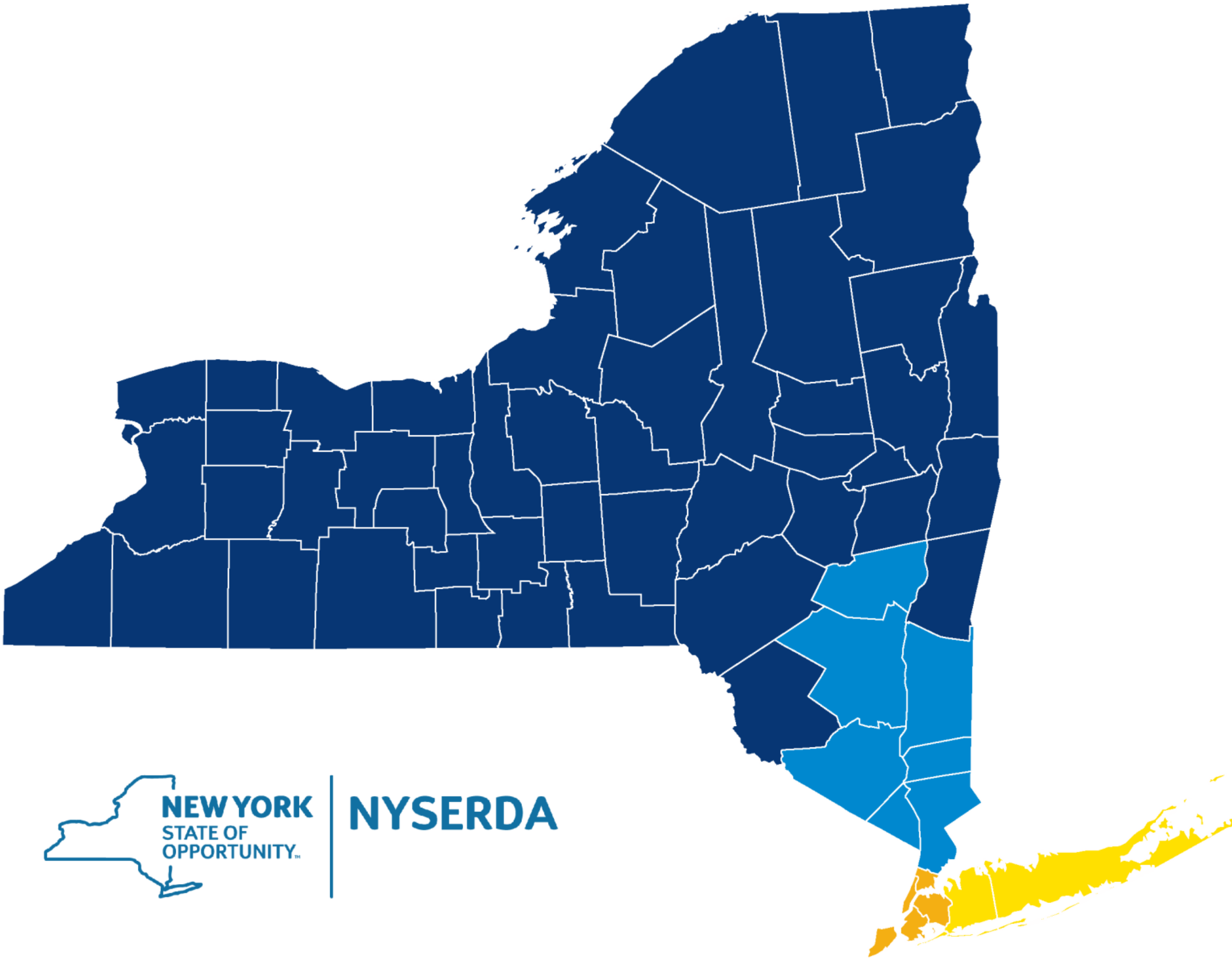

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Methodology Appendix

Assessment of Energy Efficiency and Electrification Potential in New York State Residential and Commercial Buildings

April 2023

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New York State Energy Research and Development Authority

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Notice

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition
ASHP	Air-source heat pump
ATWHP	Air-to-water heat pump
BCA	Benefit/cost analysis
BEEM	Building Efficiency and Electrification Model
CARIS	Congestion Assessment and Resource Integration Study
CEE	Consortium for Energy Efficiency
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Coefficient of performance
DEC	Department of Environmental Conservation
DOAS	Dedicated outdoor air system
DOE EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Technology
DPS	New York State Department of Public Service
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EUL	Effective useful life
gpm	Gallons per minute
GSHP	Ground-source heat pump
HVAC	Heating, ventilation, and air conditioning
HCR	New York State Homes and Community Renewal
IRR	Internal rate of return
kWh	Kilowatt hours
LBMP	Locational-based marginal pricing
LED	Light emitting diode
LMI	Low- and moderate-income
MMBtu	Million British thermal units
N_20	Nitrogen oxide
NYS	New York State
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and maintenance
PSEG	Public Service Electric & Gas Company
RBSA	Residential Building Stock Assessment
PCAF	Peak capacity allocation factor
PTHP	Packaged thermal heat pump
RGGI	Regional Greenhouse Gas Initiative
SASE	Seasonal average system efficiency
SCT	Societal cost test
SEDS	State Energy Data System
SEER	Seasonal energy efficiency ratio
TBtu	Trillion British thermal units
TDSE	Temperature derated system efficiency
TRM	Technical reference manual
VFD	Variable frequency drive
VRF	Variable refrigerant flow
VSD	Variable speed drive

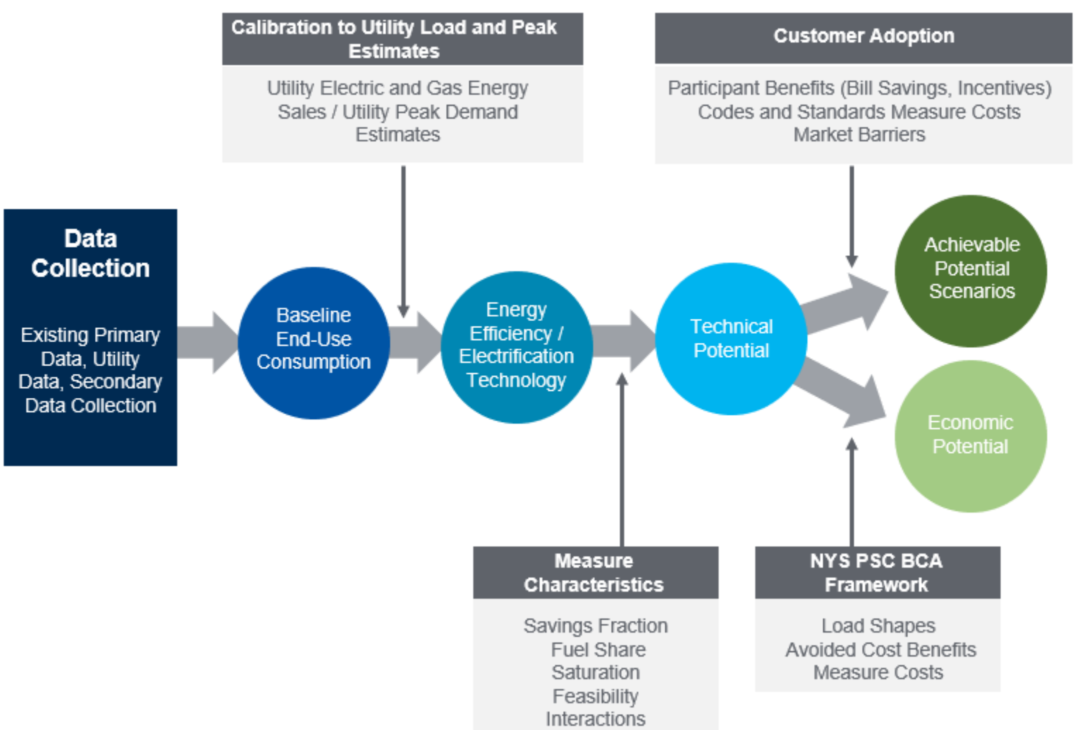
1 Overview Analysis Methodology

This appendix provides details regarding the methodology for the *Assessment of Energy Efficiency and Electrification Potential in New York State Residential and Commercial Buildings* study (revised April 2023). It describes the study's energy efficiency and electrification potential types, scenarios and scenario assumptions, energy efficiency and electrification measures and data sources used to characterize them, and the potential modeling approach.

Broadly, the methodology for this potential study relied on building stock and building energy consumption estimates, which were aggregated to estimate utility, regional, and statewide energy sales. The estimated sales values were then calibrated to individual utility sales data. The study then estimated technical, economic, and achievable potential by accounting for equipment turnover in the building stock. At each point of turnover, the study assumed an opportunity for a residential or commercial customer to install an energy efficiency or electrification measure alternative (in place of less efficient, business-as-usual options that are based on federal equipment standards, or on existing energy codes for new construction). For this study, equipment turnover was based on specific, measure-level replacement cycles.

Figure 1-1 provides an overview of the methodology used in the potential study and is followed by an explanation of the steps in the methodology.

Figure 1-1. General Methodology for Assessing Energy Efficiency and Electrification Potential



As illustrated in the figure, the first step of the study was to build a calibrated statewide energy sales profile based on building stock data and estimates of building energy use. The next step was to identify and characterize the energy efficiency and electrification measures. **Technical potential** is the maximum feasible potential, assuming that a building adopts the highest-saving measure at each turnover opportunity. **Achievable potential** accounts for customer choices under different scenario assumptions. **Economic potential** accounts for installations that are cost-effective according to the New York State (NYS) Public Service Commission's Benefit/Cost Analysis (BCA) Framework.

This study assumed that energy efficiency and electrification measures are adopted by customers over typical replacement cycles, which vary by measure and sector. In the study, shell upgrade packages are considered every 10 years in residential buildings (roughly corresponding to the sale or refinancing of a building) and every 25 years in commercial buildings (on a cycle for major capital improvements). In *Chapter 3 Building Segmentations and Measures*, Table 3-9, Table 3-10, and Table 3-11 provide replacement cycles for each building sector's measure groups.

The study used the NYSERDA in-house Building Efficiency and Electrification Model (BEEM). The BEEM toolset encompasses a specific set of measure packages selected to represent the most common energy and efficiency measures that can be installed in buildings. BEEM estimates annual adoption of measures or measure groups based on a combination of return on investment and non-economic barriers to adoption.

2 Levels of Potential and Scenarios

This potential study presents estimates of the energy and demand impacts of adopting energy efficiency and electrification measures in New York State for three potential scenarios: technical, economic, and achievable. The potential estimates represent energy savings that New York State could achieve beyond the impacts of federal equipment standards and currently enacted building energy codes. The study did not consider program potential, which would require a more detailed examination of rebate levels, marketing and administration expenditures, and the possible measure mix that New York State utilities and statewide initiatives can offer, including measures that are not cost-effective.

2.1 Technical Potential

Technical potential assumes that the highest-saving, technically feasible energy efficiency and electrification measures generally available at the time of the study will be implemented regardless of their costs or of any market barriers. This theoretical upper bound of energy savings potential is estimated after accounting for technical constraints. The technical potential approach assumes that measure replacement cycles dictate when a customer decides to upgrade to the measure.

Figure 2-1 shows the equation for calculating technical potential.

Figure 2-1. Technical Potential Equation Example

Where:

- **Applicable buildings** is the number of building units or building area applicable to a given measure, as determined by the site segmentation factoring in turnover, end-use saturations, fuel saturations, and measure penetration.
- **Feasibility factor** is the proportion of applicable units (homes or buildings) that can receive the measure. It accounts for technical limitations of installing the measure.
- **Measures per building** is the average number of measures in a household and building (such as 1.2 refrigerators per home).
- **Measure energy savings** is the amount of energy saved per measure installation, calculated by multiplying the existing or counterfactual end-use load by the percentage improvement due to the measure installation.[1]

[1] Counterfactuals represent the equipment a customer would have installed if they had not installed the efficiency measure.

There are several technical potential considerations:

- Technical potential is calculated irrespective of economics and market uptake. It does not include a benefit/cost screen or a customer adoption methodology; instead, it assumes that all sites with an applicable measure opportunity for upgrade receive that upgrade.
- Technical potential avoids double-counting of savings. For measures with multiple efficiency levels (such as seasonal energy efficiency ratio [SEER] 15 and SEER 18), technical potential will include only the highest-saving efficiency level. In the case of feasibility-constrained higher-efficiency levels, such as for deep shell measures, the lower-efficiency measure (basic shell) can be installed in the remaining applicable building stock.
- Sites are counted only once for each measure, which means the same site cannot receive potential for the same measure after the first measure installation reaches the end of its useful life.
- The model used in the study accounts for interactive effects between measures in the same measure package (for example, in a “shell + HVAC upgrade” measure package, shell improvements affect HVAC equipment upgrade savings). The study also accounted for interactive effects between measure packages. The potential study accounted for measure interactions in post-installation processing by stacking measures that interact in the order of their cost-effectiveness and reducing the building load by the savings of the preceding measures in the stack.

  For example, wall insulation that saves 10% of space heating consumption has a final percentage of 5% of the end use saved, assuming an overall applicability of 50%. This percentage represents the baseline consumption that the measure saves in an average building.

Technical potential accounts for assumed building stock conditions and the existing New York State Building Code and Federal appliance standards. Details on these, and other measure characteristics are in section *3.3.3 Measure Database*.

2.2 Economic Potential

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. The BCA Framework includes the energy-related costs and benefits experienced by the utility system, the incremental costs of energy efficiency and electrification measures, and the value of benefits associated with avoided emissions of greenhouse gases and air pollutants. For each energy efficiency and electrification 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 nominal societal discount rate of 5.76%.

2.2.1 Economic Potential Cost-Effectiveness Test

Economic potential represents a subset of technical potential, consisting only of measures that meet cost-effectiveness criteria. The study used the primary cost-effectiveness test adopted under the NYS Public Service Commission’s BCA Framework, the societal cost test (SCT). When a high-saving measure does not pass the SCT, the next highest-saving, competing measure is considered for the SCT.

The following lists the components considered in calculating benefit/cost ratios to develop the economic potential. The lifetime benefits and costs were calculated using a societal discount rate of 5.75% (as set by the NYS Department of Public Service).

2.2.1.1 Cost Components

The BCA Framework considers three main costs: incremental capital, incremental operations and maintenance (O&M), and additional electricity:

- **Incremental capital cost** represents the additional upfront costs associated with the installed electrification and efficiency measures, above the costs of corresponding counterfactual equipment. The incremental capital cost is based on the cost inputs described in section *3.3.3*.
- **Incremental O&M** represents the additional operating and maintenance costs associated with the installed measures, above the corresponding O&M costs for counterfactual equipment.
- **Additional electricity cost** is the incremental wholesale cost of electricity to serve electric loads. Though shell measures reduce the electricity load, heat pump devices increase electrical load compared to counterfactual HVAC equipment; therefore, across a portfolio of measures, net additional electricity costs are reflected on the cost side of the SCT.

2.2.1.2 Benefit Components

The BCA Framework includes six main benefits: avoided fuel cost, electric peak reduction, gas peak reduction, health value, additional low- and moderate-income (LMI) health value, and greenhouse gas reduction value.

- **Avoided fuel cost** represents the costs that would otherwise be incurred to serve the counterfactual equipment. By installing a measure technology instead of the counterfactual equipment (and for heat pumps, incurring electricity costs as described in the previous section), the counterfactual fuel costs are avoided. The U.S. Energy Information Administration (EIA) wholesale price forecasts for each fuel type are used in the calculation of avoided fuel cost.
- **Electric peak reduction** represents the extent to which measures, such as shell improvements, reduce the electricity system's consumption during peak hours. In addition, heat pumps can help reduce summer peak load compared with less efficient air conditioning units. This benefits the electricity system as less capacity is required to serve peak load, and fewer distribution system upgrades are needed. It is important to note that heat pumps may eventually *increase* the electricity system's winter peak, which would make this component a cost rather than a benefit.
- **Gas peak reduction**, similar to the electric peak reduction, represents the replacement of equipment fueled by natural gas with electric measures to allow for benefits to the gas system. This benefit occurs because of avoided upstream fixed costs and distribution capacity reductions.

- **Health values** are the societal benefits in the BCA Framework for the two health values described briefly below. Appendix G in the *New York State Climate Action Council Scoping Plan* (December 2022) provides more detailed information on health values.[2]
  - **Ambient air quality health value.** Adopted efficiency and electrification measures can improve local air quality by displacing fossil fuel equipment. Dollar-per-MMBtu estimates for health benefits from avoided fuel use, referred to as health intensity values, were developed as part of the integration analysis for the Scoping Plan based on sector-specific analyses and the attributed health values.
  - **Health benefits of LMI residential energy efficiency interventions.** In addition to the local air quality health benefits, the residential analysis included health benefits that are assumed to accrue to LMI homes where measures are installed. The additional benefit is $375.50 per year for each single-family LMI home and $204.60 per year for each multifamily LMI home.
- **Greenhouse gas reduction value** represents the greenhouse gases avoided by replacing fossil fuel equipment with electric measures. The benefit/cost analysis calculates the avoided metric tons of carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O) based on emission rates for each counterfactual fuel. Likewise, emissions from increased electricity usage are calculated and subtracted from the avoided emissions. A societal value is calculated by multiplying the net avoided emissions in each year by annual social cost values for each greenhouse gas.

2.2.1.3 Data Sources for Benefit/Cost Analysis

This potential study collected the data required to perform benefit/cost analysis from a variety of sources. Table 2-1 provides a comprehensive list of these data sources, along with notes regarding their treatment in the potential study.

2.2.1.4 Additional Economic Potential Considerations

The economic potential for a given measure can exceed the technical potential when a second measure, interacting with that first measure, fails a benefit/cost screen. For example, if a homeowner installs a weatherization measure that reduces baseline cooling consumption from 1,000 kWh to 900 kWh, then installs an efficient air conditioner that saves 10% off the baseline cooling consumption, this efficient air conditioner results in energy efficiency and electrification savings, or technical potential, of 90 kWh (900 kWh * 10%). However, if the weatherization measure had not been installed first (meaning it failed the cost-effectiveness screen in the economic potential step), the baseline consumption would have been 1,000 kWh, and the efficient air conditioner would have resulted in energy savings, or economic potential, of 100 kWh (1,000 kWh * 10%). In this case, the efficient air conditioner's economic potential (100 kWh) exceeds its technical potential (90 kWh).

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[2] See Appendix G in the New York State Climate Action Council's *Draft Scoping Plan*, published December 30, 2021, at https://climate.ny.gov/Our-Climate-Act/Draft-Scoping-Plan for more information.

Table 2-1. Benefit/Cost Analysis Data Source Summary

Data Input	Source	Notes
Wholesale electricity prices (used to calculate Additional Electricity Cost)	NYISO 2019 CARIS Study (published 2020) [a]	Electricity costs are based on locational-based marginal pricing (LBMP) forecasted in NYISO CARIS study, minus Regional Greenhouse Gas Initiative (RGGI) compliance and assuming energy losses of 7%.
Electricity generation capacity cost (used to calculate Electric Peak Reduction benefit)	NYISO Installed Capacity Market data; DPS forecasts	The electric peak reduction benefit is based on each utility's capacity and distribution costs, which are calculated based on utility filings, historical NYISO capacity auction clearing prices, and DPS forecasts. Peak reductions are calculated using a peak capacity allocation factor (PCAF) method to align kW reductions with $/kW values.
Electricity transmission and distribution capacity cost (used to calculate electric peak reduction benefit)	Utility filings	
Natural gas prices (used to calculate avoided fuel cost benefit)	EIA Annual Energy Outlook (2021) [b]	Natural gas wholesale price forecasts are applied to the avoided fuel consumption to calculate the avoided fuel cost benefit.
Natural gas capacity cost (used to calculate gas peak reduction benefit)	Utility filings, EIA, S&P Global [c]	Gas peak reduction benefit is based on upstream supply-fixed costs and distribution capacity reductions based on publicly available data from utility filings, EIA, and S&P Global. Peak reductions are calculated using PCAF method to align MMBtu/day reductions with $/MMBtu/day values.
Fuel oil prices (used to calculate avoided fuel cost benefit)	EIA Annual Energy Outlook (2021)	Fuel oil wholesale price forecasts are applied to the avoided fuel consumption to calculate the avoided fuel cost benefit.
District steam prices (used to calculate avoided fuel cost benefit)	Natural gas and oil prices from EIA Annual Energy Outlook (2021)	EIA Annual Energy Outlook (AEO) does not include prices for district steam, so a price forecast was calculated as a 90%/10% blend of natural gas and oil prices.
Ambient air quality health value (used to calculate health value benefit)	NYS Climate Action Council, Scoping Plan (2022)	The ambient air quality health value is based on dollar-per-MMBtu estimates for health benefits from avoided fuel use.
Health benefits of residential energy efficiency interventions (used to calculate health value benefit)	NYS Climate Action Council, Scoping Plan (2022)	Additional health benefits are assumed to accrue to low-moderate income homes where measures are installed. The additional benefit is $375.50 per year for each single-family LMI home and $204.60 per year for each multifamily LMI home.
Greenhouse gas emission factors for fuels (used to calculate greenhouse gas reduction value benefit)	NYSERDA and DEC Technical Documentation (2021) [d]	Emission factors for fuel are multiplied by avoided fuel consumption
Greenhouse gas emission factors for electricity (used to calculate greenhouse gas reduction value benefit)	NYSERDA Projected Emission Factors for New York State Grid Electricity white paper (2022) [e]	Emission factors for electricity are multiplied by increased electricity consumption and subtracted from avoided greenhouse gas emissions from avoided fuel
Social cost of greenhouse gases (used to calculate Greenhouse Gas Reduction Value benefit)	DEC Value of Carbon Guidelines (2022) [f]	Social costs are multiplied by avoided greenhouse gas emissions to provide a dollar-value benefit in BCA. This analysis used the social cost of carbon based on the 2% and the 3% discount rates, as published by the NYS Department of Environmental Conservation (DEC).

[a] NYISO. July 2020. *2019 Congestion Assessment and Resource Integration Study (CARIS) Report.* https://www.nyiso.com/documents/20142/2226108/2019-CARIS-Phase1-Report-Final.pdf

[b] EIA. 2021. "Annual Energy Outlook (AEO)." https://www.eia.gov/outlooks/aeo/tables_side.php

[c] S&P Global. www.spglobal.com

[d] ERG. December 20, 2021. *Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act.* Prepared for NYSERDA and DEC.

[e] NYSERDA. August 2022. *Projected Emission Factors for New York State Grid Electricity*. Report Number 22-18. https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Technical-Reports-and-Studies/Greenhouse-Gas-Emissions#other

[f] DPS. May 2022. *Establishing a Value of Carbon: Guidelines for Use by State Agencies*. Appendix: NYS Social Cost Values. https://www.dec.ny.gov/docs/administration_pdf/vocguid22.pdf

2.3 Achievable Potential Scenarios

Achievable potential is expressed through the development of illustrative scenarios that analyze the potential for adoption of measures given real-world customer motivations and constraints, including, for example, the impact of cost considerations, customer behavior, supply chain barriers, and the extent to which government programs overcome such barriers and constraints. This study determines achievable potential as a subset of technical potential. Unless subject to codes and standards, measure adoption is voluntary and is determined based on project return as experienced by the customer and non-economic barriers to adoption. This study 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.

This report presents three adoption scenarios to explore achievable potential. First, the Scenario 1. Baseline describes a case that is inclusive of enacted federal, state, and local policies, as well as anticipated advancements in New York State codes for new construction (as recommended in the Scoping Plan). Scenario 2. CapEx Incentives and Scenario 3. Reasonable Return Incentives carry forward the core Baseline Scenario assumptions and apply different approaches for upfront financial incentives to encourage adoption of energy efficiency and electrification measures. Each scenario is described below.

2.3.1 Scenario 1. Baseline

This study incorporates statewide building energy codes and federal equipment standards into estimated energy sales and end-use consumption estimates (see section *3.3.8 Codes and Standards*, below). The Baseline Scenario builds on this by incorporating state appliance and equipment efficiency standards and the enacted New York City Local Laws 97 and 154. In alignment with the Scoping Plan,[3] this scenario also assumes that new building energy codes will take effect for new construction, requiring highly efficient, zero-emission new construction starting in 2025 for single-family buildings and 2028 for multifamily and commercial buildings. These anticipated code adjustments will, in effect, expand the phase-out of fossil fuel systems in new buildings—which is already required under New York City Local Law 154—across all of New York State.

Table 2-2 provides a summary of the building codes and equipment standards included in the Baseline Scenario. This scenario does not model any new upfront financial incentives for consumers beyond currently available federal tax credits from the 2022 Inflation Reduction Act and a New York State geothermal tax credit for homeowners. The Baseline Scenario establishes a case to which additional interventions can be compared.

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[3] For more information about New York State Climate Action Council's Scoping Plan, published December 2022, access the website at climate.ny.gov/resources/scoping-plan/.

Table 2-2. Overview of Building Codes and Equipment Standards in Scenario 1. Baseline

Measure	Statewide [a]	New York City Local Law 154
Shell (New Construction)	High-performance shell (approximately passive house level) • 2025: single-family • 2028: multifamily and commercial	Though Local Law 154 does not specify shell requirements, New York City has adopted a stretch energy code. Therefore, for new construction buildings in New York City, high-performance shell measures are modeled as adopted concurrently with cold-climate heat pumps: • 2024: residential buildings ≤7 stories • 2027: all other building types
Space Heating (New Construction)	Installation of electric, cold-climate heat pumps for space heating • 2025: single-family • 2028: multifamily and commercial	No combustion with >25 $kgCO_2e$/MMBtu within building (modeled as installation of electric, cold-climate heat pumps for space heating) • 2024: Buildings ≤7 stories • 2027: Buildings >7 stories
Hot Water (New Construction)	Heat pump water heaters • 2025: single-family • 2028: multifamily and commercial	No combustion with >25 $kgCO_2e$/MMBtu within building (modeled as installation of electric, cold-climate heat pump water heater) • 2024: single-family 1 or 2 units • 2027: all other building types
Appliances/ Products	2024: standard for appliances/products not preempted by federal standards. The list of such appliances/products is presented in the methodology appendix.	Local Law 154 does not specify appliance and product standards, therefore, buildings in New York City follow the statewide requirements as stated on this table.

[a] 100% compliance is assumed to occur on the third year after building code is in effect, with compliance increasing incrementally from 70% in the first year of the building code. Cold-climate heat pumps include air-source and ground-source technologies. For appliances and product standards 100% compliance is assumed in the first year of the standard.

2.3.1.1 New York State Building Code

The New York State building code includes the current statewide new construction code and the anticipated all-electric building code (described as "zero onsite greenhouse gas emissions") for new construction. In alignment with the Climate Action Council's Scoping Plan, the modeled zero-emissions code prohibits fossil fuel equipment for space conditioning, hot water, cooking, and appliances, with a start year of 2025 for single-family and 2028 for multifamily and commercial buildings. The predetermined adoption feature of BEEM assumed 70% adoption in the first year of the code, 85% in the second year, and 100% starting in the third year.

The modeled code advancement also includes anticipated state building code shell requirements for single-family buildings (with one to four units) in 2025 and multifamily and commercial buildings in 2028. This study assumed that the anticipated state building code will aim for a significant reduction in the total energy use intensity. The study used the predetermined adoption feature to require the high-performance house shell measure package for all new construction, phasing in over three years (70%, 85%, 100%).

2.3.1.2 New York City Local Laws

Specifically for New York City buildings, the study included the effects of current Local Law 97 and Local Law 154:

- **Local Law 97.** Most existing buildings over 25,000 square feet will be required to meet new energy efficiency, electrification, and greenhouse gas emissions limits by 2024, with stricter limits coming into effect in 2030, subject to terms, conditions, and exceptions as laid out in the local law.[4] The study modeled Local Law 97 fines for exceeding greenhouse gas emissions limits as a component of the project economics for applicable large buildings.
- **Local Law 154.** This law prohibits the combustion of substances with certain emissions profiles in buildings within New York City limits.[5] Table 2-2 above highlights elements of Local Law 154 and shows timeline overlap with the anticipated state code changes. Because of segmentation differences between BEEM and Local Law 154, the study made simplifying assumptions. The study modeled Local Law 154 as an all-electric new construction code (with the BEEM predetermined adoption feature) for residential buildings less than or equal to seven stories starting in 2024 and for other residential and commercial buildings starting in 2027. Where applicable, the study applied state code when New York City code does not apply, such as Local Law 154 exemptions for restaurants and hospitals and building shell. The BEEM model assumed 70% adoption in the first year of the code, 85% in the second year, and 100% starting in the third year.

2.3.1.3 State Appliance Standards

The study models the impact of state appliance/product standards for equipment that is not currently subject to federal standards. Appliance and product types that are modeled as subject to forthcoming state appliance standards are listed below, for which the study applied an adoption rate of 100% of efficient equipment starting in 2024.

- Air purifiers
- Commercial dishwashers
- Computers and computer monitors
- General service lamps
- Pool pump replacement motors
- Portable electric spas
- Showerheads
- Faucets
- Federally exempt linear fluorescent lamps (including high color rendering index, cold temperature, and impact resistant fluorescent lamps)
- Ventilation fans

This study assumed that the state appliance standards would reflect stringent specifications and full compliance with the standard. Specific assumptions included these requirements: showerheads of 1.5 gallons per minute (gpm) or lower, kitchen faucet aerators of 1.0 gpm or lower, bathroom faucet aerators of 0.5 gpm or lower, and the presence of a thermostatic shower restriction valve. Standards

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4 See New York City Sustainable Buildings website https://www.nyc.gov/site/sustainablebuildings/ll97/local-law-97.page for more details about Local Law 99.

5 See the New York City Council website https://legistar.council.nyc.gov/LegislationDetail.aspx?ID=4966519&GUID=714F1B3D-876F-4C4F-A1BC-A2849D60D55A&Options=ID%7cText%7c&Search=combustion for more details about Local Law 154.

that were adopted by New York State in December 2022 (to take effect by July 2023) are less stringent than the study assumptions, [6] and compliance may be significantly lower given the ability for customers to buy a water fixture from other states and install it themselves.

2.3.2 Scenario 2: CapEx Incentives

The CapEx Incentives Scenario includes the elements modeled for the Baseline Scenario. It adds sustainability guidelines,[7] which New York State Homes and Community Renewal (HCR) has established for the new construction of housing for low-income households. The guidelines are modeled to require that new construction of subsidized affordable multifamily buildings adopts high-performance shell and heat pumps from 2024 onward (with incentives provided through 2027).

The scenario assumes that consumers receive an incentive amount calculated at 50% of the measure incremental cost after applicable tax credits. This incentive design is commonly used by program administrators in New York State. Incentives are modeled for all measures (except those subject to state and federal codes or standards). Incentive caps are applied to each measure, up to a maximum of $30,000 per single-family dwelling unit, $35,000 per multifamily dwelling unit, and $20 per square foot in commercial spaces.

2.3.3 Scenario 3: Reasonable Return Incentives

The Reasonable Return Incentives Scenario includes the elements modeled for the Baseline Scenario and the HCR sustainability guidelines. Like Scenario 2, this scenario models incentives that encourage households and businesses to adopt energy efficiency and electrification measures (unless measures are subject to state and federal codes and standards).

Scenario 3 applies a more tailored approach to setting incentives, in which the incentive is equal to the upfront amount required to achieve a reasonable customer rate of return on the measure's incremental lifetime cost.[8] Measures that are highly cost-effective in the Baseline Scenario (such as commercial lighting) receive little or no upfront incentive in this scenario, while measures that do not initially offer a reasonable project return (as is often the case for heat pumps) see higher incentives and may even exceed 50% of the incremental cost. Like Scenario 2, this scenario applies an incentive cap to each measure, up to a maximum of $30,000 per single-family dwelling unit, $35,000 per multifamily dwelling unit, and $20 per square foot in commercial spaces.

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6 For information on adopted standards, see NYSERDA's website at https://www.nyserda.ny.gov/All-Programs/New-York-State-Appliance-and-Equipment-Efficiency-Standards/Current-Standards and Part 509 of Title 21 of the Official Compilation of Codes, Rules and Regulations of the State of New York.

7 New York State Homes and Community Renewal. *Sustainability Guidelines: New Construction*. Spring 2022. See https://hcr.ny.gov/sustainability-guidelines.

8 Specifically, the incentive is set such that subsidized affordable multifamily buildings, public sector buildings, and certain large commercial building types achieve an internal rate of return (IRR) of 10% (corresponding to a project payback period of nine to ten years) and other residential or commercial customers see an internal rate of return of 16% (corresponding to roughly a six-year payback period).

Box 1. Incentive Design Key Considerations

A measure's specific economic assumptions affect this potential study's modeled incentives distinctly for each incentive type.

The CapEx Incentives design considers only the incremental capital cost of a measure, regardless of the economic attractiveness of that measure. With this design, high-cost measures receive higher incentives and low-cost measures receive lower incentives.

The Reasonable Return Incentives design, on the other hand, considers economic attractiveness. Measures that are already very economically attractive might receive only a small incentive or no incentive at all.

Impacts on measure incentives vary across scenarios. Some measures may receive a higher incentive under with CapEx Incentives compared to Reasonable Return Incentives scenarios, while the impact may be switched for other measures.

Consider the following illustrative examples for a single-family home:

- Installing an efficient boiler (improved HVAC) in a single-family home downstate that is heated with fuel oil or propane receives a $346 incentive under the CapEx Incentive Scenario but no incentive under the Reasonable Return Incentives Scenario. This is because this measure has a modest incremental cost and results in avoided fuel bills, which provides an economically attractive project return and negates the need for an incentive under the Reasonable Return Incentives Scenario.
- Installing Whole-house ductless heat pump in a single-family home in upstate New York receives roughly an $5,500 incentive under the CapEx Incentives Scenario (which covers half of the incremental cost above replacing a gas or oil boiler and window air conditioner). Under the Reasonable Return Incentives design, the incentive for this project is $1,700 in a home heated with fuel oil or propane, or $13,500 in a home heated with natural gas, since the difference in avoided fuel costs impacts the incentive needed to make the project return attractive.

3 Building Segmentations and Measures

This chapter provides an overview of the building segments and details of the energy efficiency and electrification measures and their characterization approach.

3.1 Building Sectors

The study estimated energy efficiency and electrification measure adoption impacts in three sectors: single-family, multifamily, and commercial. Each building sector was further broken down into size categories, building vintages, and ownership models. For example, the commercial sector was segmented into nine business types—office/government, food service, retail, grocery/convenience, warehouse, education, lodging/hospitality, health services, and hospitals.

Table 3-1 shows the building sectors, size categories, and vintages in this potential study.

Table 3-1. Building Sectors, Sizes, Types, Vintages, Income Strata, and Ownership

Sector	Size	Building Types	Vintage	Income Strata	Ownership
Single-Family (1 to 4 units)	1 unit, 2 to 4 units	N/A	Pre-1980, post-1980, new build	Market-rate, LMI	Owner-occupied, renter-occupied
Multifamily (5+ units)	Less than or equal to 7 stories, more than 7 stories	N/A	Pre-war (up to 1945), post-war (up to 1979), post-1980, new build	Market-rate, LMI	Owner-occupied, renter-occupied, subsidized
Commercial	Small/medium commercial (<= 100,000 sq. ft.), large commercial (>100,000 sq ft)	Office/government, food service, retail, grocery/ convenience, warehouse, education, lodging/ hospitality, health services, hospitals	Pre-1980, post-1980, new build	N/A	Private owner, private leased, public owner, public leased

Configurations by region, space and water heating fuel, HVAC distribution configurations, and hot water distribution were other differentiating factors used to further segment the building stock data. Regions include New York City, Long Island, Hudson Valley, and Upstate. New York City consists of the Bronx, Kings, Queens, New York, and Richmond counties. Long Island consists of Nassau and Suffolk counties. Hudson Valley consists of Dutchess, Greene, Orange, Putnam, Rockland, Ulster, and Westchester counties. Upstate consists of all other New York State counties.

The space and water heating fuels included natural gas, oil/propane, electricity, and district steam purchased from Con Edison.

3.2 Energy Efficiency and Electrification Measures

This potential study included a comprehensive set of energy efficiency and electrification measures, with measure details drawn from the 2020 New York State Technical Resource Manual (TRM) (v8) and additional data sources such as NYSERDA's 2019 *Residential Baseline Stock Assessment*.

The study developed an initial list of measures using information from several sources:

- Measures flagged as priorities by study partners
- Measures included in the 2020 New York Technical Reference Manual (TRM) (v8)
- Efficiency tiers from the Consortium for Energy Efficiency and ENERGY STAR
- Measures of interest in consultation with NYSERDA program staff
- Measures from Cadmus' extensive database, which includes details from regional and national databases (such as the California Database for Energy Efficient Resources and various TRMs)
- Selected emerging technologies and behavioral measures

This section presents an overview of the measure groups included in this study.

The study modeled energy efficiency and electrification measures as individual measures and as measure packages. For example, the single-family appliances measure package consists of ENERGY STAR® refrigerators, clothes dryers, freezers, and electric cooking equipment. Energy impacts, costs, and customer adoption for these measures were modeled as a single measure package, rather than as individual measures. Another example is for HVAC measures installed together with building shell upgrades, such as in the single-family basic shell and ground-source heat pump (GSHP) measure package.

Factors such as building age, geographical location, and HVAC distribution system limit the eligibility of a measure for different sites. Feasibility factors are used to account for the fact that some sites will be ineligible for certain types of equipment. For example, space constraints in New York City dictate that only a portion of existing buildings could install a building-level GSHP system.

The following tables list the measure packages in each building sector modeled for the potential study. Table 3-2 shows the single-family energy efficiency and electrification measures packages considered for this study, along with their corresponding measure grouping, and identifies which measure packages are electrification measure packages.

Table 3-2. Single-Family Energy Efficiency and Electrification Measures by Measure Group

<table>
<tr><th>Measure Group</th><th colspan="2">Measure Package Name</th><th>Description/Included Measures</th><th>Category</th></tr>
<tr><td>Appliances</td><td colspan="2">Appliances</td><td>ENERGY STAR refrigerators, clothes dryers, freezers, and electric cooking equipment</td><td>Efficiency</td></tr>
<tr><td>Behavioral</td><td colspan="2">Indirect energy feedback</td><td>Home energy reports</td><td>Efficiency</td></tr>
<tr><td rowspan="4">Heat Pump</td><td colspan="2">Ground-source heat pump</td><td>Heating SASE 338%, Heating TDSE 288%, Cooling SASE 634%, Cooling TDSE 539% [a]</td><td>Electrification</td></tr>
<tr><td colspan="2">Partial-load ductless heat pump</td><td rowspan="2">Heating SASE 250%, Heating TDSE 188%, Cooling SASE 469%, Cooling TDSE 352% [a]</td><td>Electrification</td></tr>
<tr><td colspan="2">Whole-house ductless heat pump</td><td>Electrification</td></tr>
<tr><td colspan="2">Whole-house ducted air-source heat pump</td><td>Heating SASE 216%, Heating TDSE 162%, Cooling SASE 441%, Cooling TDSE 331% [a]</td><td>Electrification</td></tr>
<tr><td rowspan="3">HVAC Equipment and Retrofits</td><td colspan="2">Improved HVAC</td><td>High efficiency central air conditioner and furnace, boiler (gas, oil, propane)</td><td>Efficiency</td></tr>
<tr><td colspan="2">Window air conditioner</td><td>ENERGY STAR</td><td>Efficiency</td></tr>
<tr><td colspan="2">Thermostats, tune-ups, distribution improvements, and boiler controls</td><td>Smart Wi-Fi thermostats, HVAC tune-ups, duct insulation, duct sealing, and boiler pipe insulation, boiler reset controls</td><td>Efficiency</td></tr>
<tr><td rowspan="10">Shell and HVAC Equipment</td><td rowspan="5">Basic shell and</td><td>Air-to-water heat pump</td><td rowspan="5">Basic shell:
Pre-1980 buildings: air sealing; Wall, ceiling, and floor insulation.
Post-1980: air sealing; ceiling insulation</td><td>Electrification</td></tr>
<tr><td>Ground-source heat pump</td><td>Electrification</td></tr>
<tr><td>Improved HVAC</td><td>Efficiency</td></tr>
<tr><td>Whole-house ducted air-source heat pump</td><td>Electrification</td></tr>
<tr><td>Whole-house ductless heat pump</td><td>Electrification</td></tr>
<tr><td rowspan="5">Deep shell and</td><td>Air-to-water heat pump</td><td rowspan="5">Deep shell:
Air sealing, R-20 Wall insulation, floor insulation, R-60 ceiling insulation, window upgrades</td><td>Electrification</td></tr>
<tr><td>Ground-source heat pump</td><td>Electrification</td></tr>
<tr><td>Improved HVAC</td><td>Efficiency</td></tr>
<tr><td>Whole-house ducted air-source heat pump</td><td>Electrification</td></tr>
<tr><td>Whole-house ductless heat pump</td><td>Electrification</td></tr>
<tr><td>Lighting</td><td colspan="2">Lighting</td><td>LED specialty lamps (Tier 2), general service ENERGY STAR LED lamps, TLED linear lamp</td><td>Efficiency</td></tr>
<tr><td>Plug Loads</td><td colspan="2">Plug loads</td><td>Advanced power strips, ENERGY STAR air purifier, computer, dehumidifier, TV, and variable speed pool pumps, federal standard microwaves</td><td>Efficiency</td></tr>
<tr><td rowspan="2">Shell Improvements</td><td colspan="2">Basic shell</td><td rowspan="2">See above</td><td>Efficiency</td></tr>
<tr><td colspan="2">Deep shell</td><td>Efficiency</td></tr>
<tr><td rowspan="3">Water Heating</td><td colspan="2">Heat pump water heater (HPWH)</td><td>Advanced efficiency (No Resistance/Split System) HPWH ≤ 55 GAL - UEF 3.1</td><td>Electrification</td></tr>
<tr><td colspan="2">Efficient hot water heater</td><td>Water heater Consortium for Energy Efficiency (CEE) Tier 2 tankless (Replacing ≤ 55 GAL) - UEF 0.92</td><td>Efficiency</td></tr>
<tr><td colspan="2">Low-flow water fixtures</td><td>Bathroom and kitchen aerators, low-flow shower head</td><td>Efficiency</td></tr>
</table>

SASE = seasonal average system efficiency – system efficiency accounting for distribution losses

TDSE = temperature derated system efficiency – system efficiency accounting for distribution losses and reflecting reduced performance from climate conditions at the time of peak load; see Section 3.3.5 for residential heating SASE and TDSE improvement by 2030 relative to the 2020 inputs shown in the table above

UEF = uniform energy factor; LED = light emitting diode

Table 3-3 presents the assumed savings levels from single-family shell measure packages.

Table 3-3. Savings Levels Assumptions, Single-Family Shell Measure Packages

	Single-Family Shell Measures on Heating and Cooling Energy Loads				
	Basic Shell		Deep Shell		High-Performance Shell
Climate Zone	Pre-1980	Post-1980	Pre-1980	Post-1980	New Build
5	28%	22%	55%	51%	50% (savings are incremental to existing code)
4	28%	22%	58%	54%	50% (savings are incremental to existing code)
6	28%	22%	55%	51%	50% (savings are incremental to existing code)

Table 3-4 shows the multifamily measures considered for this study, along with their corresponding measure group, and identifies which measures are electrification measures. In multifamily buildings, different measures may apply to tenants or to whole buildings. The measure names indicate the space to which they apply. Measures labeled "tenant," such as tenant lighting or ductless heat pumps, affect tenant space only (in green). Measures labeled "whole building," such as central boilers and shell improvements, affect both tenant and common area space (in blue).

Table 3-4. Multifamily Energy Efficiency and Electrification Measures by Measure Group

Measure Group	Measure Package Name	Measure Description	Electrification
Appliances	Tenant appliances	ENERGY STAR refrigerator, clothes dryers, freezers. Electric oven, range	Efficiency
Behavioral	Tenant indirect energy feedback	Home energy reports	Efficiency
	Tenant electricity submetering	Submetering electricity for individual apartments	Efficiency
Heat Pump	Tenant ducted air-source heat pump	Heating SASE 230%, heating TDSE 173%, cooling SASE 469%, cooling TDSE 352% [a]	Electrification
	Tenant ductless heat pump	Heating SASE 250%, heating TDSE 188%, cooling SASE 469%, cooling TDSE 352% [a]	Electrification
	Tenant package terminal heat pump	Heating SASE 270%, cooling SASE 379%, cooling TDSE 345% [a]	Electrification
	Whole-building air-to-water heat pump	Heating SASE 200%, heating TDSE 150%, cooling SASE 470%, cooling TDSE 350% [a]	Electrification
	Whole-building ground-source heat pump	Heating SASE 360%, heating TDSE 306%, cooling SASE 674%, cooling TDSE 573% [a]	Electrification
	Whole-building variable refrigerant flow	Heating SASE 200%, heating TDSE 150%, cooling SASE 450%, cooling TDSE 338% [a]	Electrification
HVAC Equipment	Whole-building convert steam boiler to Hydronic boiler	Gas or oil/propane hydronic boiler - advanced efficiency	Efficiency
	Improved HVAC	Whole building improved boiler, furnace, and central air conditioner	Efficiency
HVAC Retrofits	Whole-building steam retrofit package	Thermostatic radiator valves and steam trap repair	Efficiency
	Whole-building boiler control	Outside air temperature reset/cutout control	Efficiency
	Whole building energy management system	Installation of energy management system	Efficiency

Measure Group	Measure Package Name	Measure Description	Electrification
	Whole building retro-commissioning and re-commissioning	Building retro-commissioning and re-commissioning	Efficiency
	Tenant smart thermostatic radiator enclosure	Smart thermostatic radiator enclosure	Efficiency
	Whole building boiler optimization	Heat recovery from boiler flue gases to preheat boiler feed water, variable frequency drive (VFD) boiler draft fan, and boiler linkageless controls and oxygen trim controls	Efficiency
Lighting	Common area lighting	LED specialty and ENERGY STAR general service lamps, TLED linear lamps, occupancy sensors and lighting controls	Efficiency
	Tenant LED lighting	LED specialty and ENERGY STAR general service lamps, TLED linear lamps	Efficiency
Plug Loads	Tenant plug loads	Advanced power strips, ENERGY STAR dehumidifiers, air purifiers, computers, and TVs, and microwaves	Efficiency
Shell Improvements	Whole building air-sealing (basic shell)	Shell package improvements – Basic (air sealing from the apartment interior)	Efficiency
	Whole building medium shell	Shell package improvements - Medium (air sealing, double-pane windows, R-40 roof insulation)	Efficiency
	Whole building high-performance shell	Shell package improvements – high-performance	Efficiency
Shell and HVAC Equipment	Each shell package—whole building air-sealing (basic shell), whole building medium shell, and whole building deep shell—can be paired with the heat pump/HVAC measures listed below:		
	Tenant ducted air-source heat pump	See individual descriptions throughout	Electrification
	Tenant ductless heat pump		Electrification
	Tenant package terminal heat pump		Electrification
	Whole-building air-to-water heat pump		Electrification
	Whole-building ground-source heat pump		Electrification
	Whole-building improved HVAC		Efficiency
	Whole-building variable refrigerant flow		Efficiency
Water Heating	Central hot water heater	Gas or oil/propane storage water heater - advanced efficiency	Efficiency
	Tenant heat pump water heater	Residential sized heat pump water heater - 240% SASE	Electrification
	Tenant low-flow water fixtures	Kitchen and bathroom aerators, efficient showerheads and thermostatic shower restriction valve	Efficiency
	Whole-building central heat pump water heater	Commercial sized heat pump water heater - 240% SASE	Electrification

[a] SASE = seasonal average system efficiency – system efficiency accounting for distribution losses
TDSE = temperature derated system efficiency – system efficiency accounting for distribution losses and reflecting reduced performance from climate conditions at the time of peak load; see Section 3.3.5 for residential heating SASE and TDSE improvement by 2030 relative to the 2020 inputs shown in the table above

Table 3-5 presents the assumed savings levels from multifamily shell measure packages.

Table 3-5. Savings Levels Assumptions, Multifamily Shell Measure Packages

		Multifamily Shell Measures Impacts on Heating and Cooling Energy Loads						
		Air Sealing		Medium Shell		High-Performance Shell		
Climate Zone	Load Savings by Season	*Pre-1980*	*Post-1980*	*Pre-1980*	*Post-1980*	*Pre-1980*	*Post-1980*	*New Build*
5	Heating	10%	10%	30%	30%	77%	76%	50%
	Cooling	3%	3%	10%	6%	8%	-5%	10%
4	Heating	10%	10%	34%	34%	79%	78%	59%
	Cooling	4%	4%	10%	6%	21%	-2%	5%
6	Heating	10%	10%	30%	30%	75%	75%	45%
	Cooling	4%	4%	10%	6%	16%	2%	9%

Table 3-6 shows the commercial energy efficiency and electrification measures considered for this study, along with their corresponding measure group, and identifies which are electrification measures.

Table 3-6. Commercial Energy Efficiency and Electrification Measures by Measure Group

Measure Group	Measure Package	Measure Description	Electrification
Appliances	Appliances/plug loads	Commercial appliances and plug loads	Efficiency
Heat Pump	Air-source heat pump	Commercial air-source heat pump [a]	Electrification
	Ground-source heat pump	Commercial ground-source heat pump	Electrification
HVAC Equipment	Improved HVAC	Efficient boilers, efficient furnaces	Efficiency
HVAC Retrofits	Commissioning and tune-up	This study applied the following components to applicable HVAC configurations: [b] Commissioning, continuous commissioning, re-commissioning, retro-commissioning, boiler maintenance, chiller tune-up, direct expansion tune-up and diagnostic, furnace and heat pump tune-ups	Efficiency
	HVAC controls – non-thermostat	This study applied the following components to applicable HVAC configurations: [a] Thermostatic radiator valves, roof-top unit supply fan VFD and controller, economizer controller, and CO_2 sensor (full advanced rooftop controls), CO sensors Rooftop unit with automated fault detection and diagnostics capability economizer, boiler controls – high, turndown burners, linkageless, boiler controls, boiler reset controls, VFD boiler draft fan, add oxygen trim controls to boiler (TEMP-A-TRIM), additional control features, variable speed drive (VSD) for secondary chilled water loop, chilled water temperature reset, install economizer, HVAC fan system installation with VSD, air-side economizer, optimize economizer	Efficiency
	HVAC controls - thermostat	Installation of emergency management system, Wi-Fi thermostat (learning type) and learning type with seasonal savings)	Efficiency
	Distribution improvements	This study applied the following components to applicable HVAC configurations: [a] Above-code boiler and chiller pipe, code hot water pipe insulation, duct repair and sealing, hot water circulation insulation, duct insulation, steam trap repair	Efficiency

Measure Group	Measure Package	Measure Description	Electrification
Lighting	Lighting controls	Advanced lighting and control design, occupancy sensors, daylight controls, continuous dimming, 3-step dimming, time clock	Efficiency
	Lighting equipment	Commercial lighting	Efficiency
Refrigeration	Refrigeration system upgrades	Added doors, anti-sweat controls, case replacement, refrigeration defrost, electronically commutated motor evaporator fans, display case LEDs, display case motion sensors, display case ac motor, electronically commutated motor evaporator fan controller, floating condenser head pressure controls, mechanical subcooling, night covers for display cases, no heat case covers, commissioning/recommission, strip curtains for walk-ins, economizers added to walk-in cooler	Efficiency
Shell Improvements	Code minimum shell	Code minimum shell: air sealing, wall and roof insulation to the 2018 energy code, and double-pane windows	Efficiency
	Basic shell	Basic shell: Pre-1980 buildings: air sealing plus double-pane windows Post-1980 buildings: air sealing	Efficiency
Shell Improvements and HVAC	Each shell package-basic shell, code minimum shell, and high-performance shell—can be paired with the following improvements and HVAC: Air-source heat pump Ground-source heat pump Improved HVAC	See individual descriptions throughout	Electrification
Water Heating	Heat pump water heater (commercial sized)	Commercial sized heat pump water heater	Electrification
	Water heater usage and controls	Drain water heat recovery water heater, low-flow faucet aerators, low-flow pre-rinse spray valves - CEE Tier 2, low-flow showerheads, ultrasonic faucet control, water heater setback thermostat	Efficiency

[a] The BEEM toolset models a variation of air-source heat pump (ASHP) technology for each commercial building type based on the most common HVAC configuration. For example, the ASHP technology for small offices or small grocery stores is a variable refrigerant flow (VRF) system with energy recovery ventilator, whereas large hotels are considered to install a two-pipe air-to-water heat pump with water-cooled chillers. In the commercial sector, heat pumps for space conditioning are bundled with additional efficiency measures that may include more efficient lighting, appliances, plug loads, and water heating equipment.
[b] The study applied measures only to appropriate HVAC distribution configurations (for example, boiler maintenance applied only to sites with boilers).

HVAC distributions impact the heat pump technology type offered to each commercial building type, as the measure packages are designed around the optimal use of existing resources and measure compatibility with the buildings' existing systems and setups. Air-source heat pump (ASHP) measures are particularly impacted by the HVAC distribution system of each commercial building type. For example, for restaurants with an existing rooftop, packaged heating and cooling system, the modeled ASHP technology is a variable refrigerant flow (VRF) system integrated with a dedicated outdoor air system (DOAS), whereas a large hotel will utilize an air-to-water heat pump (ATWHP) paired with the existing/new water-cooled chiller.

Efficiency and electrification measures for HVAC systems were modeled as follows:

- **Improved HVAC.** Like-for-like replacement with a best-in-class efficiency system
- **Air-source heat pump (ASHP).** Installation of a mini-split, VRF, or centralized ASHP to provide heating and cooling. In the analysis for this study, mini-splits were used for small commercial spaces in New York City, VRF systems in small commercial spaces outside of New York City, and centralized ASHPs for large commercial buildings.
- **Ground-source heat pump (GSHP).** Installation of a ground field sized to provide heating and cooling, as well as a water source heat pump system and DOAS for distribution and ventilation.

Where the base distribution and ventilation systems required modification to accommodate a water-based system in the ASHP or GSHP options, the study team adjusted the internal system requirements in the model as well to allow for efficient distribution and DOAS with energy recovery ventilators.

3.2.1 Measure Permutations

As presented in section *3.1 Building Sectors* above, this study segmented the market to analyze energy efficiency and electrification potential for the most prominent fuel types in residential and commercial buildings, including electricity, natural gas, fuel oil and propane, and district steam purchased from Con Edison. This study considered region (New York City, Long Island, Hudson Valley, and Upstate), electric utility service territory, building vintage, ownership, building size (for example less than or equal to seven stories and greater than seven stories for multifamily), metering type, and all major residential and commercial end uses.

The segmented building stock data are offered the applicable energy efficiency and electrification measures as listed in Table 3-2, Table 3-4, and Table 3-6 in section *3.2 Energy Efficiency and Electrification Measures* above. As shown in Table 3-7, this study examined 96 unique measures, hence more than 135,472 energy efficiency and electrification measure permutations across all fuel types (electric, natural gas, fuel oil and propane, and district steam). This study considered measure savings and costs separately for each measure permutation across applicable differentiating factors (such as geographic area, vintage, and ownership) within the single-family, multifamily, and commercial sectors.

Table 3-7. Measure Counts and Permutations

Sector	Total Unique Measure Package Count	Total Measure Package Permutations
Single-Family	24	45,493
Multifamily	47	47,043
Commercial	25	42,936
Total	**96**	**135,472**

3.3 Measure Database

The study considered measure installations at the replacement cycle of the existing equipment and, therefore, did not assess energy efficiency or electrification potential for early replacement. The following lists some of the key input parameters for the study:

- ***Technical feasibility*** is the percentage of buildings where customers could install a particular measure, accounting for physical constraints.
- ***Energy savings*** is the average annual savings as a result of installing a particular measure attributable to a specific energy end-use, in percentage terms.
- ***Equipment cost*** is the full counterfactual and measure equipment costs.
- ***Installation cost*** is the expense of installing the measure, accounting for differences in labor rates by region, urban versus rural areas, and other variables.
- ***Operation and maintenance cost*** is the annual expense of operating or maintaining the counterfactual or measure equipment.
- ***Replacement cycle*** is number of years that a piece of equipment is used before replacement.
- ***Measure life*** is the expected useful life of measure equipment.
- ***Measure saturation*** is the percentage of homes that have already installed a particular measure.

Specific to the state's multifamily building sector, energy efficiency and electrification measures were classified into three categories:

- ***Tenant measures*** such as tenant lighting or ductless heat pumps are applicable only to tenant spaces in multifamily buildings.
- ***Common area measures*** such as lighting in hallways or stairwells are applicable only to common area spaces in multifamily buildings.
- ***Whole-building measures*** such as boiler recommissioning are applicable to both tenant and common area spaces in multifamily buildings.

For this study, the commercial analysis considered heat pump technologies and building shell improvements. The study designed the commercial measure packages to reflect the measure portfolio investment strategies seen in the commercial sector. Therefore, retrofitting lighting, plug loads and appliances, and domestic hot water equipment were included in the heat pump improvement packages, where applicable.

The study developed a database of technical and market details for the measures that included the key metrics described above and used the data sources listed in Table 3-8.

Table 3-8. Key Measure Data Sources

Input	Data Sources
Load and Energy Savings	NYSERDA BEEM inputs, study partner data and feedback, 2020 New York TRM (v8), ENERGY STAR, DOE EERE,[a] Regional Technical Forum, regional and well-respected TRMs, additional research for this study
Equipment and Labor Costs	NYSERDA BEEM inputs, study partner data and feedback, RSMeans,[b] ENERGY STAR, DOE EERE,[a] *California Database for Energy Efficient Resources*, Regional Technical Forum, incremental cost studies, regional and well-respected TRMs, online retailers, Cadmus research
Measure Life	NYSERDA BEEM inputs, study partner data and feedback, 2020 New York TRM (v8), ENERGY STAR, *California Database for Energy Efficient Resources*, regional and well-respected TRMs, Cadmus research
Technical Feasibility	Regional building stock assessments, study partner data and feedback, Cadmus research
Measure Penetration	NYSERDA BEEM inputs, study partner data and feedback, regional building stock assessments, U.S. Energy Information Administration (EIA) *Commercial Energy Consumption Survey*, ENERGY STAR market shipment reports, Cadmus research

[a] U.S. Department of Energy, Office of Energy Efficiency and Renewable Technology (DOE EERE). http://energy.gov/eere/office-energy-efficiency-renewable-energy

[b] RSMeans. Last updated 2021. "Comprehensive Database for Cost Estimation." https://www.rsmeans.com/products/online.aspx

3.3.1 Measure Baselines

The baseline condition of the measure packages is either the existing condition/equipment or a counterfactual one.

The baseline condition for energy efficiency measures such as refrigeration system upgrades, commissioning and tune-ups, HVAC controls and distribution upgrades, and building shell upgrades is considered to be the existing condition.

Other measures such as heat pumps, improved fossil fuel HVAC equipment, and LED lighting are considered to be a counterfactual condition. Counterfactuals represent the equipment a customer would have installed if they had not installed the efficiency measure. For an efficient boiler or furnace, for example, the counterfactual is a federal standard boiler or furnace.

3.3.2 Energy Savings

The study estimated energy savings for each measure in relation to its baseline condition. For example, if a measure reduces end-use energy consumption by 10%, the study team applied the 10% savings percentage to the baseline condition's energy consumption to arrive at the measure's end-use consumption. These estimates account for interactive effects across end uses (for example, when shell upgrade measures are installed, space heating and cooling loads for HVAC measures decrease).

The study relied on a number of sources to develop savings estimates:

- **NYSERDA Residential Building Stock Assessment.** For single-family space heating and cooling, the study team analyzed uses presented by the heating or cooling delivered loads in the 2019 *Residential Building Stock Assessment* (RBSA). The annual space heating and cooling loads in the multifamily sector are based on building simulation results. Single-family domestic hot water loads are from the RBSA, and multifamily domestic hot water loads are based on the 2020 New York State TRM.

- **Building simulation profiles**. The commercial analysis utilizes EnergyPlus as a building energy simulation platform to obtain 8760 hourly load profiles for each energy end use under existing, counterfactual, and measure conditions. The hourly profiles report end-use energy load and end-use equipment energy consumption, based on selected performance curves for each end-use equipment. The geometry and building characteristics for existing conditions for this study were based on the commercial building reference models and energy prototype building models from the U.S. Department of Energy.
- **Recent NYSERDA and New York State utility program evaluations, program data, and potential studies.**
- **U.S. Department of Energy Uniform Methods Project or other standard evaluation protocols.** The *Uniform Methods Project*'s protocols define standard calculations for estimating energy savings for a number of measures. The study's savings calculations were consistent with these and other similar industry standards.
- **ENERGY STAR calculators.** The study used the U.S. Environmental Protection Agency (EPA) ENERGY STAR calculators, which provide estimates of per-unit savings for a number of measures, including efficient appliances (such as refrigerators, freezers, and clothes washers) and efficient home electronics (such as televisions, computers, and monitors).
- **2020 New York State TRM (v8).**
- **Other state and regional TRMs.**
- **U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy (DOE EERE) technical support documents.** The DOE EERE includes estimates of equipment energy consumption in technical support documents for numerous energy-efficient equipment types.

3.3.3 Counterfactual and Measure Costs

The study relied on a number of sources to develop installed cost estimates for counterfactual and measure equipment:

- **RSMeans.** RSMeans provides construction cost data, including costs for several building retrofits (such as weatherization, windows, and other shell upgrades).
- **ENERGY STAR.** The EPA provides current equipment costs for several ENERGY STAR–rated units.
- **DOE EERE technical support documents.** The DOE EERE includes estimates of equipment and labor costs in technical support documents for several types of energy-efficient equipment.
- **Incremental cost studies.** TRMs often require incremental cost studies that show baseline and efficiency measure costs (such as for labor, equipment, and operation and maintenance). States frequently update these studies to incorporate the most recent cost data. These studies include measures that are most commonly offered through utility-sponsored energy efficiency and electrification programs.
- **Online retailers.** The study reviewed prices listed on manufacturer or retailer websites. Although online retailers may not provide estimates of installation (labor) or annual operation and maintenance costs, they provide reliable equipment costs.

- **NYSERDA cost assumptions.** As part of ongoing NYSERDA work related to the BEEM tool and program planning, NYSERDA has cost assumptions for a number of BEEM measures (including shell improvements). These cost assumptions are New York–specific and are often derived in consultation with industry experts. NYS utility study partners had a chance to review and provide feedback on these cost assumptions.

Heat pump costs for single-family homes are based on NYSERDA's LMI Heat Pump Adder Pilot (through which over 400 projects were installed by August 2022), Massachusetts's heat pump programs,[9] and refined based on additional market research. Multifamily costs are based on a combination of the single-family costs, market research and case studies, and NYSERDA multifamily program data.

Commercial measure cost input data were based on a cost model, where demolition, installation, and equipment costs were populated for each measure (and measure package) in each of the commercial building types. Costs were calculated as a function of heating/cooling capacities and the required number of equipment to meet the total load, square footage of insulation/windows required, ancillary equipment, estimates of labor hours for equipment installation. The data were obtained from market research and quotes from equipment suppliers.

Because cost varies widely across the state, the study used BEEM's cost-scaling capability to adjust costs by region (New York City, Long Island, Hudson Valley, and Upstate). The same measure usually costs more in New York City than elsewhere in the state.

In addition, LMI housing units are assumed to incur additional costs compared to market rate sites (10% higher for single-family and 20% higher for multifamily units). These cost increases reflect the higher likelihood of overdue maintenance costs, limited access hours, and/or requirements specific to subsidized affordable housing.

3.3.4 Equipment Replacement Cycle and Measure Life

The study used estimates of each measure's effective useful life (EUL) to calculate the lifetime net present value benefits and costs for each measure.

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9 For more information, see Massachusetts Clean Energy Center's "Costs Comparison Tool" https://public.tableau.com/views/AirSourceHeatPumpDashboard/Dashboard?%3AshowVizHome=no. The study accessed the data on August 11, 2022.

The study relied on a number of sources to develop measure life estimates:

- 2020 New York TRM (v8)
- NYSERDA RBSA
- EUL studies, such as EULs derived by the Association of Home Appliance Manufacturers
- DOE EERE technical support documents
- ENERGY STAR
- Study partner feedback on BEEM inputs
- Regional TRMs

The study used estimated replacement cycles for each measure to determine the natural rate of equipment replacements. The study assumes that customers decide on installing the counterfactual or the measure equipment when the existing equipment is up for replacement.

Table 3-9 through Table 3-11 shows each measure group's assumed EUL and replacement cycle for the single-family, multifamily, and commercial sectors respectively. As each measure group contains multiple measure, the tables provide the average for the group to simplify reporting.

Table 3-9. Single-Family Measure Group Average EUL and Replacement Cycles

Measure Group	Average Effective Useful Life (EUL)	Average Replacement Cycle
Appliances	13	7
Behavioral	3	2
Heat Pump - Air-Source	15	20
Heat Pump - Ground-Source	25	20
Heat Pump - Partial-Load Ductless	15	10
Heat Pump – Whole-House Ductless	15	20
Heat Pump Water Heater	20	10
Hot Water Heater	20	10
Improved HVAC	22	20
Lighting	20	7
Low Flow Fixtures	10	10
Plug loads	8	7
Shell	25	10
Shell and Heat Pump	20	20
Shell and Improved HVAC	22	20
Thermostat, HVAC Tune-Up, Distribution Improvements, and Boiler Controls	10	8
Window AC	12	10

Table 3-10. Multifamily Measure Group Average EUL and Replacement Cycles

Measure Group	Average EUL (Years)	Average Replacement Cycle (Years)
Appliances	13	7
Behavioral	5	5
Boiler Controls	16	16
Convert Steam Boiler to Hydronic Boiler	22	20
Energy Management System	15	15
Heat Pump	19	20
Heat Pump Water Heater	20	10
Hot Water Heater	15	10
Improved HVAC	25	20
Lighting	20	7
Low Flow Fixtures	10	10
Plug loads	8	7
Retrocommissioning	7	7
Shell	25	20
Shell and Heat Pump	20	20
Shell and Improved HVAC	22	20
Shell and Variable Refrigerant Flow	15	20
Smart Thermostatic Radiator Enclosure	15	15
Steam Retrofit Package	6	6
Variable Refrigerant Flow	15	20

Table 3-11. Commercial Measure Group Average EUL and Replacement Cycles

Measure Group	Average EUL (Years)	Average Replacement Cycle (Years)
Commissioning and Tune Up	20	20
Distribution Improvements	20	20
Heat Pump	20	25
Hot Water Heater	20	20
HVAC Controls	16	16
Improved HVAC	20	25
Lighting	20	10
Lighting Controls	11	11
Refrigeration System Upgrade	14	14
Shell	50	25
Shell and Heat Pump	20	25
Shell and Improved HVAC	20	25
Water Heat Usage and Controls	12	12

3.3.5 Coefficient of Performance

Coefficient of performance (COP) inputs are used to convert delivered energy to energy consumption (electricity, fuel, or district steam) of the equipment. The calculated energy consumption values are used to estimate energy bills. For conventional equipment, COP inputs are based on the 2019 RBSA.

Heat pump COP inputs are based on a series of white papers and analyses prepared by NYSERDA contractors using field test and pilot program data.[10,11,12] The study team analyzed inputs for seasonal average system efficiency (SASE) and temperature derated system efficiency (TDSE) to calculate heat pump electricity consumption at each hour of the year. The SASE and TDSE parameters represent only a heat pump system's performance and do not consider the overall HVAC system's performance when backup or supplemental heating exists.

- **Seasonal average system efficiency (SASE)** describes equipment efficiency averaged over a typical year of operation. This is similar to the more common seasonal average COP inputs for heating or cooling but includes heating/cooling distribution losses, where applicable. For equipment whose performance depends strongly on ambient temperature, SASE does well to describe annual efficiency, but not hourly efficiency during extreme temperatures.
- **Temperature derated system efficiency (TDSE)** describes equipment heating and cooling efficiency during the coldest (heating) and hottest (cooling) hours of the year.[13] Similar to SASE, TDSE layers distribution losses on top of the COP. For equipment whose performance depends strongly on ambient temperature, TDSE provides an appropriate efficiency for performance during summer and winter peak events, whereas SASE would overstate performance during these hours.

Improvements in heat pump technologies through 2030 are expected to result in greater efficiency. The analysis assumed that, by 2030, heat pump equipment will be field tested for the COP approach to estimate engineering efficiency, resulting in the changes to SASE values shown in Table 3-12. Note that TDSE values are also expected to improve, though the study team set these values conservatively to improve at half the rate of SASE values. Improvements apply only to heating SASE and TDSE; cooling performance is not expected to improve dramatically.

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10 For GSHP COP inputs: Henderson, H.I. 2020. *White Paper: Savings Calculations for Residential Ground Source Heat Pumps: The Basis for Equivalent Full Load Hours (EFLH) and Seasonal Efficiency Factors.* Prepared for NYSERDA and New York State Department of Public Service.

11 Other heat pump COP inputs: June 2020. "White Paper: Savings Calculations for Residential Air Source Heat Pumps: The Basis for Modifying EFLH and Seasonal Efficiency Factors for 'Whole House' and 'Displacement' Applications." Prepared for NYSERDA and New York State Department of Public Service.

12 Peak cooling COP inputs developed by NYSERDA contractors.

13 Heating TDSE is applied from 5 a.m. to 7 a.m. and 6 p.m. to 11 p.m. December through February. Cooling TDSE is applied from 1 p.m. to 6 p.m. on non-holiday weekdays from last week of June through end of August.

Table 3-12. Residential Heating SASE and TDSE Improvement by 2030 Relative to 2020

Equipment	2020 SASE	2030 SASE	2020 TDSE	2030 TDSE
GSHP	3.38 – 3.78	3.90 – 4.36	2.88 – 3.21	3.10 – 3.46
Ducted ASHP	2.16 – 2.40	2.72 – 3.03	1.62 – 1.80	1.83 – 2.03
Ductless ASHP	2.5 – 2.78	3.20 – 3.56	1.88 – 2.08	2.14 – 2.37
PTHP	2.70	3.04	2.40	2.55
VRF, ATWHP	2.00	2.30	1.50	1.61

For commercial sector analysis, performance curves available in the EnergyPlus software were used to derive heat pump COP inputs that account for changes in temperature and load. The EnergyPlus building simulations produced energy consumption values for buildings that use natural gas as their heating and hot water fuel.

3.3.6 Technical Feasibility

Technical feasibility represents the percentage of buildings that could feasibly install an energy efficiency or electrification measure. Technical limitations include equipment capability or space limitations. For example, ductless heat pumps could not feasibly be installed in all apartments of high-rise multifamily buildings due to space constraints related to the exterior unit and refrigeration lines. The study relied on three types of sources to develop feasibility estimates:

- **Energy efficiency and electrification program evaluations** that include research to identify technical barriers to installing energy efficiency and electrification measures.
- **Study partner data and feedback.**
- **Additional measure characterization research** (including from the Federal Energy Management Program and the U.S. Department of Energy) that identifies technical limitations for energy efficiency and electrification measures. These sources allowed the study to estimate the proportion of homes that can feasibly install each measure. In some instances, the study used engineering judgment to approximate technical constraints.

3.3.7 Measure Saturation

Measure saturation represents the percentage of buildings that have already installed an energy efficiency or electrification measure. The study relied on several sources to develop estimates of measure saturation that account for current saturations of energy-efficient equipment, building energy codes and standards, and the natural adoption of efficiency measures:

- Recent stock assessments and surveys (such as the 2018 U.S. Energy Information Administration [EIA] *Commercial Energy Consumption Survey* and 2018 NYSERDA *Single-Family Residential Building Stock Assessment*)
- Preliminary (partial) data from the ongoing NYSERDA *Statewide Multifamily Baseline Study*
- Study partner data and feedback on inputs, including updating measure saturations using study partner program accomplishments
- ENERGY STAR reports

3.3.8 Codes and Standards

The study accounted for changes in state energy codes and federal standards over the planning horizon. These changes affect customers' energy-consumption patterns and behaviors and will impact which energy efficiency and electrification measures continue to produce energy savings over minimum requirements. The study captured current efficiency requirements, including those enacted but not yet in effect.

The study used the 2020 New York State Energy Conservation Construction Code as the baseline for new construction with an assumed 100% code compliance for new buildings. The study measured new construction building energy efficiency and electrification savings relative to the code requirements for each building component. For example, the study calculated new construction building shell savings in New York City as the increment of energy savings achieved from installing additional insulation or air sealing relative to the energy code requirement for New York City.

The study did not attempt to predict how federal standards might change in the future for the base case; rather, the study factored in only the legislation that has already been enacted, with the possible exception of lighting. The study determined the best assumptions for lighting counterfactuals and the evolution of state energy codes for the baseline and additional scenarios in discussion with NYSERDA.

The study also explicitly accounted for several other pending federal standards. Table 3-13 and Table 3-14 list the recently enacted or pending standards for residential-sized equipment that were accounted for in this study, while Table 3-15 and Table 3-16 include these details for commercial-sized equipment. The study also incorporated other standards that became effective for equipment prior to 2021. For measures where a future standard would have a higher efficiency than a current standard counterfactual, the study adjusted the baseline to the new federal standard.

Table 3-13. Current and Pending Federal Electric Residential-Sized Equipment Standards by End Use

End-Use Equipment Type (Electric)	Current (Baseline) Standard	New Standard (Year Effective)
Central Air Conditioner	2023	No new standard pending
Clothes Washer	2018	
Cooking Oven	2012	
Cooking Range	2012	
Dehumidifier	2019	
Dryer	2015	
Freezer	2015	
Furnace Fan	2019	
Heat Pump	2023	
Linear Fluorescent Lamp	2018	TBD
Lighting General Service Lamp	2020	
Microwave	2016	No new standard pending
Package Terminal Air Conditioner	2017	
Pool Pump	2021	
Refrigerator	2015	
Room Air Conditioner	2015	
Water Heater GT 55 Gallon	2015	
Water Heater LE 55 Gallon	2015	

Table 3-14. Current and Pending Natural Gas/Other Fossil Fuel Residential-Sized Equipment Standards by End Use

End-Use Equipment Type Natural Gas/Other Fossil Fuel)	Current (Baseline) Standard	New Standard (Year Effective)
Clothes Washer	2018	No new standard pending
Cooking Oven	2012	
Cooking Range	2012	
Dryer	2015	
Heat Central Fuel Oil Boiler	2021	
Heat Central Natural Gas Boiler	2021	
Heat Central Natural Gas Furnace	2015	
Heat Central Propane Boiler	2021	
Pool Heater	2014	
Water Heater GT 55 Gallon	2015	
Water Heater LE 55 Gallon	2015	

Table 3-15. Current and Pending Electric Commercial-Sized Equipment Standards by End Use

End-Use Equipment Type (Electric)	Current (Baseline) Standard	New Standard (Year Effective)
Air-Cooled Unitary Air Conditioner	2009, 2010, and 2023	No new standard pending
Air-Cooled Unitary Heat Pump	2009, 2010, and 2023	
Automatic Commercial Ice Maker	2019	
Commercial and Industrial Air Compressor	No current standard	2026
Computer Room Air Conditioner	2013 and 2014	No new standard pending
Dedicated-Purpose Pool Pump	2022	
Electric Motor	2017	
Evaporatively Cooled Unitary Air Conditioner	2004, 2014, and 2015	
Packaged Terminal Air Conditioner	2011 and 2017	
Packaged Terminal Heat Pump	2011 and 2013	
Pump	2021	
Refrigerated Beverage Vending Machine	2020	
Refrigeration Equipment	2018	
Single Package Vertical Air Conditioner	2016, 2017, and 2020	
Single Package Vertical Heat Pump	2016, 2017, and 2020	
Small Electric Motor	2016 and 2018	
Variable Refrigerant Flow Air Conditioner	2009 and 2010	
Variable Refrigerant Flow Heat Pump	2004, 2009, 2010, 2013, and 2014	
Walk-In Cooler and Walk-In Freezer	2018 and 2021	
Water Heating Equipment	2004 and 2018	
Water-Cooled Unitary Air Conditioner	2004, 2014, and 2015	

Table 3-16. Current and Pending Natural Gas/Other Fossil Fuel Commercial-Sized Equipment Standards by End Use

End-Use Equipment Type (Natural Gas/Other Fossil Fuel)	Current (Baseline) Standard	New Standard (Year Effective)
Air-Cooled Unitary Air Conditioner Providing Natural Gas Heat	2010, 2017, and 2023	No new standard pending
Air-Cooled Unitary Heat Pump	2010, 2017, and 2023	
Clothes Washer	2018	
Commercial Packaged Boiler	2013	2024
Evaporatively Cooled Unitary Air Conditioner	2014 and 2015	No new standard pending
Unit Heater	2009	
Variable Refrigerant Flow Air Conditioner Providing Natural Gas Heat	2010	
Variable Refrigerant Flow Heat Pump	2010	
Warm Air Furnace	2023	
Water Heating Equipment	2016	
Water-Cooled Unitary Air Conditioner	2014 and 2015	
Water-Source Heat Pump	2016	

4 Potential Modeling

This chapter describes more specifics about study's approach to model technical, economic, and achievable potential scenarios.

4.1 Commercial Sector Modeling

The study's modeling approach for the commercial sector was distinct from the modeling approach for single-family and multifamily buildings. For residential buildings, the model generated hourly energy consumption profiles for each end use (including space heating, space cooling, water heating, appliances, plug loads, and lighting) and for each measure permutation via the profile selection feature for counterfactual and measure conditions.

For the commercial sector, the model used building-level energy simulation profiles to represent energy consumption as a whole, which helped capture interactive and rebound effects among end uses. The study assigned each counterfactual and measure profile to a reference installation based on profile attributes that included building types, building ages, climate zones, measure packages, and counterfactual heating fuel types. Note that this approach required interacting the data with thousands of building simulation profiles outside the model. Table 4-1 shows the assumed HVAC distribution type and ASHP technology used in the building simulations by building type and size. Modeled system characteristics and costs represent the HVAC distribution and the types of ASHP shown in this table.

Table 4-1. Commercial Building Simulations HVAC Distribution and ASHP System Assumptions

Size/BEEM Building Type	HVAC Distribution	Air-Source Heat Pump Measure Type Offered
Small/Medium Commercial		
Office/Government	Packaged/ducted heating and cooling systems - rooftop	VRF + ERV+ DOAS
Retail		
Food Service		
Grocery/Convenience		
Education	Packaged/ducted heating and cooling systems - rooftop	Four-pipe ASHP
Warehouse	Packaged/ducted heating and cooling systems - rooftop	VRF + ERV+ DOAS
Health Services	Packaged ducted heating and cooling systems - split system w/ variable air volume system (zoned)	Two-pipe ASHP[a]
Lodging/Hospitality	Room heating and cooling systems- baseboard/window AC/PTAC (zoned)	PTHP by room
Large Commercial		
Office/Government	Ducted heating and cooling systems - chilled water w/ variable air volume system (zoned)	Two-pipe ASHP[a]
Hospitals		
Health Services	Packaged ducted heating and cooling systems - split system w/ variable air volume system (zoned)	Two-pipe ASHP[a]
Education	Ducted heating and cooling systems - chilled water w/ variable air volume system (zoned)	Two-pipe ASHP[a]
Lodging/Hospitality	Ducted heating and cooling systems - chilled water w/ variable air volume system (zoned)	Four-pipe ASHP
Retail	Packaged ducted heating and cooling systems - split system w/ variable air volume system (zoned)	VRF + ERV+ DOAS
Warehouse		

[a] Plus water cooled chillers and the needed cooling tower

4.2 Interactive Effects

The study accounted for interactive effects between measures in three ways:

- The study accounted for **interactions between measures in the same measure package** by ensuring multiple measure components impacting the same end use accounted for the cumulative impact of all other applicable measure components (that is, accounting for measure "stacking" between different measures within the same measure package). Specifically, for building shell measure components interacting with space heating and cooling equipment or retrofit measure components, the model applied building shell savings first to reduce the building heating and cooling loads before applying the non-shell measure components. This approach accounted for interactive effects within each measure package in the per-unit savings and the technical, economic, and achievable potentials.
- The study accounted for **interactions between different measure packages within the same fuel** by stacking measure packages that interact in the order of their cost-effectiveness and reducing the end-use load by the savings of the preceding measure packages in the stack, assuming customers will install the most cost-effective measures first. This approach accounted for interactive effects in the technical, economic, and achievable potentials.
- The study accounted for **interactions between electrification measure packages and subsequently installed energy efficiency measure packages**. An adjustment was necessary because the model does not dynamically adjust the fuel type or heating coefficient of performance (COP) of a building after it has been electrified. Without an adjustment, a gas heated building in which a heat pump has been installed in one year and a shell improvement in a subsequent year would still produce gas savings as if it were heated by a gas furnace.

  To account for this, the study tracked the percentage of buildings that electrified in each year for each portion of the building segmentation and reduced the fossil fuel potential for the applicable installations of non-equipment measures accordingly. At the same time, the study increased the electric potential for those measures to account for the fact that they should save electricity if they were installed after building electrification. The study converted the lost fossil fuel efficiency potential into electricity efficiency potential using COP ratios between gas equipment and heat pumps.

  The impact was considerably more minor in the achievable case due to the relatively low heat pump adoption as a proportion of the total building stock when compared with the technical and economic cases. Consequently, the study adjusted technical and economic potentials only.

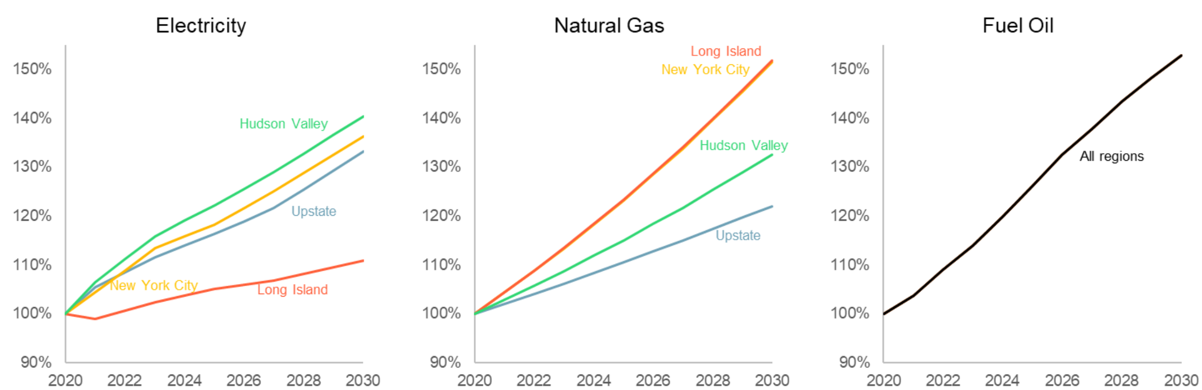
4.3 Retail Rates

Retail rate information was sourced from utility websites and from the Genability database at the start of 2020.[14] Rate calculations reflect energy and demand charges with tiers and/or rates that vary by time-of-use period and by season as well as reflecting a basic charge.

Customer bills are calculated based on the most popular standard rates of each utility. For residential customers in PSEG Long Island territory, the analysis uses an electric heating rate for customers whose space heating load is served primarily by electricity, either before or after installation of a measure package. Other utilities have introduced opt-in or pilot electric heating rates for residential customers, but these have limited adoption to date and are therefore not considered in this analysis.

Retail rate escalation factors are uniquely defined by utility and by customer class. Figure 4-1 and Figure 4-2 show the retail rate escalation assumed in the analysis, averaged across all customers in the residential class for each region. To be consistent with avoided cost escalation factors, electricity rate escalation is based on forecasts from the Congestion Assessment and Resource Study (CARIS), prepared by the New York Independent System Operator (NYISO),[15] and relevant avoided cost components.

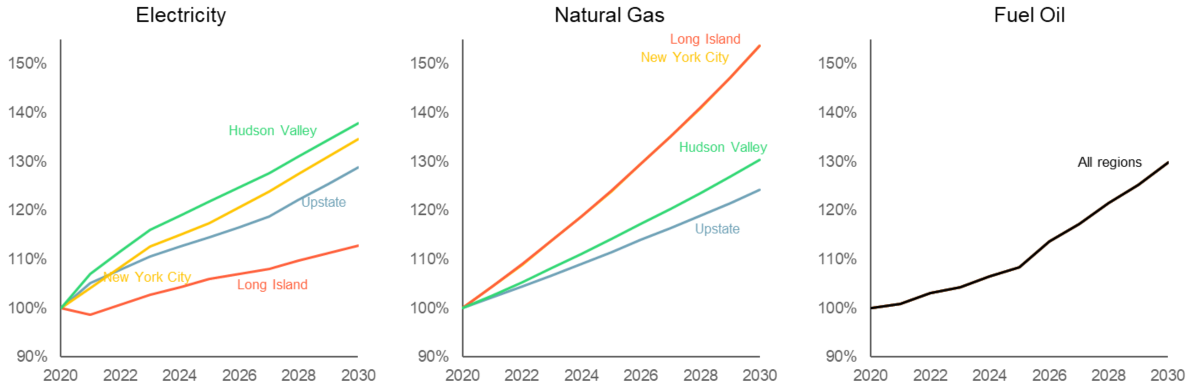
Figure 4-1. Nominal Residential Average Rate Escalation Relative to 2020 Values



14 Genability. "Unmatched Access to Energy Data and Analytics." Information accessed at the website https://www.genability.com/. Genability is now part of Arcadia.

15 New York Independent System Operator. July 2020. 2019 CARIS Report. *Congestion Assessment and Resource Integration Study*. https://www.nyiso.com/documents/20142/2226108/2019-CARIS-Phase1-Report-Final.pdf

Figure 4-2. Nominal Commercial Average Rate Escalation Relative to 2020 Values



4.4 Measure Competition

To avoid a scenario where a single building installs multiple measures that serve the same end use, such as a GSHP or an ASHP installed in single-family home, the study assigned all measures to a competition group. Each building could adopt only a single measure within that competition group. The study applied measure competition differently for each level of potential:

- ***Technical potential.*** The study assigned technical potential measures within a competition group to portions of potential installations accounting for technical feasibility and savings. BEEM assigns the maximum technically feasible installation of the highest-savings measures in a competition group to the potential installations first. The next highest-saving measures in a competition group accounts for the remaining potential installs, up to the maximum technical feasibility limit. This process continues until all measure installation opportunities have been filled.
- ***Economic potential.*** The study sorted competing measure (for example, GSHP or ASHP) that can be installed in a building in order of their per-building energy savings potential. The study then tested the cost-effectiveness of the measure, starting with the highest-saving measure that can be installed (accounting for technical limitations, as just described for technical potential). When a measure passed the societal cost test (SCT), the technical potential for that measure was counted as economic potential. When a measure failed the SCT, the technical installations for that measure were reallocated to the highest-savings competing measure that did pass the SCT.
- ***Achievable potential.*** For voluntary achievable installations, BEEM calculates annual adoption rates independently for each competing measure (see the next section, *4.5 Voluntary Measure Adoption Modeling*). An annual adoption rate is assigned to the counterfactual by subtracting the highest measure package adoption rate from 100%. Finally, each measure or counterfactual adoption rate is divided by the sum total of all adoption rates (including counterfactual) to produce its final adoption rate to ensure that the total adoption among all measures and counterfactual is exactly 100%.

4.5 Voluntary Measure Adoption Modeling

For achievable potential, the study distinguished between measures installed due to code and equipment standards or due to voluntary adoption. Modeling installations due to code and equipment standard is relatively straightforward, requiring only a notation of the measures that will be adopted and setting the rate at which adoption is phased in to 100%. BEEM models voluntary adoption through a Bass diffusion adoption approach that accounts for the cost-effectiveness of measures from the customer perspective. BEEM's adoption algorithm applies the annual adoption rate to the annually applicable sites to estimate the number of achievable installations in a given year.

The study performed the stacking calculation for achievable potential independently from the stacking calculations for technical or economic potential because the mix of installed measure packages was different for achievable potential.

4.5.1 Adoption Model

This discussion of the BEEM adoption model draws from internal NYSERDA BEEM documentation, particularly a memo from the study team describing the adoption algorithm in detail. The adoption model in BEEM consists of two major components:

- **Projecting the maximum adoption percentage** that will ever be achieved as a function of the project return (or corresponding payback). A higher project return corresponds to achieving a higher adoption potential. This component is discussed in the next section, *4.5.2 Maximum Adoption Percentage Based on Economic Return*.
- **Projecting how adoption percentages will increase over time** from current, typically low levels to reach the final maximum adoption percentage. The study modeled this component based on an assessment of barriers to adoption, including customer behavior barriers, technology barriers, and other nonfinancial barriers. As discussed in section *4.5.3 S-Curve: Shape of Adoption Over Time* below, this component is expressed through a curve that describes how the shape and speed of the adoption level increases over time.

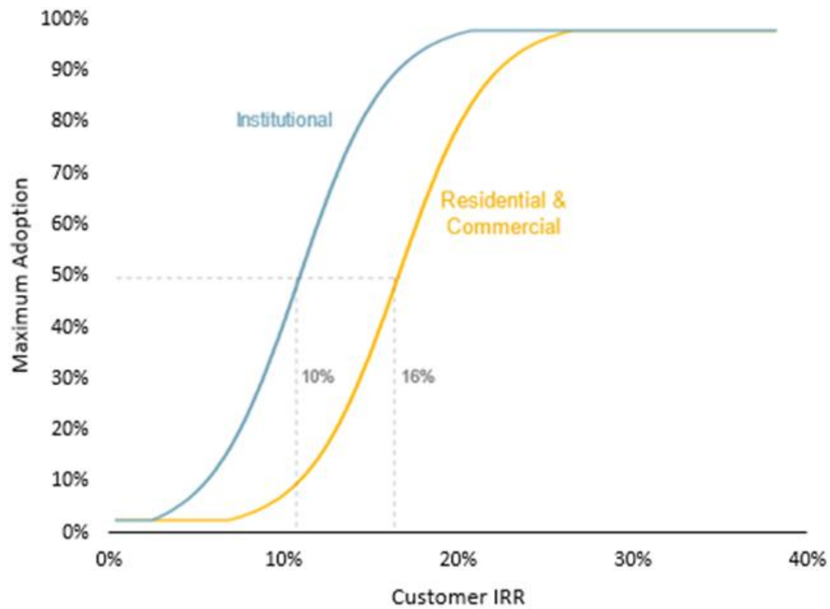
Adoption of the measures under consideration in BEEM tends to be linked to end-of-life replacement cycles. The model therefore applies an annual adoption rate (where adoption is modeled as a percentage of the sites that are ready for end-of-life replacement each year, rather than as a percentage of total building stock). This modeling choice means that it takes longer to achieve a certain level of penetration. Getting to 100% penetration requires not only achieving an annual adoption percentage of 100%, but also maintaining this adoption level for the number of years equal to the replacement cycle.

4.5.2 Maximum Adoption Percentage Based on Economic Return

This study modeled voluntary measure adoption based on a combination of the project return as experienced by the customer and non-economic barriers to adoption. The analysis determined the customer's willingness to adopt a measure based on project return on investment, expressed here as internal rate of return (IRR), on the incremental capital cost of the measure under consideration compared to the counterfactual alternative. For each customer type, a correlation was established between the measure IRR and a resulting maximum adoption rate.

As shown in Figure 4-3, the vertical value of a curve sets the maximum fraction of customers who would adopt a technology for a given IRR. The dashed lines demonstrate that maximum adoption by half of the institutional customers (public sector buildings and subsidized affordable multifamily buildings) would require an IRR of 10%, while a similar fraction of residential or commercial customers would adopt given an IRR of 16%. The correlations between IRR and maximum adoption rate used here are broadly consistent with those used in prior NYSERDA analyses.

Figure 4-3. Maximum Adoption Rate as a Function of Internal Rate of Return



4.5.3 S-Curve: Shape of Adoption Over Time

The analysis estimates the annual adoption from the maximum annual adoption percentage (from Figure 4-3) and a series of s-curves that are derived for each measure package and market segment based on specific measure attributes. As shown in Figure 4-4, each s-curve describes how adoption rates increase over time as technologies evolve from nascency to maturity. Table 4-2 shows the assignment of each measure to a corresponding s-curve by assessing customer, technology, and market barrier attributes.

In brief, the adoption of a measure in a given year is set by the product of the IRR maximum adoption percentage and the value derived from placement on an s-curve. A measure that has attributes of complex or invasive technology, limited customer awareness, and other unaddressed barriers to adoption would fall on a curve closer to the bottom of the shaded region in Figure 4-4, resulting in low near-term adoption even with a strong project return on investment.

The s-curve describes the length of time and shape of the adoption pattern to achieve the maximum adoption percentage. For modeling adoption, BEEM uses the Bass diffusion model, a simple differential equation that describes the s-curve pattern of new product adoption:

$$Bass\ diffusion\ adoption\ rate(t) = \frac{1 - e^{-(p+q)T}}{1 + (\frac{q}{p})e^{-(p+q)T}}$$

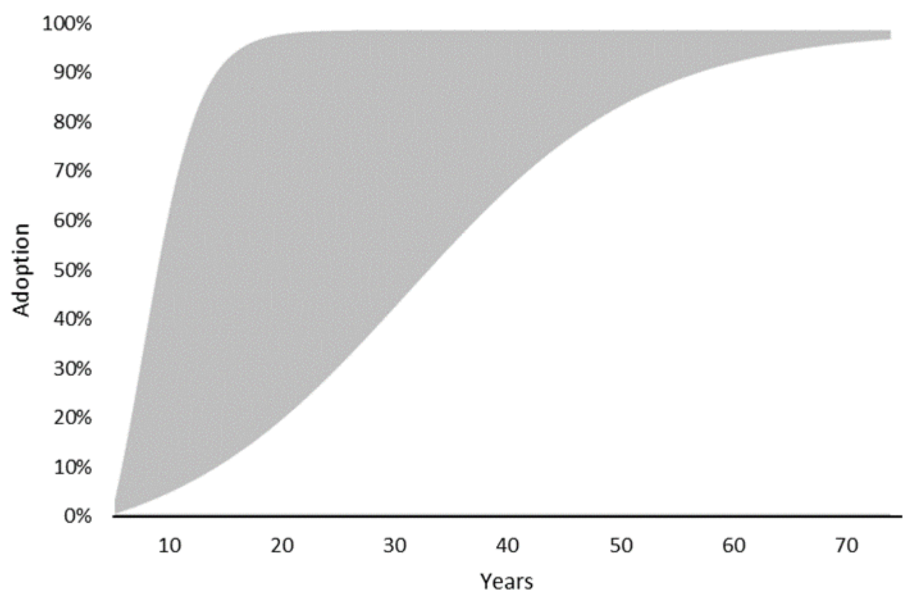
Two coefficients, *p* and *q*, influence the slope and duration of the adoption curve produced by the Bass diffusion model.

- *p* represents the coefficient of innovation
- *q* represents the coefficient of imitation

A significant amount of research has been done to evaluate adoption curves for various products and their associated *p* and *q* values. BEEM draws from a 2011 paper by Daim, Iskin, and Ho that analyzes the pace, cost, and value of adoption, and the efficiency of residential energy management technologies to develop a set of four adoption curves.[16]

The study team assumed that the range of adoption curves reflected in this paper is reasonable for technology uptake where barriers to adoption (such as technology complexity, customer awareness, and supply chain issues) are addressed effectively. However, for measures where barriers remain high, the study extended the duration of the adoption curves. The resulting s-curve range is shown in Figure 4-4.

Figure 4-4. BEEM S-Curve Range



The study used a scoring system to assign measures to s-curves. With this scoring matrix, the study evaluated measure packages by the reference attributes, or characteristics, that capture the current state of a technology and a customer's willingness or ability to adopt a measure package. The matrix also provides the option to adjust these reference attributes in scenario modeling due to policy

16 Daim, Tugrul, Ibrahim Iskin, and Daniel Ho. October 2011. "Technology Forecasting for Residential Energy Management Devices." *Foresight* 13(6): 70-87. See https://www.researchgate.net/publication/235261177_Technology_forecasting_for_residential_energy_management_devices for this document.

interventions or market developments. Table 4-2 lists the scoring matrix reference attributes and weightings.

Table 4-2. Scoring Matrix

Reference Attributes		
Customer	**Technology**	**Barriers**
Captures the ease and willingness of customers to adopt a measure package (setting aside project return)	Captures aspects of technologies such as transaction costs (hassle factor), technology complexity, depth of renovation or operational change required, and ancillary benefits.	Captures other characteristics that limit the adoption of measure packages, such as customer awareness and confidence, supply chain and workforce development, availability of finance solutions, and landlord/tenant split-incentive issues

The **customer attribute** captures the ease and willingness of customers to adopt a measure package (setting aside project economics that are addressed using a scalar, as discussed above). For example, when a measure meets financial requirements, commercial customers may respond more quickly than multifamily customers, who must weigh the impacts of measures across many tenants. The customer scoring in BEEM is based on sector type, with the commercial sector receiving a favorable score, the single-family sector receiving a medium score, and the multifamily sector receiving an unfavorable score. Further nuances can be captured based on ownership type. Note that this attribute is intended to capture inherent differences between customer types. Aspects that are or should be expected to be impacted by policy interventions (such as issues around landlord/tenant split incentives) are typically captured by the barriers attribute.

The **technology attribute** captures aspects of technologies such as transaction costs (hassle factor), technology complexity, depth of renovation or operational change required, and ancillary benefits. For example, lighting receives a favorable score since it is a relatively simple solution to implement. However, deep shell packages receive an unfavorable score due to their potentially high level of intrusiveness and their complexity. The study based this scoring on the current state of a measure package.

The **barriers attribute** captures other characteristics that limit the adoption of measure packages, such as customer awareness and confidence, supply chain and workforce development, the availability of finance solutions, and landlord/tenant split incentive issues. The study based the ranking of this characteristic on the technology being considered. For example, due to workforce limitations, technologies with less mature markets face greater barriers than those with more mature markets. The study also differentiated barriers by customer sector.

The study used this scoring framework and the resulting weighted score to determine the associated p and q values that define each measure's unique s-curve, selecting from the full range shown in Figure 4-4, above.

In brief, the study determined the annual adoption rate for a given measure by multiplying the adoption percentage from its unique s-curve by the IRR scalar percentage then applied this annual adoption rate to the annually applicable sites to estimate the number of achievable installations in a given year.

4.6 Sales Calibration

As illustrated in Figure 1-1, the first step of the study was to build a calibrated statewide energy sales profile based on building stock data and estimates of building energy use. The methodology included a step to calibrate the statewide energy sales profile to verified utility-level energy sales data.

Table 4-3 shows the data sources consulted to develop utility-specific calibration factors. For electricity sales, the study compared the EIA Form 861 data against utility-provided sales data (as this data was made available) and found that the two sources generally aligned. For natural gas and fuel oil/propane, calibration of fossil fuel loads was performed at a statewide level based on available data.

Table 4-3. Format and Data Sources for Calibration Factors

Electric Utility	Electric (kWh)	Electric (kW)	Gas	Fuel Oil/ Propane	District Steam
Central Hudson Gas & Elec Corp	EIA 861, utility sales data	Utility data, NYISO Gold Book	EIA State Energy Data System (SEDS), utility sales data	EIA SEDS	No calibration (insufficient data)
Consolidated Edison Co-NY Inc					
Long Island Power Authority					
New York State Elec & Gas Corp					
Niagara Mohawk Power Corp					
Orange & Rockland Utils Inc					
Rochester Gas & Electric Corp					

The study adjusted system peaks by energy sales calibration factors, since utility-provided peak estimates included industrial and transportation loads, which are not the subject of this study.

Table 4-4 shows EIA 2020 statewide energy sales in trillion British thermal units (TBtu).

Table 4-4. EIA 2020 Statewide Energy Sales (TBtu)

<table>
<tr><th>Sector</th><th>Utility</th><th>Electric</th><th>Gas</th><th>Oil/Propane</th><th>District Steam</th></tr>
<tr><td rowspan="7">Residential</td><td>Central Hudson Gas & Elec Corp</td><td>7.93</td><td rowspan="7">451.80</td><td rowspan="7">106.40</td><td rowspan="7">No calibration</td></tr>
<tr><td>Consolidated Edison Co-NY Inc</td><td>50.11</td></tr>
<tr><td>Long Island Power Authority</td><td>34.20</td></tr>
<tr><td>New York State Elec & Gas Corp</td><td>25.51</td></tr>
<tr><td>Niagara Mohawk Power Corp.</td><td>43.64</td></tr>
<tr><td>Orange & Rockland Utils Inc</td><td>6.26</td></tr>
<tr><td>Rochester Gas & Electric Corp</td><td>10.31</td></tr>
<tr><td rowspan="7">Commercial</td><td>Central Hudson Gas & Elec Corp</td><td>6.36</td><td rowspan="7">298.60</td><td rowspan="7">63.10</td><td rowspan="7">No calibration</td></tr>
<tr><td>Consolidated Edison Co-NY Inc</td><td>121.72</td></tr>
<tr><td>Long Island Power Authority</td><td>31.47</td></tr>
<tr><td>New York State Elec & Gas Corp</td><td>19.34</td></tr>
<tr><td>Niagara Mohawk Power Corp.</td><td>42.38</td></tr>
<tr><td>Orange & Rockland Utils Inc</td><td>6.79</td></tr>
<tr><td>Rochester Gas & Electric Corp</td><td>10.52</td></tr>
<tr><td colspan="2">Total</td><td>416.55</td><td>750.40</td><td>169.50</td><td>No calibration</td></tr>
</table>

5 Result Validation and Quality Assurance/Quality Control

The study team worked with NYSERDA to validate model outputs:

- **Quality assurance/quality control of BEEM model results.** The study team performed raw output validations internally for interim modeling outputs and each scenario to ensure the quality of the results from different levels and perspectives. Specifically, the study team validated the commercial sector modeling by reviewing building simulation profiles, cost-effectiveness results, and annual energy consumption results along with adoption forecasts plus cost decline results.
- **Quality assurance/quality control of new features.** Several changes were made to the BEEM model for this study. The study tested and validated new features that were introduced to BEEM, such as modeling the LL97 requirement.
- **Comparison to key metrics at NYS level.** For electric and natural gas fuels, the study calculated the BEEM tool existing conditions input fuel and peak demand in aggregate for all end uses in all sectors for New York State buildings. The study compared these constructed sector-specific loads to utility residential and commercial sales for New York State.
- **Quality assurance/quality control of measure-level potential results.** The study conducted a thorough review and benchmarking of measure-level potential results to identify and rectify measure-specific issues. This included identifying odd results, investigating the drivers, and adjusting inputs if necessary.