.43	1.64	2.91	3.54
Total Cumulative Savings (million MMBtu)	**0.64**	**2.45**	**4.31**	**5.22**

Results by energy expenditure tier

Table C-7. Emissions and energy savings by tier, 50% Incentive scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
Tier 1	41	112	163	194
Tier 2	1	3	5	7
Tier 3	6	17	22	27
Total Cumulative Savings (thousand MTCO2e)	**48**	**132**	**190**	**229**
Cumulative Energy Savings (million MMBtu)				
Tier 1	0.41	1.39	2.36	2.83
Tier 2	0.01	0.04	0.10	0.14
Tier 3	0.06	0.25	0.52	0.69
Total Cumulative Savings (million MMBtu)	**0.48**	**1.68**	**2.99**	**3.67**

Table C-8. Emissions and energy savings by tier, IRR Incentive scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
Tier 1	42	114	163	193
Tier 2	1	3	5	7
Tier 3	7	18	22	28
Total Cumulative Savings (thousand MTCO2e)	**50**	**135**	**191**	**228**
Cumulative Energy Savings (million MMBtu)				
Tier 1	0.43	1.42	2.40	2.86
Tier 2	0.01	0.05	0.10	0.15
Tier 3	0.06	0.26	0.55	0.72
Total Cumulative Savings (million MMBtu)	**0.50**	**1.73**	**3.05**	**3.72**

Table C-9. Emissions and energy savings by tier, Carbon Price + Enabling Investments scenario, selected years

	2025	2030	2037	2042
Cumulative Emissions Savings (thousand MTCO2e)				
Tier 1	53	160	238	282
Tier 2	1	5	10	15
Tier 3	8	27	37	47
Total Cumulative Savings (thousand MTCO2e)	**63**	**192**	**285**	**344**
Cumulative Energy Savings (million MMBtu)				
Tier 1	0.55	1.98	3.31	3.91
Tier 2	0.01	0.07	0.18	0.26
Tier 3	0.08	0.39	0.82	1.05
Total Cumulative Savings (million MMBtu)	**0.64**	**2.45**	**4.31**	**5.22**