New York State Energy Research and Development Authority

Energy Efficiency and Renewable Energy Potential Study of New York State

Volume 2: Energy Efficiency Methodology and Detailed Results

Final Report

April 2014

Report Number 14-19

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Volume 2: Energy Efficiency Methodology and Detailed Results

Final Report

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Notice

Abstract

This study presents the potential for increased adoption of energy efficiency and renewable energy technologies in New York State. It focuses on the long-term potential using a twenty-year study period, 2013–2032. Efficiency potential results are presented in terms of "achievable potential" and "economic potential" (the cost-effective energy savings). The report presents these results statewide as well as separately for each of four regional zones (Long Island, New York City, Hudson Valley, and Upstate). The efficiency portion of the study includes electricity, natural gas, and petroleum fuels in the building and industrial sectors, but excludes transportation energy use. For renewable energy, the study analyzes the economic potential and the "bounded technical potential," a measurement of what theoretically would be possible if cost were not a factor. These figures are for renewable resources serving the energy needs of buildings and electric generation. The major renewable resource categories include biomass, hydro, solar, and wind. The study also assesses alternative allocations between various renewable technology options. Overall, the study finds that large amounts of energy efficiency and renewable energy potential exist through the study period. Pursuing additional cost-effective clean energy potential in the State is anticipated to result in long-term net benefits to New York citizens.

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1 Overview and Approach

The general approach and scope of this study are described in Volume 1. This section expands on the information provided in Volume 1, with additional detail specific to the energy efficiency potential assessment as it applies to all sectors (residential, commercial, industrial). The following section then provides more specific detail by sector.

1.1 Modeling Approach

Our general approach is a top-down analysis that begins with the energy forecast by sector, estimates the quantities of energy for various end uses, building types, and industrial sub-sectors for each year of the forecast, and then determines the amount of energy that can be saved by each efficient technology or practice within each "bucket" of applicable end-use energy. The approach used for the energy sales disaggregation is described below for each sector.

The study includes potential assessments for electricity, natural gas, and petroleum fuels. The petroleum fuels include distillate and residual fuel oil, LPG/propane, and kerosene – these have been assessed in aggregate rather than individually.

The following steps summarize the modeling approach used to assess the energy efficiency potential. Some of these modeling steps and their required inputs are described in greater detail in Volume 1, and some are expanded upon in the sections below.

1. Determine the energy forecast for each fuel type (electric, natural gas, petroleum fuels).
2. Disaggregate the end-use energy by market segment (e.g., by end use and building type), to which efficiency measures apply.
3. Identify efficiency measures applicable to each market segment.
4. Characterize the costs, savings, and lifetimes of the efficiency measures.
5. Determine the cost-effectiveness of the efficiency measures.
6. Estimate measure market saturations and their applicability to the end-use energy categories as determined in step 2.
7. Estimate annual measure penetrations (or installation rates) depending on the potential scenario
8. Estimate annual program costs (achievable scenario only).
9. Perform the modeling, which accounts for measure installations by year, and their annual costs and savings.

Appendix H in Volume 4 provides a summary of the assumptions and inputs used for the analysis.

1.2 Market Segmentation

The market for energy efficiency applications is segmented differently for each of the residential, commercial, and industrial sectors. For the residential sector, efficiency applications are segmented primarily by major end use and building type (single family and multifamily). The commercial sector also segments the market by end-use and building type, but with a larger number of each due to the much greater variation in building types and technology applications in the commercial sector. In contrast, the industrial sector is segmented primarily by the type of industry (chemicals, mining, etc.) due to the application-specific nature of each industry.

The multifamily market spans both the residential and commercial sectors. Buildings with five or more living units were considered to be multifamily for the study. Larger multifamily buildings with central systems are generally on residential rates and were thus included in the residential analysis for this study. However, because natural gas and petroleum fuel opportunities are commercial in nature (e.g., large central boilers and water heating systems), we analyzed them under the commercial approach. We did not have suitable data for a detailed segmentation of the multifamily market between the residential and commercial sectors, and thus assumed that buildings with 20 or more units would have centralized heat and hot water suitable for the commercial analysis. Most multifamily electric usage was assumed to be in the residential sector. Given these assumptions, the multifamily segmentation was less rigorous than the primary segmentation of the residential, commercial, and industrial sectors. The multifamily results are presented within the detailed building-type results for each sector.

The market segments are further described below for each sector.

1.3 Technology Characterization

The next step in the analysis is to characterize the efficiency measures that are either currently available or are expected to be available over the time frame of the analysis. Measure characterizations describe all aspects of an efficiency measure necessary to assess its impact, including the amount of energy it saves, its cost, the situations in which it is technically feasible, its expected useful operating life, and others. Measure characterizations must always be stated relative to an appropriate baseline. For example, we must assess how much energy an efficiency measure will save as compared to some other less efficient technology or equipment.

Although many potential studies are developed with the intent of informing program design and planning assistance in the near term (e.g., up to about 5 years), the emphasis of this study is on long-term projections of efficiency potential. Therefore, rather than seek a relatively high degree of confidence in the early years of the forecast, this study emphasizes estimates of the energy efficiency potential in the medium and long term under various scenarios for the future. The study thus has a focus on longer-term technology trends and on emerging technologies, which can be applied to alternative policy scenarios.

To support this approach, we have generally characterized bundled or "aggregate" measures as opposed to highly specific or "granular" measures. For example, we have characterized "interior lighting controls" in aggregate, rather than analyze separate measures for occupancy sensors, daylight dimming, and other individual types of lighting controls. The use of more highly aggregated measures provides greater flexibility for longer-term projections of the potential impacts for different scenarios. However, this approach still requires us to develop underlying individual component measures which inform the aggregate measures' costs and savings in the initial analysis year(s). These aggregate measure characterizations are then adjusted through time as necessary to reflect prevailing trends and assumptions of dominating technologies and practices.

The scope of the energy efficiency assessment did not include the following measures:

- Fuel switching measures.
- Combined heat and power (CHP). Those who wish further information on potential energy savings from CHP in New York should refer to the 2002 *Combined Heat and Power Market Potential for New York State*.[1]
- Passive solar homes. However, see the Advanced Solar Homes section of Volume 3 for a discussion of solar design opportunities and the associated potential for increased efficiency for residential new construction.
- Demand response measures.

Another area outside the scope of the study is the impact of increased energy efficiency on power factor, which is the ratio of the real power serving the electric load to apparent power in the circuit. Electric utilities seek to maintain a high power factor, which minimizes energy losses in the distribution system. There was no practical way to evaluate the impact of efficient equipment on power factor for the various efficiency scenarios, thus we are not able to speculate on whether there is any net effect on the power factor. This could be an area for future study.

Appendix D in Volume 4 provides the full measure characterizations for each sector. More detail on the measure characterizations is provided below for each sector.

1.4 Electric Load Shapes

Because the market price of electric energy varies on an hourly and daily basis, an accurate estimate of the benefits of avoiding electricity consumption must consider the timing of these avoided kilowatt-hours. For ease of analysis, the avoided energy supply costs in this study were divided into six energy costing periods: summer peak and off-peak, winter peak and off-peak, summer shoulder, and winter shoulder (see Appendix A in Volume 4 for the exact time periods of the energy costing periods). The analysis requires electric load shapes to determine the portion of

[1] NYSERDA. 2002. *Combined Heat and Power Market Potential For New York State*. Prepared for NYSERDA by Energy Nexus Group and Onsite Energy Corporation. http://www.nyserda.ny.gov/Energy-Innovation-and-Business-Development/Research-and-Development/Onsite-Power-Applications/Combined-Heat-and-Power/Market-Potential-for-CHP.aspx. Accessed July 2013.

each measure's annual electric energy savings that occurs during each of these six periods. We developed load shapes specific to each end use and building type or industrial segment in this study. In the case of weather sensitive end uses (e.g., cooling and heating), load shapes were differentiated by regional analysis zone. Peak demand coincidence factors were also associated with each load shape, to determine the benefit of demand reduction during peak times as expressed by an avoided capacity value.

We derived our load shapes from 2002 Itron eShapes data for New York State. The eShapes data provide hourly load profiles by building type and end use for a variety of New York weather stations. This data set remains the best-available data for the broad range of building types, end uses, and climates accounted for in the analysis.

1.5 Measure Cost-Effectiveness

Measure cost-effectiveness is based on an assessment of the measures' costs and benefits. A measure is considered to be cost-effective if its benefits equal or exceed its costs. Only cost-effective measures are included in the economic and achievable potential scenarios. For an overview of the costs and benefits associated with efficiency measures, and the methodology for assessing cost-effectiveness, see the Assessment of Cost-Effectiveness section in Volume 1. The measure benefit-cost ratios are presented in Appendix H in Volume 4.

In some cases, measures may not be cost-effective if installed in the near-term, but may become so in future years due to either to higher future avoided energy costs or to lower costs or other changes in measure characterizations. In such a case, the measure is included in the economic potential, but only beginning when it becomes cost-effective.

The following sections describe how all cost-effective measures are combined into the estimates of the economic and achievable potential scenarios.

1.6 Economic Potential

The economic efficiency potential includes all efficiency potential that is cost-effective, assuming there are no market barriers to adoption of efficiency measures. Put another way, the economic potential assumes that people will choose to implement all cost-effective efficiency measures without the need for efficiency programs. Estimates of economic efficiency potential typically assume immediate installation of all cost-effective measures. To the extent that there are substantial opportunities for retrofit measures, this results in a theoretical potential that far exceeds what is feasible in the short-term, as there would be insufficient resources to implement all retrofits in one year. To generate an economic potential estimate with more relevance for public policy planning, we have prepared a *resource-constrained* economic potential. This estimate assumes that all market-driven measures (i.e., natural replacement, new construction, and renovation) are implemented at the time they become available, but that implementation of cost-effective retrofit measures is spread out over several years.

The economic analysis prioritizes measures that have the highest energy savings, rather than those that are the most cost-effective. As a result, the economic analysis maximizes the efficiency potential and may not include measures that would be included in an achievable scenario. For example, the economic analysis assumes that all efficient cooling source equipment is “tier II”, which is more efficient than “tier I” equipment. The achievable scenario would include installation of both tier I and tier II equipment, since not everyone would be willing to install the more expensive or complex tier II equipment.

The economic potential does not explicitly distinguish between electric, fossil fuel, and petroleum fuel measures, as might occur in an achievable scenario with separate efficiency programs for these fuel types. The economic study results thus reflect the impact of all efficiency measures for all fuel types. Some measures have both primary and secondary fuel types. For example, efficient lighting measures reduce waste heat and thus increase the heating load, which increases overall fossil fuel use. This increase in fossil fuel use is reflected in the total economic efficiency potential for natural gas and petroleum fuels.

Our analysis accounts for interactions between measures installed in the same space. Individual measure savings are not necessarily additive. Because of interactions between measures, the total potential for all measures is less than the sum of individual measure opportunities. For example, building envelope improvements will reduce the cooling load and will thus lower the savings opportunities for high-efficiency air conditioning. The potential estimates take into account all the interactions between measures. This therefore represents the total economic savings achievable with maximum measure adoption. Note however, that if some measures were eliminated, the potential for remaining measures might increase depending on their original interactions with the removed measures.

Our analysis also accounts for measures installed in different markets where the markets affect one another. New measures can be installed in existing buildings either on an early-retirement (retrofit) basis, at the time of natural replacement, or at the time of renovation or remodeling. To avoid double counting, our analysis incorporates the changing eligible stock of equipment over time, based on the measure penetrations for each existing market. For example, if 10% of existing lighting fixtures are retrofit with high efficiency models, then only 90% of the original population of lighting remains eligible for efficiency upgrades in the natural replacement (or replace-on-failure) market in that year. However, assuming the fixtures had a 15-year measure life, the original 10% of lighting fixtures would again become eligible for replacement after 15 years. Similarly, once a building is renovated or remodeled, the opportunity for retrofit is diminished until the end of the measure lives for those measures installed during the renovation.

Finally, we note that the analysis did not consider any overall increase in economic activity that may result from implementation of efficiency measures and a shift to a more energy-efficient economy.

1.7 Achievable Potential

In contrast to the economic potential, the achievable potential recognizes all real-world market barriers to the implementation of cost-effective energy efficiency, and the need for funded programs to help overcome those market barriers. The achievable potential represents that which is actually possible for a given level of funding or other real-world policies.

This study does not presume any specific portfolio of efficiency programs. Likewise, the assessment is not based on any particular model for program administration. Instead, we assume the efficiency programs are well-designed, well-executed, aggressive, and integrated across fuel types. This approach is consistent with the study emphasis on the longer-term (10-20 year) efficiency potential.

Many efficiency measures have multiple fuel impacts. For example, weatherization and building shell measures provide savings for both cooling (typically electric) and heating (typically fossil fuel). Efficiency programs that are limited to assessing either electric or fossil fuel savings would not recognize the combined benefits of electric and fuel savings for such measures. With integrated programs, the total impacts of efficiency measures are assessed without regard to the type of energy saved.

The *incremental cost* of an efficient measure is its cost relative to baseline equipment or practices, including any difference in installation costs. Efficiency potential studies commonly differentiate between achievable scenarios based on the degree to which each scenario offsets the incremental measure costs as one way of promoting their adoption. Of course, efficiency programs use a wide variety of methods to overcome market barriers, including marketing and education, technical assistance and training, upstream buydowns, and other elements of program design.

Given these considerations, the achievable potential was defined as follows for this study:

> The achievable potential is the cost-effective energy efficiency that could realistically be captured with well-designed, aggressive efficiency programs, in which approximately half of the full incremental costs of all efficiency measures is offset by efficiency program incentives.

Efficiency program spending was limited to a level commensurate with paying incentives that average out to 50% of measure incremental costs. The assumed incentives as a percent of incremental cost varied by market or by individual measure, as described below for each sector, but averaged out to 50% of incremental costs for each sector and program year. This represents a level of investment that is considerably higher than New York’s current spending on efficiency programs, but well below what could be achieved with unconstrained investment in energy efficiency.

The achievable analysis relied on the same cost-effective aggregate measures as were used for the economic potential. However, the economic potential assumed that the efficiency measures with the highest savings levels would be implemented. For the achievable scenario we assumed a more realistic mix of measures, e.g., a mix of High Efficiency Cooling Equipment Tier I and Tier II instead of assuming all installations were at the Tier II level (with higher savings).

1.7.1 Measure Penetrations Methodology

The estimation of measure penetrations, or installation rates, in response to financial incentives and other types of program intervention, is the basis for estimating achievable program savings and associated program costs. Our methodology for estimating penetration rates begins with an assessment of each measure's market barriers.

Market barriers have been extensively discussed in the literature. For the purposes of our methodology, we consider market barriers grouped into four categories:

- **Awareness:** of efficiency measures' potential application, benefits, and possible incentives
- **Willingness:** due to magnitude of lifetime benefits, personal/organizational practices, split incentives, uncertainty or distrust of performance/benefits, fear of unintended consequences, hassle factor, irreversibility, etc.
- **Availability:** of equipment or installation contractors.
- **Cost:** initial cost, operation and maintenance costs, access to financing

We first assess the impact of the "awareness" market barrier on a measure's penetration rates. End-users, retailers, or contractors must be aware of an efficiency measure before it has the potential to be installed. "Awareness" means that one knows enough about the measure to have some opinion as to whether it's worth consideration. Our methodology estimates an initial, current awareness and assumes that awareness will grow in response to program activity. We assumed the achievable scenario had well-funded, aggressive marketing and outreach activities to expand awareness of efficiency opportunities. Based on this assumption, we estimated the maximum awareness that could be attained for each measure, and the number of years needed to reach that level of awareness. In a given year, only the "aware" portion of the population is considered to be available for efficiency measure installations. Note that for some technologies it is possible for customers to participate in a program and receive an indirect incentive without being personally aware of the program, as with upstream buydown or supplier training programs. Therefore, efficiency measure "awareness" can be addressed by the program strategy at the customer level or within the supply chain.

We next assess and estimate the level of the "willingness" barrier for each measure on a scale of 1 to 5 (ignoring cost, which is a separate market barrier). We also estimate the first-year penetration rate based on current market conditions. The estimated level of the willingness barrier has associated with it a maximum penetration rate and the number of years to overcome market barriers and reach that penetration. The maximum penetration for the aware population is generally estimated in the range of about 50–85% depending on the measure and applicable options for program delivery.

The level of the willingness barrier also has associated with it the shape of the adoption curve for achieving the maximum penetration rate. We assume a standard S curve (sigmoid curve) where the adoption rate generally increases in the initial years in response to program intervention, eventually leveling off as it approaches the maximum penetration. The initial rate of response to program interventions is highest for measures with the lowest level of market barriers. For each year the "willingness" penetration is applied to the aware population to determine the resulting measure penetration.

Measure "availability" is factored in at this point, which may lower the penetration rate due to limited availability of equipment or installation contractors. However, availability is usually not a limiting factor for increasing measure adoption rates. While some measures may have availability constraints, such as for measures that require specialized contractors, we generally assume that the market will respond in the near term when demand outstrips supply.

The last category of market barriers is "cost," or the incremental costs of an efficiency measure over baseline equipment or practices. From the customer's perspective, the incremental cost is decreased by any incentive received. The customer economics are typically measured by the measure's participant benefit-cost ratio (BCR) and its simple payback. The BCR represents lifetime benefits relative to costs, and is thus a better measure of overall customer economics. However, although the simple payback ignores lifetime benefits, it is often given significant weight in the decision of whether to invest in energy efficiency. For various reasons, decision makers often place greater value on near-term rather than long-term cost-benefit trade-offs. We account for this by determining an *implicit participant BCR* for each measure based on a relatively high *implicit discount rate*.[2,3,4] We apply an implicit discount rate of 35%, which is roughly the median of published values.[5] This has the effect of decreasing the value of future benefits, thus giving a higher relative value to measures with shorter payback periods.

Based on each measure's implicit BCR, we estimate the annual penetration rate as a portion of the penetration already derived based on awareness, willingness, and availability. The higher the implicit BCR, the greater the portion of the population assumed to install the efficiency measure. The resulting annual penetration rates are applied to determine a measure's achievable potential in each year.

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2 Eto, Joseph, Ralph Prahl, Jeff Schlegel. 1996. *A Scoping Study on Energy-Efficiency Market Transformation by California Utility DSM Programs*. LBNL-39058. Prepared for the California Demand-Side Measurement Advisory Committee.

3 Moezzi, Mithra, Maithili Lyer, Loren Lutzenhiser, James Woods. 2009. *Behavioral Assumptions in Energy Efficiency Potential Studies*. Prepared for the California Institute for Energy and Environment (CIEE) Behavior and Energy Program.

4 Sanstad, Alan, W. Michael Hanemann, Maxamilian Auffhammer. 2006. "Chapter 6, End-Use Energy Efficiency in a 'Post-Carbon' California Economy: Policy Issues and Research Frontiers." In *Managing Greenhouse Gas Emissions in California*. Prepared by the California Climate Change Center at UC Berkeley.

5 Sanstad et al. 2006, Table 1.

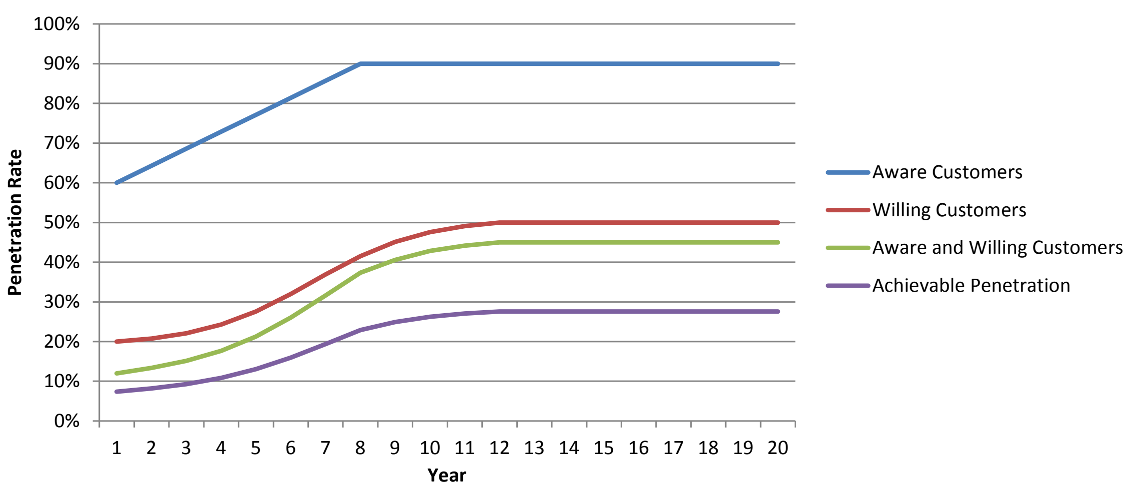
The achievable measure penetrations are presented in Appendix F in Volume 4.

1.7.1.1 Example of Estimating Measure Penetrations

As an example, consider the aggregate measure for commercial Task Lighting in the lost opportunity market (natural replacement, new construction, and renovation). For this measure we assumed an initial awareness of 60% and a maximum awareness of 90% that could be achieved over 8 years. We assumed that commercial Task Lighting has somewhat high market barriers (4 on a scale of 1 to 5), and an initial "willingness" penetration rate of 20%. For the assumed level of willingness barriers, and assuming fully-funded, optimized program delivery, the measure was assumed to have a maximum penetration of 50% that could be achieved over a period of 12 years. We also assumed that measure availability was not a limiting factor. Applying these assumptions (excluding the "cost" barrier) resulted in an overall penetration rate of 12% in the first year (60% aware * 20% willing), increasing to 45% by year 12 (90% aware * 50% willing).

The achievable penetration rates were then estimated based on the measure's implicit participant BCR. Applying an implicit discount rate of 35%, we found the measure's implicit participant BCR to be 2.45. Based on this implicit participant BCR, the annual achievable penetrations were estimated to be 61% of the penetrations calculated above based on the other market barriers. The figure below presents the assumptions applied and the resulting achievable penetration rates for this example.

Figure 1. Example of Estimating Measure Penetration Rates.



1.7.2 Program Costs

Program costs include measure incentives along with other efficiency program costs, including marketing and outreach, technical assistance, building space to support program staff and operations, monitoring and evaluation of programs to measure and validate the savings, performance incentives for program administrators, and general program administration. We assumed the achievable scenario had well-funded and aggressive marketing and outreach activities to overcome various market barriers, and estimated the program costs based on the experience of current top-performing efficiency programs, scaling that cost data to the New York market and relative to incentive spending.

1.7.3 Free Ridership and Spillover Assumptions

Efficiency programs provide various incentives to promote the adoption of efficiency measures. Of course, some people or businesses take advantage of incentives for efficient equipment that they would have bought without the incentive – these are *free riders* to the efficiency program. The savings from free riders' efficiency measures should not be attributed to the efficiency program since they would have installed the measure without the program.

At the same time, efficiency program activities tend to have a *spillover* effect, whereby they encourage adoption of efficiency measures by people who would not have done so without the program, but who for various reasons never collect an incentive. The savings of their measures should be attributed to the program since they would not have installed the measure without the program.

The balance between free ridership, which decreases program savings relative to the number of program participants (who receive an incentive), and spillover, which increases savings relative to the number of participants, is hotly debated within the industry. Program evaluations often find free ridership to be a greater factor, but many argue that free ridership is easier to measure and spillover is often ignored, and that the broader impacts of spillover take place over longer time horizons.[6,7]

This achievable scenario is focused on the longer-term potential for well-funded programs operating over two decades, with an expectation of a significant level of market transformation. We have also assumed that the savings from naturally occurring efficiency, much of which would typically be attributed to free riders, are embedded in the underlying econometric energy sales forecasts. As such, our top-down methodology considers the savings from

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[6] State and Local Energy Efficiency Action Network. 2012. *Energy Efficiency Program Impact Evaluation Guide*. Prepared by Steven R. Schiller, Schiller Consulting, Inc. http://www1.eere.energy.gov/seeaction/pdfs/emv_ee_program_impact_guide.pdf

[7] Blumstein, Carl. 2009. *Program Evaluation and Incentives for Administrators of Energy-Efficiency Programs: Can Evaluation Solve the Principal/Agent Problem?* ECEEE Paper 3147. http://www.ucei.berkeley.edu/PDF/csemwp184.pdf. Accessed 9/25/2013.

those "naturally occurring" free riders as unavailable for energy efficiency. Given these factors, we have therefore assumed for this study that the effects of free ridership and spillover cancel each other out. We believe any uncertainty introduced by this assumption will be small relative to the overall uncertainties in a study of this duration and scope.

1.8 Technology Learning Curve Effects

Learning curve effects have been observed for many new technologies as demand for them grows and their production volumes increase. The observed effect is that we learn how to refine and streamline the production process over time, resulting in lower costs per unit of output. Learning curve effects are separate from cost reductions due to economies of scale.

The degree to which energy efficiency technologies are subject to learning curve effects, and thus lower costs over time, is debatable. For emerging technologies there is certainly often a reduction in cost over time. But efficient technologies are different from many other products in that they are generally installed in place of lower-efficiency equipment to serve the same function. The impetus to install efficient equipment is that its incremental cost relative to baseline equipment be low enough to make the equipment desirably cost-effective. When the cost has come down enough that demand increases, the technology may have already experienced a substantial portion of the learning curve effects. Another aspect is that baselines gradually rise over time whether due to increased codes and standards, greater market acceptance, or a combination of reasons. So as costs come down, the energy savings may be reduced as well so that the cost per unit of energy saved remains fairly constant. There may be game-changing technologies like solid-state lighting that experience learning curve effects, but it is unclear if it would be appropriate to assume learning curve effects for all or a large part of the overall efficiency portfolio. In fact, the overall cost of energy efficiency per unit of energy saved has tended to track fairly constant over time, rather than experiencing a gradual reduction in the cost, as the market for efficiency responds to a multitude of economic, social, and political feedback effects.

Given these considerations, we have not applied any broad learning curve assumptions to our efficiency measure characterizations. For selected measures like LED lighting there is clearly an expectation of reduced costs in the future per lumen of light produced, and this is reflected in our solid-state lighting measure characterizations. But we handle this as a specific case that should not necessarily be extrapolated to a larger class of efficiency measures.

2 Portfolio Level Results

The section provides additional study results to those already presented in the Energy Efficiency High-Level Results in Volume 1. Following the portfolio level results we present more detailed disaggregated results for each sector.

All electric savings and forecast energy values are at the "point of purchase" as opposed to "at meter." Point of purchase savings correspond to avoided costs at the entrance to the utility service territories and include savings in transmission line losses. Customer meter level savings also reflect a reduction in distribution level losses commensurate with reduced system deliveries.

Figure 2 shows historic and baseline forecasts for each fuel, along with a shaded wedge showing the potential and lower resulting forecast if all achievable savings were captured. The overall achievable electric potential is 18% of forecast baseline load in 2030. Capture of this potential would result in a slightly declining electric demand in the first decade (i.e., negative "load growth"), followed by a slight rise in electric demand in the second decade. The increase in electric load in the second decade is a result of two factors, and should be viewed as a conservative estimate of future long term potential. First, as the study period expands, many of the early installed measures reach the end of their useful life and savings attributed to those measures goes away. We do not automatically assume these efficiency measures will necessarily be replaced with similar high efficiency versions absent continued market intervention programs and funding. Second, the effects of technology advancement over time become more and more speculative as one goes farther into the future. We have been conservative in assumptions about potential emerging technologies that cannot be defined with any reliability at this time. However, experience has shown that over decades technology advancement is likely to more than keep pace with improving baseline efficiency. For example, in 1989 the American Council for an Energy Efficient Economy (ACEEE) performed an electric efficiency potential study for New York State and estimated 30% achievable potential. After more than 14 years as a state leader in efficiency programs, Optimal Energy (with VEIC and ACEEE) performed a 2003 statewide electric efficiency potential study that estimated almost identical achievable potential as had existed in 1989.[8,9] We therefore consider this uptick a conservative estimate of the potential, which can be revisited in a future study.

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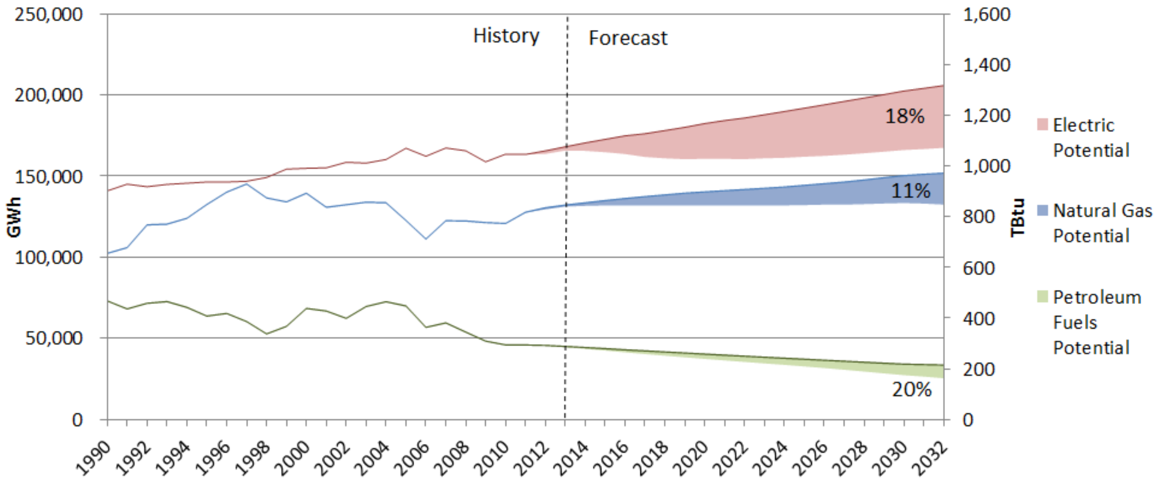
8 Miller, Peter, Joe Eto and Howard Geller. 1989. *The Potential for Electricity Conservation in New York State*. Energy Authority Report 89-12, prepared for the New York State Energy Research and Development Authority by the American Council for an Energy-Efficient Economy.

9 Optimal Energy Inc., Vermont Energy Investment Corp. (VEIC), American Council for an Energy-Efficient Economy (ACEEE). *Energy Efficiency and Renewable Energy Resource Development Potential in New York State: Final Report*, Volumes 1 to 7. Prepared for the New York State Energy Research and Development Authority.

Figure 2. Achievable Savings Potential by Fuel Relative to Sales Forecast.

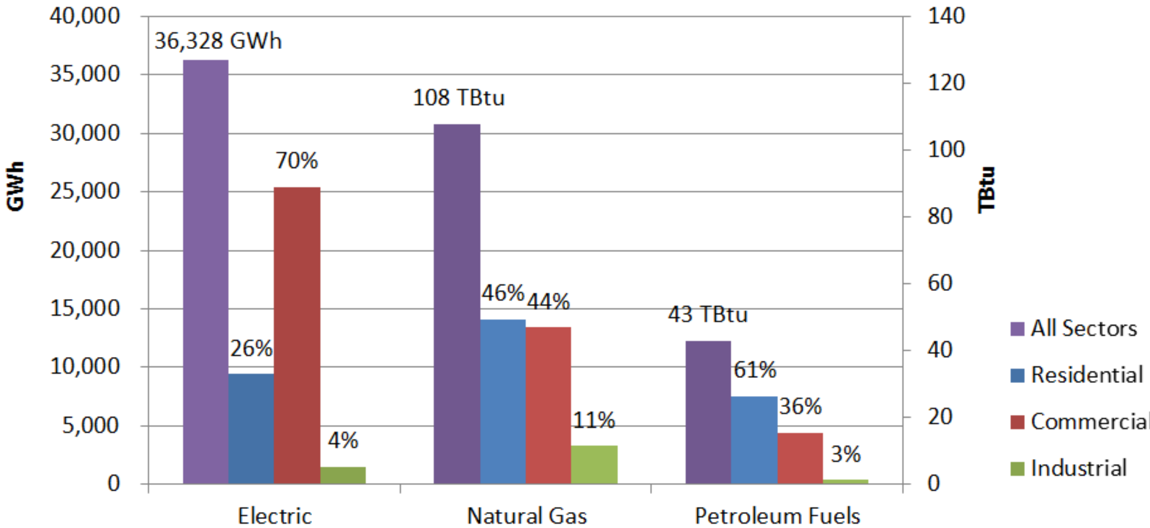
Percentages on the right refer to achievable savings as a percent of forecast in 2030.



The natural gas potential is estimated at 11% by 2030, roughly offsetting expected baseline forecast load growth. Natural gas potential tends to be relatively lower than electric for a number of reasons, where the primary driver is the relatively low cost of natural gas making efficiency measures less cost-effective. Petroleum potential is estimated at 20% by 2030, similar to electricity. Capture of this achievable petroleum potential would further reduce forecast loads that are already predicted to drop as a result of the current and projected significant economic savings of conversions to gas and environmental policies to reduce carbon and particulate emissions from heavy oil.

Figure 3 shows the achievable potential by fuel and sector. For electric, commercial buildings offer a significantly larger portion of savings than residential or industrial. This is to be expected, and consistent with the results of many efficiency portfolios that find both more and more cost-effective electric opportunities in the commercial sector. This is partly driven by the higher electric loads in commercial facilities and greater cooling needs, the longer run hours of equipment and more favorable economics of efficiency, and also the dramatic progress in the past through efficiency programs and codes and standards that have significantly reduced cost-effective residential opportunities from lighting and appliances.

Figure 3. Achievable Savings Potential by Fuel and Sector, 2030.



Natural gas savings by sector are relatively even between residential and commercial, reflecting the large building shell and space heating opportunities in the residential sector. For petroleum, residential offers the greatest share of efficiency potential. This is driven by the relatively higher market share of oil in residential homes and the lower heating needs of larger commercial buildings.

Overall, industrial efficiency potential is much less significant in New York than commercial and residential sectors, driven primarily by the relative shifts in the economy away from heavy industries and toward more service industries (generally classified under commercial).

Figure 4 shows a disaggregation of the achievable scenario petroleum efficiency potential by fuel type. As is expected, the vast majority of potential comes from distillate oil, followed by LPG (propane). The graph also shows the significant forecasted usage reductions expected during the planning period from residual #4 and #6 fuel oil.

Table 1 shows annual program costs for the achievable scenario for selected years, broken out by sector.

Figure 4. Achievable Savings Potential by Individual Petroleum Fuel Relative to Sales Forecast.

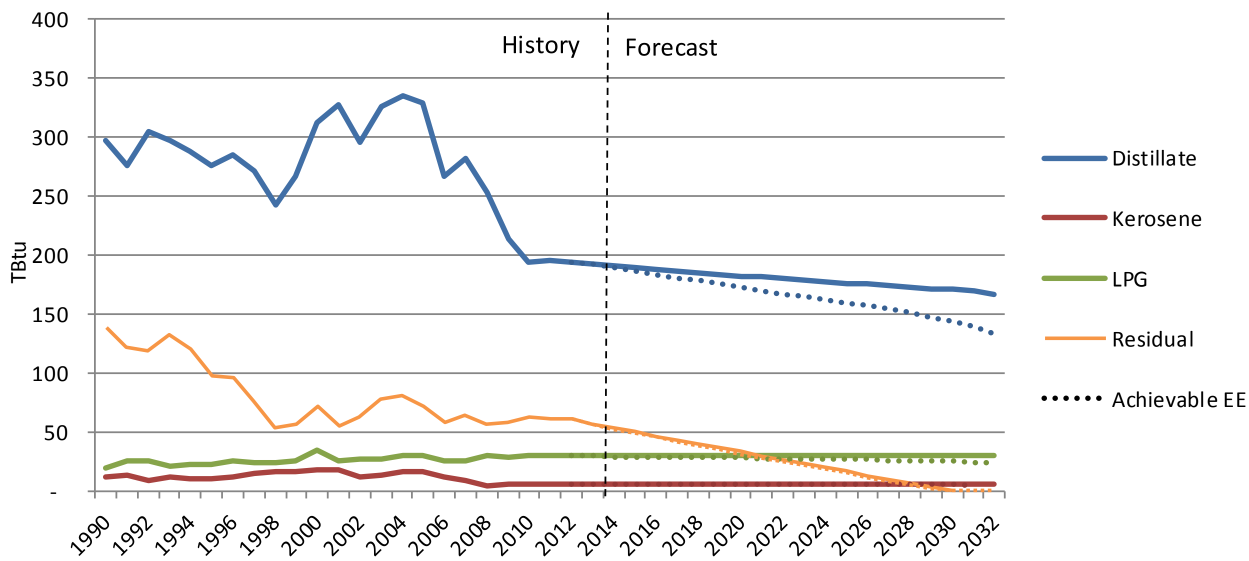


Table 1. Summary of Program Costs by Sector, Achievable Scenario (Non-Discounted Million 2012$).

Sector	2013	2015	2017	2020	2025	2030
Residential	$384	$491	$513	$450	$951	$2,178
Incentive Costs	$258	$330	$345	$302	$638	$1,462
Non-Incentive Costs	$126	$162	$169	$148	$313	$716
Commercial	$941	$1,030	$998	$981	$904	$990
Incentive Costs	$621	$679	$658	$647	$597	$653
Non-Incentive Costs	$320	$350	$340	$334	$308	$337
Industrial	$14	$92	$140	$42	$27	$26
Incentive Costs	$9	$57	$87	$26	$17	$16
Non-Incentive Costs	$5	$35	$53	$16	$10	$10
All Sectors	**$1,092**	**$1,342**	**$1,392**	**$1,257**	**$1,685**	**$2,972**
Incentive Costs	$724	$887	$919	$833	$1,122	$1,984
Non-Incentive Costs	$368	$455	$474	$424	$564	$987

2.1 Electric Efficiency Potential

Table 2 provides a summary of the economic and achievable electric potential relative to the sales forecast. In addition, the potentials are compared to projected savings for New York's current Energy Efficiency Portfolio Standard (EEPS) initiative. The electric economic potential is 36% and 45% of the forecast for 2020 and 2030, respectively. Pursuit of the achievable scenario would generate savings of 12% and 18% in 2020 and 2030, respectively, reflecting more than twice the savings currently forecast from the EEPS initiative by 2030.

Table 2. Summary of Economic and Achievable Electric Efficiency Potential Relative to Sales Forecast and NYS EEPS, 2020 and 2030.

		2020	2030
Statewide Forecast (GWh)		182,406	202,397
Economic Potential (GWh)		66,123	91,856
	% of Forecast	*36%*	*45%*
Achievable Potential (GWh)		21,748	36,328
	% of Forecast	*12%*	*18%*
Savings from EEPS (GWh)		11,230	17,013
	% of Forecast	*6%*	*8%*

Figure 5 shows coincident summer peak demand savings by sector and analysis zone for the achievable scenario. The largest share of peak savings comes from New York City. This is reflected both by its large energy consumption and higher summer cooling loads relative to the other zones.

Figure 5. Achievable Coincident Summer Peak Savings Potential by Zone and Sector, 2030.

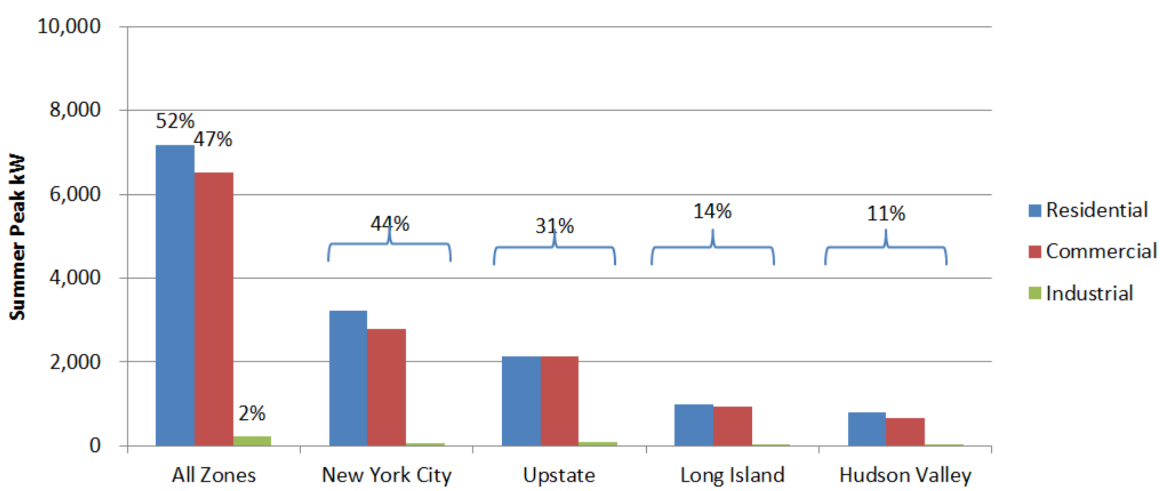


Figure 6 shows the distribution of the total economic potential electric savings among the Residential, Commercial, and Industrial sectors. As discussed above, roughly 64% of the potential is available from commercial, with the bulk of the remainder from residential.

Figure 6. Sector Distribution of Economic Electric Efficiency, 2030 (GWh).

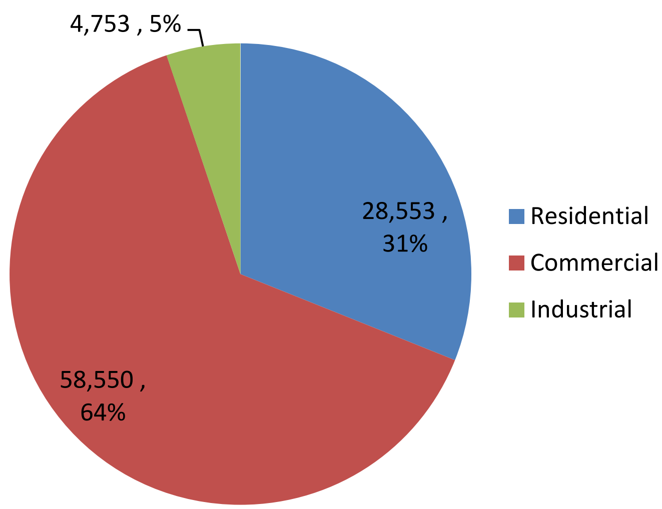
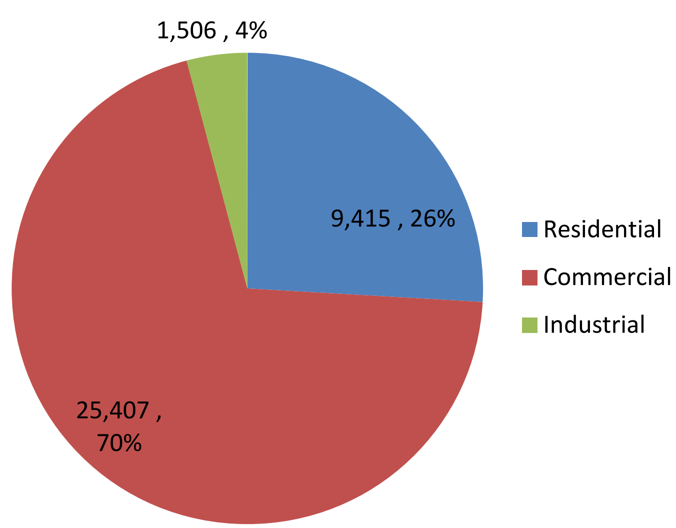


Figure 7 shows the distribution of the electric achievable potential savings among the Residential, Commercial, and Industrial sectors. The commercial sector makes up an even larger portion – 70% vs. 64% – of the potential compared to the distribution of economic savings.

Figure 7. Sector Distribution of Achievable Electric Efficiency, 2030 (GWh).



2.2 Natural Gas Efficiency Potential

Table 3 provides a summary of the economic and achievable natural gas potential relative to the sales forecast and EEPS projections. The natural gas economic potential is 20% and 33% of forecast for 2020 and 2030, respectively. Pursuit of the achievable scenario would generate savings of 6% and 11% in 2020 and 2030, respectively. This reflects about a third of the entire economic opportunities, but 3 times more in 2020 than current EEPS targets and about ten times more by 2030.

Table 3. Summary of Economic and Achievable Natural Gas Efficiency Potential relative to Sales Forecast and NYS EEPS, 2020 and 2030.

		2020	2030
Statewide Forecast (BBtu)		896,194	960,460
Economic Potential (BBtu)		182,928	321,130
	% of Forecast	*20%*	*33%*
Achievable Potential (BBtu)		53,014	107,899
	% of Forecast	*6%*	*11%*
Savings from EEPS (BBtu)		14,100	14,100
	% of Forecast	*2%*	*1%*

Figure 8 shows the distribution of economic potential savings for natural gas by sector. The greatest potential is in the residential sector, with 46% of the total savings potential.

Figure 8. Sector Distribution of Economic Natural Gas Efficiency, 2030 (BBtu).

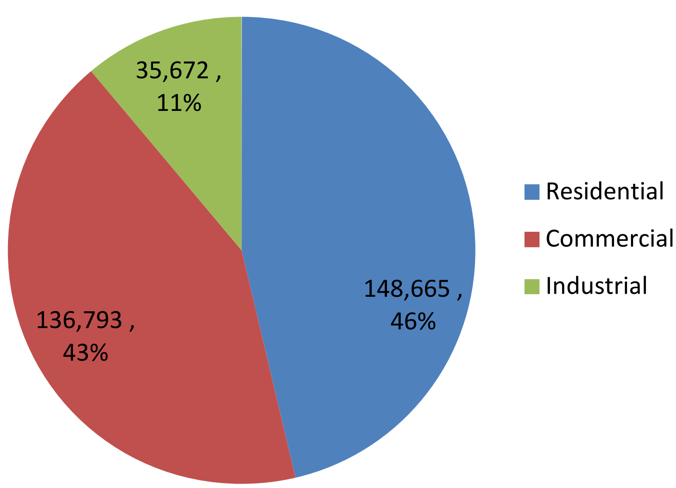
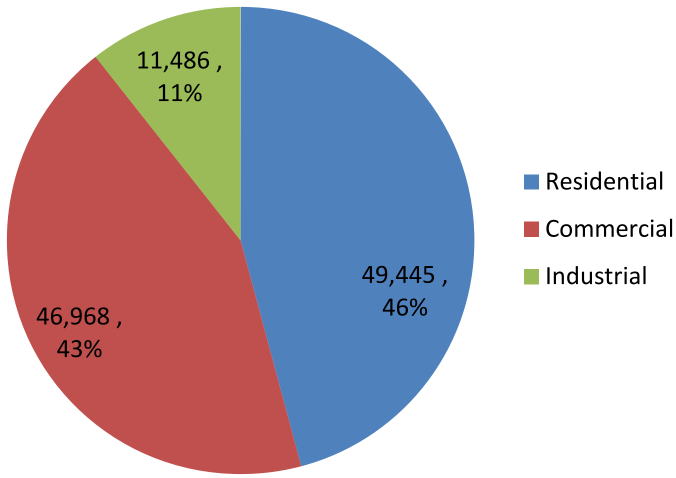


Figure 9 shows the distribution of the achievable potential savings for natural gas by sector. The opportunities are fairly evenly split between residential and commercial, with 43% and 46%, respectively. Industrial potential is about 11% of the total reflecting the diminishing role of heavy industry in New York's economy.

Figure 9. Sector Distribution of Achievable Natural Gas Efficiency, 2030 (BBtu).



2.3 Petroleum Fuels Efficiency Potential

Table 4 provides a summary of the economic and achievable petroleum fuels potential relative to the sales forecast. The petroleum economic potential is 25% and 55% of forecast for 2020 and 2030, respectively. Pursuit of the achievable scenario would generate savings of 7% and 20% in 2020 and 2030, respectively. This reflects about a third of the entire economic opportunities. New York does not currently have EEPS targets for petroleum fuels.

Table 4. Summary of Economic and Achievable Petroleum Fuels Efficiency Potential relative to Sales Forecast, 2020 and 2030

	2020	2030
Statewide Forecast (BBtu)	257,449	217,757
Economic Potential (BBtu)	63,710	119,969
% of Forecast	*25%*	*55%*
Achievable Potential (BBtu)	18,435	43,020
% of Forecast	*7%*	*20%*

Figure 10 shows the distribution of economic potential savings for petroleum fuels by sector. The residential sector offers the greatest share of petroleum efficiency at 60%, followed by commercial at 38% and industrial at 2%

Figure 10. Sector Distribution of Economic Petroleum Fuels Efficiency, 2030 (BBtu).

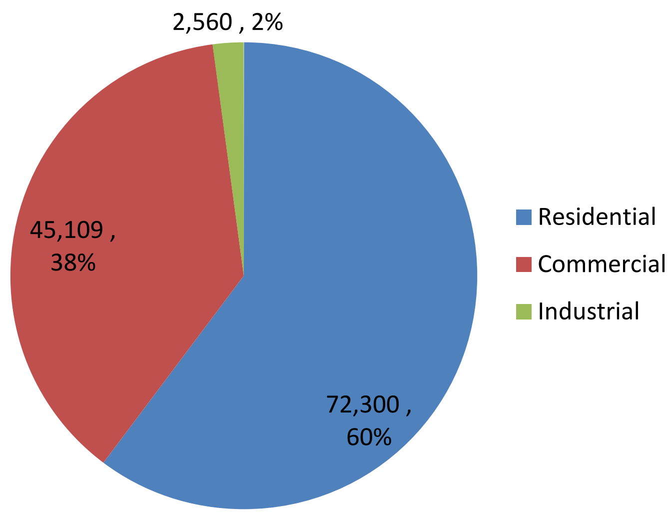
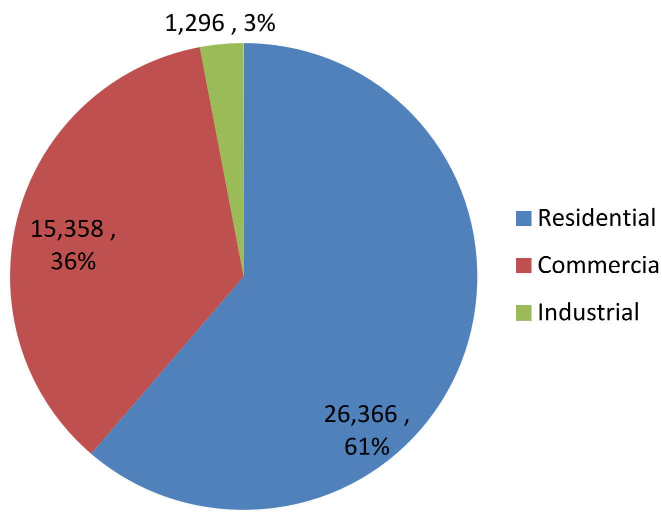


Figure 11 shows the distribution of the achievable potential savings for petroleum fuels by sector. As with the economic potential, the residential sector offers the greatest share of petroleum efficiency at 61%, followed by commercial at 36% and industrial at 3%. The somewhat higher portion of residential opportunities compared to natural gas reflects the greater market share of oil in this sector.

Figure 11. Sector Distribution of Achievable Petroleum Fuels Efficiency, 2030 (BBtu).



2.4 Emissions Reductions

We assessed the emissions reductions associated with energy savings for three categories of emissions. Greenhouse gas reductions were assessed in terms of CO_2-equivalent, or the equivalent amount of CO_2 representing various greenhouse gases (CO_2 is by far the main greenhouse gas reduced by energy efficiency). In addition, we assessed the reductions of two primary criteria pollutants, nitrogen oxides (NOx) and sulfur dioxide (SO_2), which are precursors to smog and acid rain, and cause other health hazards.

Emissions were calculated from the corresponding energy savings using a emissions factors for each fuel type: electric energy, natural gas, and petroleum fuels. The factors only account for the “smokestack” emissions for electric generation, and for the end use consumption for natural gas and petroleum fuels. The upstream impacts of extraction, refinement, and transportation of primary fuels were not included in the analysis. For the specific values applied and their sources, see Appendix J in Volume 4.

Table 5 provides projected emissions reductions for the economic potential in 2020 and 2030, and Table 6 provides the same for the achievable potential. The estimated 2030 economic and achievable CO_2e emissions reductions are equivalent to removing 10.2 and 3.8 million vehicles, respectively, from the road that year.[10]

Table 5. Annual Emissions Reductions, Economic Potential, 2020 and 2030.

Note: t = metric tons, MMtCO_2e = million metric tons of CO_2 equivalent.

Sector	Economic, 2020			Economic, 2030		
	CO_2e (MMtCO_2e)	**NOx (t)**	**SO_2 (t)**	**CO_2e (MMtCO_2e)**	**NOx (t)**	**SO_2 (t)**
Residential	10.17	11,551	9,679	20.43	23,111	17,376
Commercial	17.87	20,304	18,261	25.49	28,759	25,504
Industrial	3.18	3,281	2,120	3.29	3,344	1,969
Total	**31.22**	**35,135**	**30,059**	**49.21**	**55,214**	**44,850**

Table 6. Annual Emissions Reductions, Achievable Potential, 2020 and 2030.

Note: t = metric tons, MMtCO_2e = million metric tons of CO_2 equivalent.

Sector	Achievable, 2020			Achievable, 2030		
	CO_2e (MMtCO_2e)	**NOx (t)**	**SO_2 (t)**	**CO_2e (MMtCO_2e)**	**NOx (t)**	**SO_2 (t)**
Residential	2.48	2,841	2,469	6.94	7,907	5,977
Commercial	5.84	6,653	6,098	10.10	11,465	10,652
Industrial	1.39	1,468	1,071	1.09	1,120	671
Total	**9.71**	**10,961**	**9,638**	**18.13**	**20,492**	**17,300**

[10] Assuming 4.8 t/CO_2e/vehicle/year, as calculated in EPA Clean Energy Calculations and References, accessed March 2014: http://www.epa.gov/cleanenergy/energy-resources/refs.html

3 Residential Efficiency

This section presents detailed results of the residential sector efficiency potential, as well as explanations of the residential methodology and major inputs and assumptions.

3.1 Summary of Results

Figure 12 shows the total achievable scenario efficiency potential by region and fuel type in 2030. For electric, the largest region is New York City, followed by Upstate, Long Island, and the Hudson Valley. This reflects the New York City region accounting for the greatest share of residential electric load and the relatively higher cooling loads in that region. For petroleum, relative shares switch between New York City and Upstate, reflecting the relatively higher heating loads in that region and the relative greater portion of end users without natural gas availability.

Figure 12. Distribution of Residential Achievable Efficiency Potential by Region and Fuel Type, 2030.

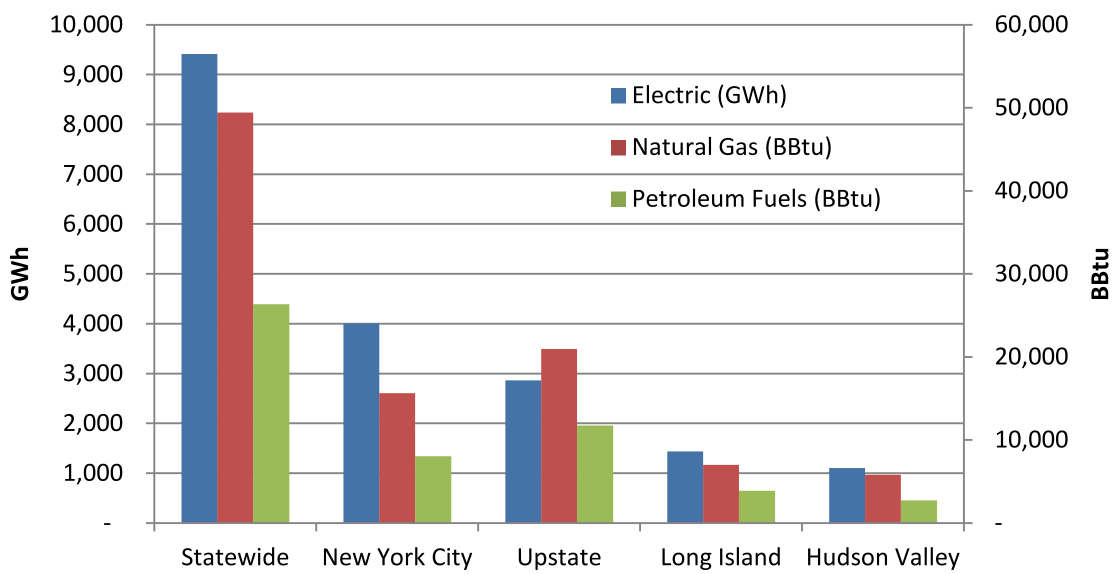


Table 7 shows the total savings for each fuel by major market category for the residential economic and achievable scenarios. Appliances and plug loads represent the greatest economic savings opportunity in the residential electric sector, while lighting represents the greatest achievable savings opportunity. This reflects the fact that the barriers in the lighting market are relatively low compared to those for appliances and plug loads. The heating and cooling market represents the largest economic and achievable savings opportunity for both natural gas and petroleum fuels.

Table 7. Residential Sector Economic and Achievable Savings Potential by Market, 2030.

Market	Electric Savings (GWh)	Natural Gas Savings (BBtu)	Petrol Fuels Savings (BBtu)
Economic	**28,553**	**148,665**	**72,300**
Lighting	5,761	(7,721)	(3,978)
Water Heating	3,357	69,079	22,294
Heating and Cooling	7,295	86,336	51,704
Appliances and Plug Loads	12,140	971	2,280
Achievable	**9,415**	**49,445**	**26,366**
Lighting	3,427	(4,593)	(2,366)
Water Heating	684	14,177	4,642
Heating and Cooling	2,310	39,638	23,568
Appliances and Plug Loads	2,994	223	523

Table 8 provides economic impacts by major market category for the residential economic and achievable scenarios. Overall, capture of the achievable potential would result in nearly $24 billion in gross benefits for an investment of $16 billion, for a benefit-cost ratio of about 1.5. New York's economy would capture about $7.6 billion in present value net benefits by 2032.

Table 8. Residential Sector Cost-Effectiveness Results by Market, Achievable Scenario, Total for 2013-2032 (Present Value Million 2012$).

Market	Costs (Million$)	Benefits (Million$)	Net Benefits (Million$)	BCR
Economic	**$33,468**	**$73,465**	**$39,997**	**2.20**
Lighting	$4,054	$5,780	$1,725	1.43
Water Heating	$6,948	$18,853	$11,905	2.71
Heating and Cooling	$17,653	$35,858	$18,204	2.03
Appliances	$4,812	$12,974	$8,162	2.70
Achievable	**$16,004**	**$23,601**	**$7,597**	**1.47**
Lighting	$1,852	$2,526	$674	1.36
Water Heating	$1,995	$3,874	$1,879	1.94
Heating and Cooling	$10,825	$14,007	$3,182	1.29
Appliances	$1,332	$3,194	$1,862	2.40

3.2 Overview of Approach

This study's comprehensive, long-term focus required a proper assessment of equipment stock turnover and the interactive effects within and between measures. To do this with specificity over the long term, we bundled measures by end-use so that energy impacts could be characterized across a changing mix of technologies. For example, an increase in the penetration of simple water saving devices such as thermostatic flow-control valves reduced the per-unit savings available from the adoption of more efficient water heating equipment and drain water heat recovery units. Similarly the adoption of CFLs and LED lighting impacted the savings potential of lighting controls. Aggregating measures within the energy end-use categories enabled our end-use models to remain anchored to the energy sales forecast while retaining the granularity of individual technology cost and savings characterizations.

3.3 Energy Sales Disaggregation

A top-down disaggregation of the energy sales was used to split the residential electricity consumption by end use and building type (single family and multifamily). The disaggregation was based primarily on RECS[11] data and NYSERDA's Patterns and Trends New York State Energy Profiles report.[12] These sources provided details such as consumption by end-use, type of equipment and building type details required for the analyses. Specifically, the breakdown of household energy consumption in the Patterns and Trends report was used as a starting point for current consumption by end use and fuel type.

End use consumption was corroborated by category and fuel with a bottom-up modeling of bundle characterizations where data were available. For instance, the proportion of lighting electricity consumption (including the impact on increased heating fuel to compensate for reduced waste heat to conditioned spaces due to lighting measures) utilized the RECS data for lighting electricity consumption and space heating technology type, fuel, and household distributions. The disaggregation was compared to independent estimates, where available, of the number of sockets per household by building type, hours of use per socket, average wattage and distribution by lamp/fixture technology type (incandescent, CFL, LED). Similarly the baseline inventory of the existing stock of building thermal performance, hot water, and heating and cooling equipment were developed for annual savings penetrations of the aggregate measure characterizations.

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11 U.S. Energy Information Administration. 2009. "Residential Energy Consumption Survey (RECS)." http://205.254.135.7/consumption/residential/data/2005/#consumption-expenditures. Accessed July 2013.

12 NYSERDA. 2011. *Patterns and Trends - New York State Energy Profiles: 1995-2009.* http://www.nyserda.ny.gov/en/Publications/Energy-Analysis-Reports.aspx. Accessed July 2013.

3.4 Measure Characterization

The approach to comprehensive and long term analysis of efficiency savings is a multi-faceted task that requires estimates of rapidly evolving efficient technologies such as lower power chipsets in consumer electronics, exponential improvements in LED lighting, and new application areas for heat pump technologies. The performance and cost-effective penetration of these products and systems were modeled and compared with estimates of baseline market activity performance, and federal standard levels.

The models were informed by a top-down disaggregation of energy consumption into the following four main categories for analysis and measure characterization, as shown in the following table. For a complete listing of residential measure characterizations, see Appendix D in Volume 4.

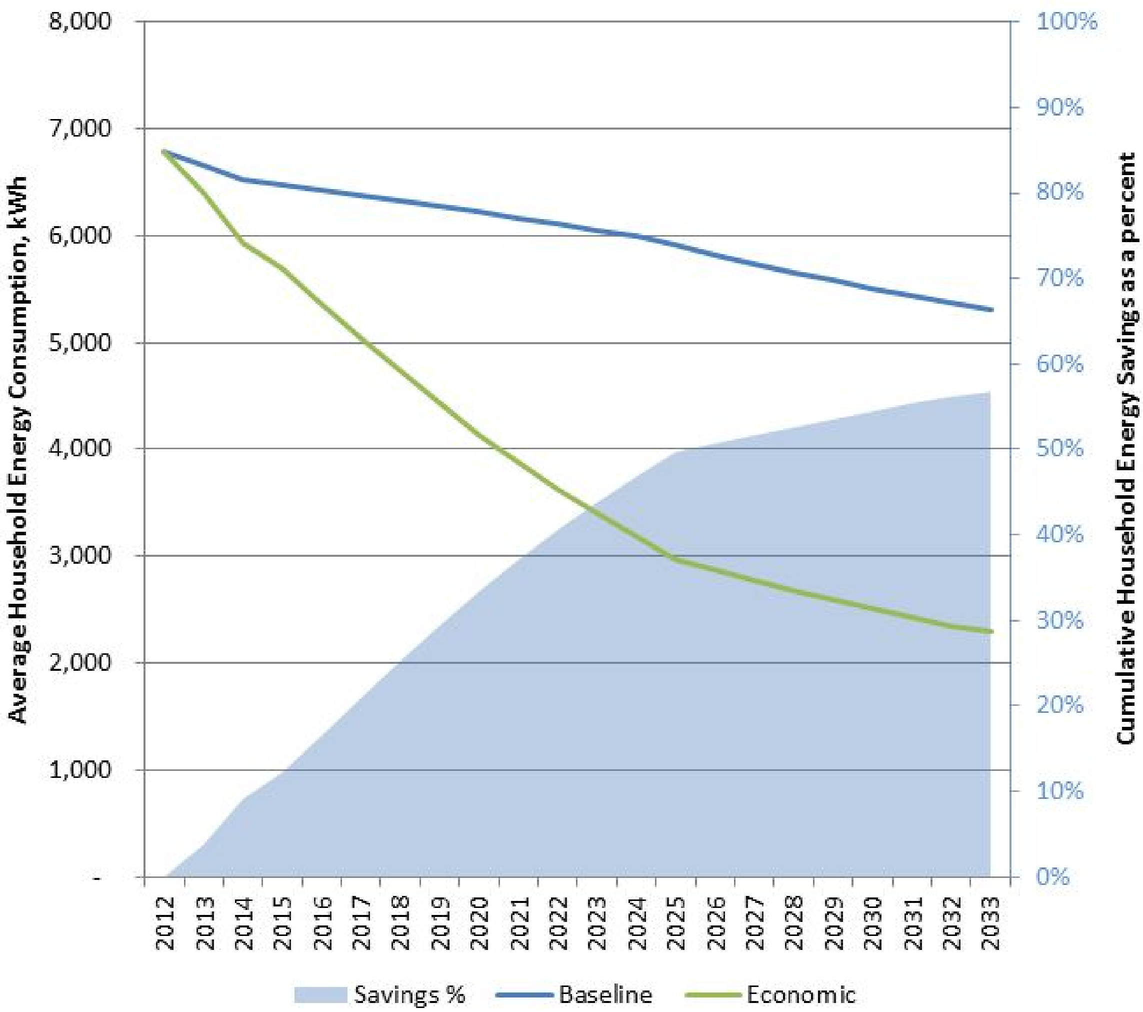
Table 9. Residential Aggregate Measure Categories with Component Measures.

End-use Category	Component Efficiency Measures	Aggregated Analysis Type
Lighting	• Standard CFLs • Specialty CFLs • LEDs • Controls & Integrated Design	Energy Intensity Model
Hot Water	• Low-Flow Aerators & Showerheads , Thermostatic Flow Shut-off Valve • Drain Water Heat Recovery Devices • Structured Plumbing • Gas Condensing Storage Water Heaters • Gas Condensing Tankless Water Heaters, • Gas Heat Pump Water Heaters • Electric Heat Pump Water Heaters	Energy Intensity Model
Thermal Comfort	Prototype building types: • Ranch/MH • Town and/or Row houses • Colonial/2-story • Garden Apartments Building (2-4 unit) • Other (e.g., houseboats, small RVs) • Heating and Cooling Equipment Replacement and Advanced Controls (Smart Thermostats)	Prototype Building Model, HVAC Equipment Turnover
Appliances and Plug Loads	Combined package of: • Major electric appliances (refrigerator/freezer, clothes washer and drier, etc.) • Brushless fan motor retrofit for furnaces • Advanced Power Strips and control/operation	Appliance Package Model

The quality of information and type of end-use category for lighting and hot water permitted the construction of energy intensity models to aggregate and capture the effects of changing baselines and equipment stock turnover. This approach allowed for deeper investigation into the nature of the savings opportunities, the rates of change, and incorporation of interactive effects from the installation of multiple efficiency measures. These models were constructed specific to these two end-use categories, based upon the characterization of component measures and the rate of replacement.

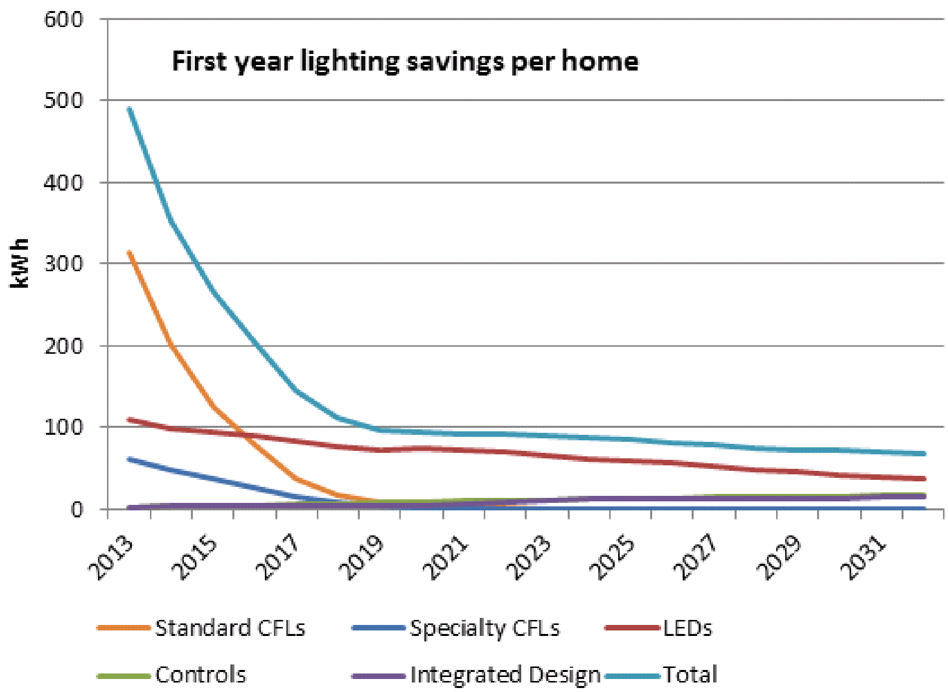
Figure 13 indicates the declining baseline energy consumption per household for all hot water uses. Savings from reduced energy intensities are relative to this baseline. Both lines are estimates based upon the total efficiency of household hot water systems based upon a distribution of technology types and penetrations.

Figure 13. Residential Hot Water Energy Intensity Model.



For the lighting end use, Figure 14 shows the decline in savings due to previous installations of efficient lighting measures. For example, the annual savings of a specialty CFL installed in 2013 would be nearly five times the annual savings of a specialty CFL installed in 2019. This is because the average energy intensity of standard lights in 2019 is lower due to improvements in energy efficiency of the baseline.

Figure 14. Residential First-Year Lighting Savings Per Home.



The other two energy end use categories were not well-suited to the approach used for the hot water and lighting end uses. For the thermal comfort end use, the collection of highly building-specific shell and systems (such as air-sealing, building shell, heating, cooling and ventilation) has too much variation between building types for a coherent energy intensity model. Instead, prototype building types were analytically built and modeled using simulation software to handle the measure interactions. The prototypes and their energy efficient attributes were designed to represent archetype residential buildings that could be allocated across the state in accordance with census household information. The different regional climates were then applied in proportion to the prototypes and the energy impacts were calculated. The outputs of these models were used to estimate the savings available to the heating and cooling equipment and controls replacement measures.

The appliances and plug loads energy end use category relied on a similar prototypical approach. Variation in appliance and plug load usage between building types was assumed to vary much less on average than the appliance and plug load energy consumption by users within each building type. Therefore, a single appliance package prototype was modeled. This package included retrofits for all major appliances (relative to non-ENERGY STAR levels of energy consumption), basic electronic upgrades (advanced power strips and controls), and furnace fan motor replacements.

The impact of significant emerging technologies and trends was modeled, wherever feasible, within each residential energy end-use category. Some trends, like the transition to solid-state lighting, have been extensively studied, and follow fairly predictable paths of improvement. Other trends, such as the volatility in the make-up and consumption of plug loads, are confounded by the opposing effects of increased power efficiencies of electronic devices, and their growth in number. In all cases, the treatment of cost and savings for each was informed by the potential application to the energy end-use category, the specific technology at hand, and comparable historic precedents. The following table summarizes the emerging technologies and trends considered for developing and characterizing efficiency measures.

Table 10. Residential Emerging Technologies and Trends.

End-Use	Emerging Technologies and Trends
Lighting	• Transition from incandescent/CFL mix to SSL continues and accelerates due to declining per lumen costs, saturation of product compatibility, application areas and availability. • Occupancy & light-level controls • Reduced lighting demand through integrated lighting design (fixture efficiency, controls, and day and task-lighting)
Space Comfort	• “Smart” dispatch & operation of equipment (adaptive and connected thermostats, variable load (“reset”) controls, and other controls optimizations. • Ventilation: distribution efficiencies and enthalpy recovery • Steady and increasing comprehensive envelope improvements (air-sealing and insulation) in existing buildings • Heat pumps (ground, water, and multi-stage air-source; variable speed, inverter-based) • Low-load brushless permanent magnet (DC-based) motors and electronic controls improves system comfort effectiveness to reduce “over ventilation” and “over-cooling”
Water Heating	• Condensing Gas and Combination Space heating, Tankless, Hybrid. • Heat Pump: electric and gas-fired, direct and vented, waste-heat recovery • Thermostatic automatic flow restriction and Low-flow showerheads and faucet aerators. • Distribution System: drain-water heat recovery, structured plumbing, on demand circulator pump.
Appliances and Plug Loads	• Smart controls: advanced power strips, remote operation, sensors and diagnostics. • Low-power electronics (standby and power-supplies) • End use saturation and consumer trends

General	• Market Segmentation and Delivery
	  ○ Ubiquitous Ratings & Certifications
	  ○ (Site-specific opportunity identifications, assessment, resolution; “Green Button” & Social Information Technologies)
	• Holistic and Integrated Design and Controls.
	• Smarter “defaults” convenient, lower cost, lower energy settings.

A total of 21 aggregate measures were included in the analysis, including separate characterizations for single- and multifamily buildings. These measures were characterized by year, as needed, to reflect changes in measure costs and savings over the study period. This resulted in a total of 138 residential measures for each of the four regional analysis zones.

Appendix D in Volume 4 provides the full list of residential measures with their characterizations.

3.5 Market Characterization

While residential energy use is in some ways more homogeneous than either of the commercial or industrial sectors, the residential sector has a much smaller per-site consumption and savings opportunity. Household-level information of specific building and equipment, and behavior details are required to model the twenty-year cost and savings impacts of measure-based comprehensive residential energy efficiency.

We built residential end-use category characterizations with the data available from appliance saturation surveys, energy efficiency program plans and evaluations, the census-based Residential Energy Consumption Survey, and long-term single and multifamily housing projections. The specifications of federal minimum appliance energy standards and energy codes established the baseline energy consumption for the residential market.

Our model used the population-weighted average climate information (heating and cooling degree days), building type (single and multifamily and prototypical construction) and heating and cooling equipment allocation within each of the four regional analysis zones.

3.6 Analysis of Economic Potential

We assumed that widely-available lower cost measures (e.g., lighting and controls, low-flow devices for hot water usage) would be rapidly deployed and reach high penetration rates within 5 to 10 years. For medium-priced measure bundles like the appliance and controls package and the heating and cooling package we assumed a replacement rate equal to annual sales estimates (equipment household saturation divided by the average equipment lifetime). For higher-cost measures like building shell upgrades and air sealing that require a certified contractor base and have longer project durations, we assumed that the full 20-year study period would be required to capture all of the cost-effective opportunity.

3.7 Analysis of Achievable Potential

In accordance with the study's scenario methodology, we assessed the constraints of communication, psychology and program costs within each residential energy end-use category. Market barriers including awareness, willingness, and customer economics were modeled as constraints on efficiency penetrations in addition to the resource and cost-effectiveness constraints modeled in the economic potential.

These factors are specific to each measure due to the inherent differences between technologies and the complexity of realizing the savings potential. Some, such as lighting have high visibility and low-market barriers relative to the challenges of sophisticated hot water measures, and proportionally higher costs and lower demand for thermal comfort measures. Within each category, we assessed and estimated these initial and ongoing limiting factors. In each case we assumed a minimum initial and maximum final level, and estimated a rate of improvement between the two. The considered barriers to adoption included cost, complexity, trade-offs in capability and or convenience, non-energy benefits, and other details that are known from program experience to affect residential customer decision-making.

This approach provided a consistent manner to address the complex problem of predicting statewide market behaviors. In some cases, such as the lighting bundle, the initial penetration rate could be established definitively from existing market data for solid-state lighting (SSL), and the time to achieve maximum penetration could be aligned with the SSL projections of its capability to saturate lighting end-uses. In others, such as thermal comfort, the initial critical constraint for adoption is a resource constraint of trained and capable personnel rather than awareness. Our approach allowed for changes over time to appropriately model these known effects and complications.

3.7.1 Program Costs

Program Costs include the cost of customer incentives and the cost of program administration as a percentage of total incentive amounts. For the achievable scenario, the proportion of incremental cost paid by incentive ranged from a high of 70% for lighting measures, to a low of 30% for the building shell measures of the thermal comfort end-use. These levels were based on the costs and specific market barriers to adoption for each aggregated measure. As described above in the general approach to the energy efficiency potential, program costs were estimated based on the experience of the current highest-performing efficiency programs.

Table 11 shows the residential program costs, by major market category, for the achievable scenario. The costs are split between incentive and non-incentive costs. The heating and cooling market is generally the most expensive – a reflection of the high cost of the equipment and the high incentives required to move efficient equipment into the market.

Table 11. Residential Sector Program Costs by Market, Achievable Scenario (Non-Discounted Million 2012$).

Market	2013	2015	2017	2020	2025	2030
Lighting	$97	$142	$77	$38	$28	$25
Incentive Costs	$65	$95	$52	$26	$19	$17
Non-Incentive Costs	$32	$47	$25	$13	$9	$8
Water Heating	$60	$82	$151	$140	$217	$151
Incentive Costs	$40	$55	$101	$94	$145	$102
Non-Incentive Costs	$20	$27	$50	$46	$71	$50
Heating and Cooling	$136	$155	$169	$225	$659	$1,954
Incentive Costs	$91	$104	$113	$151	$442	$1,311
Non-Incentive Costs	$45	$51	$55	$74	$217	$643
Appliances	$92	$113	$117	$47	$47	$47
Incentive Costs	$62	$76	$78	$32	$32	$32
Non-Incentive Costs	$30	$37	$38	$16	$16	$16
Residential Sector Total	**$384**	**$491**	**$513**	**$450**	**$951**	**$2,178**
Incentive Costs	$258	$330	$345	$302	$638	$1,462
Non-Incentive Costs	$126	$162	$169	$148	$313	$716

3.8 Detailed Results for the Residential Sector

This section provides detailed results for the economic and achievable scenarios for the residential sector, including results by end-use and building type.

3.8.1 Residential Economic and Achievable Electric Potential

As shown in Table 12 , the most significant achievable energy savings potential in the residential sector comes from lighting and thermal comfort, with 36% and 25% of the total savings respectively. The balance is split fairly evenly between the remaining end uses.

Table 12. Distribution of Residential Electric Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

Other appliances include clothes washers, dryers and dishwashers.

End Use	Economic		Achievable	
	Savings (GWh)	% of Total	Savings (GWh)	% of Total
Lighting	5,761	20%	3,427	36%
Thermal Comfort	7,295	26%	2,310	25%
Refrigerators	4,338	15%	1,070	11%
Electronics and Controls	3,916	14%	966	10%
Other Appliances	3,886	14%	958	10%
Water Heating	3,357	12%	684	7%
Total	**28,553**	**100%**	**9,415**	**100%**

Table 13 shows that single family homes account for approximately two thirds of the total residential achievable scenario potential, with multifamily capturing about one third.[13]

Table 13. Distribution of Residential Electric Efficiency by Building Type, Economic and Achievable Scenarios, 2030.

Building Type	Economic		Achievable	
	Savings (GWh)	% of Total	Savings (GWh)	% of Total
Single Family	18,525	65%	6,111	65%
Multifamily	10,028	35%	3,304	35%
Total	**28,553**	**100%**	**9,415**	**100%**

3.8.2 Residential Economic and Achievable Natural Gas Potential

Table 14 shows the distribution of economic and achievable natural gas savings by end use in 2030. About 70% of the achievable opportunity comes from reductions in space heating usage, with the remainder coming from water heating systems and usage.

13 Note that some additional multifamily potential for central systems in large multifamily buildings classified as commercial customers are included in the commercial sector results.

Table 14. Distribution of Residential Natural Gas Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Space Heating	79,586	54%	35,268	71%
Water Heating	69,079	46%	14,177	29%
Total	**148,665**	**100%**	**49,445**	**100%**

Table 15 shows the distribution of natural gas savings by end use for the economic and achievable scenarios in 2030. About 70% of the opportunities come from reductions in single family homes, with the remainder coming from multifamily.

Table 15. Distribution of Residential Natural Gas Efficiency by Building Type, Economic and Achievable Scenarios, 2030.

Building Type	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Single Family	97,797	66%	34,211	69%
Multifamily	50,868	34%	15,234	31%
Total	**148,665**	**100%**	**49,445**	**100%**

3.8.3 Residential Economic and Achievable Petroleum Fuels Potential

Table 16 shows the distribution of petroleum fuel savings by end use for the economic and achievable scenarios in 2030. About 80% of the opportunities come from reductions in space heating usage, with the remainder coming from water heating systems and usage. This somewhat higher share of savings from space heating for petroleum – as compared to natural gas – reflects the relatively smaller prevalence of petroleum water heating and the general older age and lower efficiency of petroleum heating systems.

Table 16. Distribution of Residential Petroleum Fuel Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Space Heating	50,007	69%	21,725	82%
Water Heating	22,294	31%	4,642	18%
Total	**72,300**	**100%**	**26,366**	**100%**

Table 17 shows the split in petroleum savings by building type for the economic and achievable scenarios. Single family homes account for about 75% of the opportunities. The relatively large single family share of potential for petroleum – as compared to natural gas – reflects the higher market share of oil in single family homes, and in particular, the relatively high availability of natural gas downstate where more multifamily buildings are located.

Table 17. Distribution of Residential Petroleum Fuel Efficiency by Building Type, Economic and Achievable Scenarios, 2030.

Building Type	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Single Family	51,907	72%	19,192	73%
Multifamily	20,393	28%	7,174	27%
Total	**72,300**	**100%**	**26,366**	**100%**

4 Commercial Efficiency

This section presents detailed results of the commercial sector achievable efficiency potential, as well as explanations of the commercial methodology and major inputs and assumptions.

4.1 Summary of Results

Figure 15 shows the total commercial sector achievable potential in 2030 for each fuel and region. For electricity New York City and Upstate regions each account for about a third of the statewide potential, with Long Island and Hudson Valley accounting for the remainder. For natural gas and petroleum New York City accounts for the largest share, with about 50% of the statewide potential, reflecting the relatively high population and fossil fuel consumption in that region. The Upstate region has about a third of the statewide fossil fuel potential, with Long Island and Hudson Valley accounting for the remainder.

Figure 15. Distribution of Commercial Efficiency by Region and Fuel Type, Achievable Scenario, 2030.

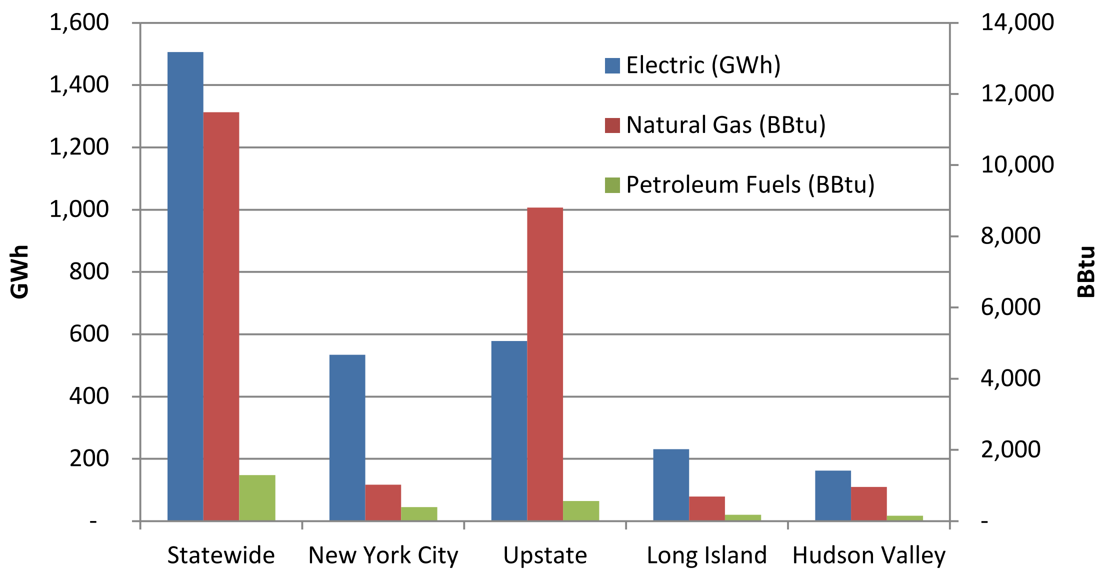


Table 18 shows the economic and achievable savings, by major market category, for the each fuel. The new construction market represents the greatest economic opportunity for electric savings, while the retrofit market represents the greatest achievable opportunity. This trend is also apparent in natural gas and petroleum fuels.

Table 18. Commercial Sector Economic and Achievable Savings by Market, 2030

Market	Electric Savings (GWh)	Natural Gas Savings (BBtu)	Petro Fuels Savings (BBtu)
Economic	**58,550**	**136,793**	**45,109**
New Construction	28,992	71,114	22,393
Equipment Replacement	12,218	28,165	10,723
Retrofit	17,340	37,513	11,994
Achievable	**25,407**	**46,968**	**15,358**
New Construction	7,259	13,490	4,381
Equipment Replacement	7,183	10,969	3,992
Retrofit	10,966	22,509	6,984

Table 19 provides economic impacts, by major market category, for the commercial economic and achievable scenarios. Overall, capture of the achievable potential would result in $36 billion in gross benefits for an investment of $16 billion, or a benefit-cost ratio of 2.25. New York's economy would capture about $20 billion in present value net benefits by 2032

Table 19. Commercial Sector Cost-Effectiveness Results by Market, Economic and Achievable Scenarios, Total for 2013-2032 (Present Value Million 2012$)

Market	Costs (Million$)	Benefits (Million$)	Net Benefits (Million$)	BCR
Economic	**$37,962**	**$93,438**	**$55,476**	**2.46**
New Construction	$15,692	$40,530	$24,838	2.58
Equipment Replacement	$9,163	$22,246	$13,083	2.43
Retrofit	$13,107	$30,661	$17,555	2.34
Achievable	**$15,936**	**$35,795**	**$19,859**	**2.25**
New Construction	$3,490	$8,688	$5,198	2.49
Equipment Replacement	$3,419	$8,959	$5,540	2.62
Retrofit	$9,027	$18,148	$9,121	2.01

4.2 Overview of Approach

The commercial sector, which includes institutional buildings, is relatively complex due to its wide variety of building types and sizes, the multitude of services provided, and the large number of potential efficiency applications. For example, different commercial building types have widely different occupation regimens, so that measure impacts and cost-effectiveness can vary widely between different building types. As well, the commercial sector is overall the largest energy consumer, and commercial electric usage is forecast to increase by about 40% over the next 20 years, while the residential and industrial electric usage essentially stay flat.

The top-down approach to the commercial analysis is similar to that used for the other sectors, but the energy and measure segmentation is more detailed. As described below, the segmentation by market, building type and analysis zone resulted in nearly 4,500 measure permutations. Due to its complexity and the large number of measure permutations, the commercial analysis relies on a commercial-specific model that processes the unique characterization of measures by building type, estimates the effect of measure interactions, and tracks the remaining energy available for energy efficiency as new installations are modeled.

The assessment of potential proceeds by applying a series of factors to a defined quantity of energy. These factors are applied to the forecasted building-type and end-use or industrial segment sales by year to derive the potential for each measure for each year in the analysis period, as shown in the following equation and described in the subsequent bullets.

Energy Savings	=	kWh Sales	x	Applicability Factor	x	Feasibility Factor	x	Turnover Factor (replace-ment only)	x	Not Complete Factor (retrofit only)	x	Savings Fraction	x	Net Penetration Rate

- **Sales** is the total quantity of energy consumed by a particular end-use in a particular building type or industrial segment, across the entire market of interest, expressed in kWh or MMBtu. In this analysis, we assessed potential in each of four different regional analysis zones.
- **Applicability** is the fraction of the end-use level energy sales (from the sales disaggregation) for each building type or industrial segment that is attributable to equipment that could be replaced by the high-efficiency measure. For example, for ambient lighting it would be the portion of total building type lighting electrical load consumed by ambient lighting.
- **Feasibility** is the fraction of end-use sales for which it is technically feasible to install the efficiency measure. Numbers less than 100% reflect engineering or other technical barriers that would preclude adoption of the measure. Feasibility is not reduced for economic or behavioral barriers that would reduce penetration estimates. Rather, it reflects technical or physical constraints that would make measure adoption impossible or ill advised.

- **Turnover** is the number or percentage of existing equipment that will be naturally replaced each year due to failure, remodeling, or renovation. This applies to the natural replacement ("replace on burnout") and renovation markets. In general, turnover factors are assumed to be 1 divided by the measure life (e.g., assuming that 10% (1/10) of existing stock of equipment is replaced each year for a measure with a 10 year estimated life).
- **Not Complete** is the percentage of existing equipment that already represents the high-efficiency option. This only applies to retrofit markets.
- **Baseline Adjustment** adjusts the savings downward in future years for early-retirement retrofit measures to account for the fact that newer, standard equipment efficiencies are higher than older, existing stock efficiencies. This factor is only applied after the existing equipment would have reached its end-of-life (it is not shown in the above formula).
- **Savings Fraction** represents the percent savings (as compared to either existing stock or new baseline equipment for retrofit and non-retrofit markets, respectively) of the high efficiency technology. Savings fractions are calculated based on individual measure data and assumptions about existing stock efficiency, standard practice for new purchases, and high efficiency options. Our estimates of savings fraction and all of the preceding factors are described in the "Measure Characterization" section.
- **Annual Net Penetrations** are the difference between the base case measure penetration (with no efficiency programs) and the measure penetrations that could be achieved with sustained efficiency initiatives. For the resource-constrained economic potential, it is assumed that 100% penetration is captured for all markets, with retirement measures generally being phased in and spread out over time to reflect resource constraints such as contractor availability. We describe our penetration estimates in the "Potential Estimate" section.

In the top-down approach, measure costs are expressed relative to energy savings (i.e., units of dollars per kWh or MMBtu saved) rather than equipment units. For purposes of estimated potential, total costs in each year are determined by multiplying the measure cost per unit energy saved by projected energy savings in that year. This same approach is used for other measure impacts such as operation and maintenance savings.

The actual factors used for the commercial analysis are presented in Appendix E in Volume 4.

The following sections provide additional detail specific to the commercial sector analysis.

4.3 Energy Sales Disaggregation

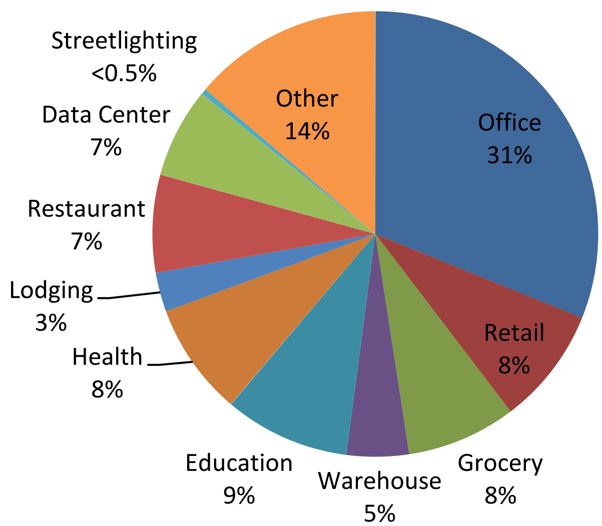
The commercial sector is relatively complex in that commercial sales are disaggregated into eleven end uses and twelve building types. This section provides an overview of the commercial sales disaggregation, while Appendix C in Volume 4 provides complete tables of the disaggregation.

Historical electric sales by regional analysis zone were first disaggregated into twelve building types using proprietary electric load data from three New York utilities – one for New York City, one for Hudson Valley, and the other for the Upstate region.[14] These data reflected early to mid-1990s conditions, the best available data for this task.

Current year sales were estimated using economic growth data (business-level gross domestic product) by county from Moody's (www.economy.com). As growth data in terms of electric, natural gas, and petroleum-based fuel sales were not available, economic growth was adopted as a suitable proxy. Figure 16 shows the resulting distribution of electric energy sales by building type for 2013.

Figure 16. Commercial Electric Sales Distribution by Building Type, 2013.

Note: The "Other" building type includes buildings with commercial activity that do not fit into any other category (e.g. airplane hangars, crematoriums, laboratories, etc.).



New York data on gas usage by building type were not available. As a result, the analysis started with the disaggregated electric load by building type. Based on average existing building energy intensities per square foot by building type for electricity and gas, the analysis estimated the natural gas consumption by building type. The estimates of energy intensity by building type were derived from 2002 Itron "eShapes" data. The eShapes data provide annual hourly "8760" end-use energy load shapes by building type for a broad array of New York weather stations. These are based on Itron modeling of thousands of existing commercial facilities audits. Figure 17 shows the resulting distribution of natural gas and petroleum fuels sales by building type for 2013.

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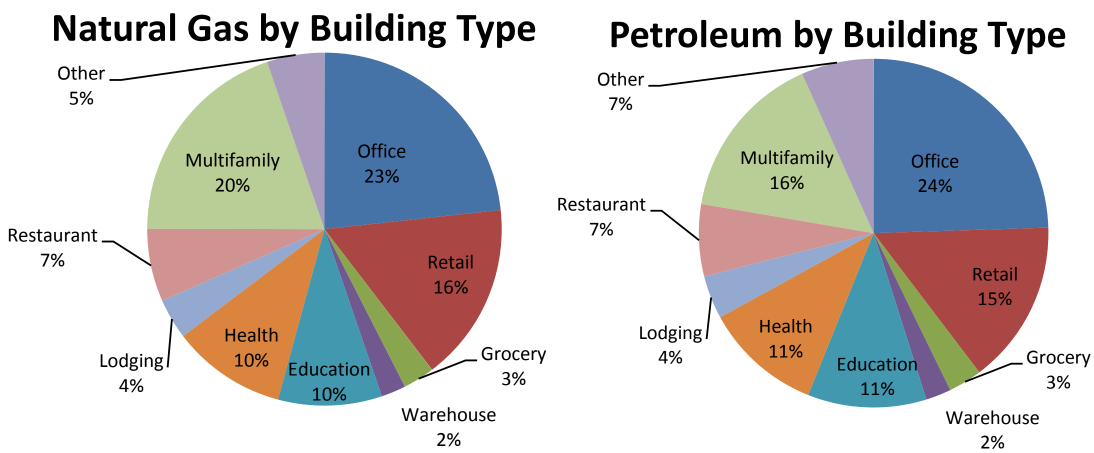
[14] The building types include Office, Retail, Grocery, Warehouse, Education, Health, Lodging, Restaurant, Data Center, Multifamily, Street Lighting, and Other. The multifamily building type only applies to central, commercially-metered systems, generally for multifamily buildings of at least 20 units.

Figure 17. Commercial Natural Gas and Petroleum Fuels Distribution by Building Type, 2013.

Note: The “Other” building type includes buildings with commercial activity that do not fit into any other category (e.g. airplane hangars, crematoriums, laboratories, etc.).

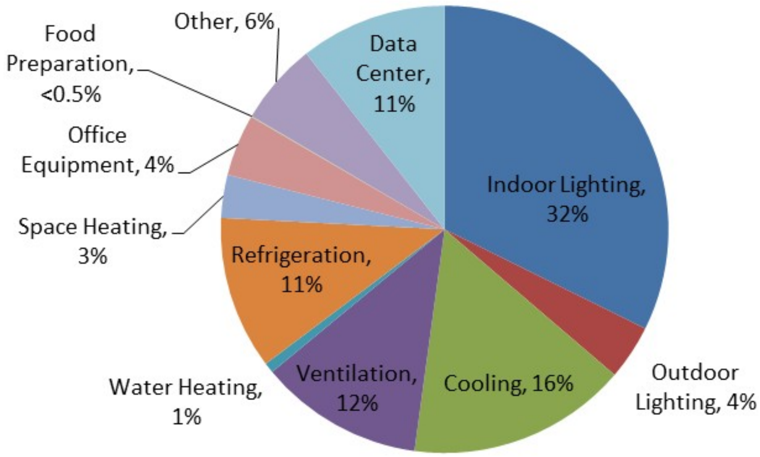


Again using eShapes data, we further disaggregated the zonal building-type sales forecasts into eleven separate end uses, using end-use energy intensities (kWh/sq. ft. or MMBtu/sq. ft.) by building type.[15] Separate end-use energy intensities were applied for the New York City, Long Island, and Upstate zones and each building type based on eShapes data using New York City’s LaGuardia Airport, Islip, and Albany weather stations, respectively. No eShapes data were available for weather stations within the Hudson Valley, so the Albany weather station was assumed as a suitable proxy. Figure 18 shows the resulting distribution of electric sales by end use for 2013.

15 The end uses include Interior Lighting, Exterior Lighting, Space Cooling, Ventilation, Water Heating, Refrigeration, Space Heating, Office Equipment, Food Service, Data Center, and Other.

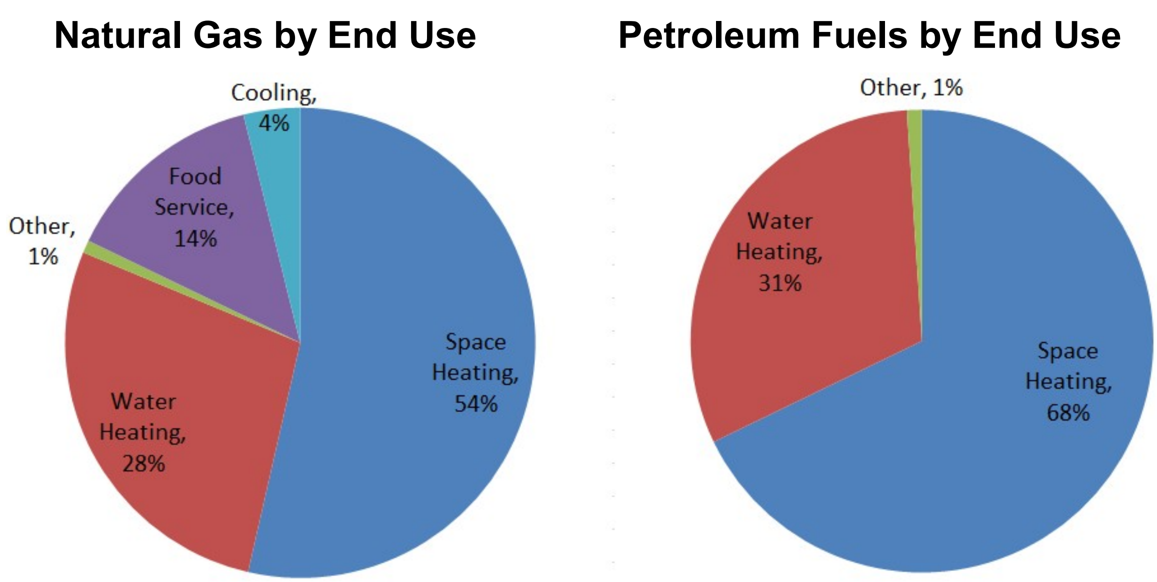
Figure 18. Commercial Electric Sales Distribution by End Use, 2013.

Note: The “Other” end use category includes end uses that do not fit into any other commercial end use (e.g. televisions, cleaning equipment, security systems, etc.).



Distribution of petroleum-based fuels by building type and end-use was assumed to be identical to that of natural gas with the exception that the cooling and food service end uses are not included. Figure 19 shows the resulting distribution of natural gas and petroleum fuels sales by end use for 2013.

Figure 19. Commercial Natural Gas and Petroleum Fuels Distribution by End Use, 2013.



Finally, end-use energy growth forecasts for 2013 through 2032 were adopted from the 2011 US DOE Building Energy Data Book and normalized to the overall sales growth rates from the electric, natural gas, and petroleum-based fuel sales forecasts.

Based on the EIA forecast of commercial new construction and projected improvements in energy use intensities per square foot for new and existing buildings, we estimated that approximately 80% of overall statewide load growth results from new construction over the analysis period.

4.4 Measure Characterization

The commercial sector analysis relied on aggregate measures generally organized by end use, which were then characterized for each applicable building type. This approach enables the top-down analysis of efficiency potential based on the energy sales disaggregation by end use and building type for each measure. We characterized measures separately for the lost opportunity (natural replacement and new construction/renovation) and retrofit markets.

The approach to developing aggregate measure characterizations differed by measure type and available data, but for many measures the approach followed a common set of steps. First, aggregate measure characterizations were developed by organizing the complete list of individual component measures into bins by end-use. Where measures overlap multiple end-uses, they are left as individual component measures. We refined the end-use bins of component measures by creating sub-groups based on similar component measure functionality. For example, measures in the indoor lighting end-use bin have been further refined into ambient lighting, task lighting, accent lighting, lighting controls, and lighting design. Each of those sub-groups represents an aggregate measure used in the analysis.

Having defined all of the aggregate measures, we then developed characterizations using a weighted average savings approach. To define the weighting factors for each component measure, we first identified each of the individual measures as either competing with or augmenting other component measures. Where component measures compete directly for savings, the weighting factors are scaled based on the prevalence of each component measure. For example, in the commercial hot water end-use bin the source equipment aggregate measure contains heat pump water heaters, tankless water heaters, and high-efficiency tank-type water heaters. A hot water system can only have one of those as its generation source, so the weighting factors are scaled to reflect the prevalence of installation of each of those components. Because every hot water system needs a generation source, the scaled weighting factors for each component measure total 100 percent.

Where component measures augment savings, the weighting factors reflect the interaction with the other component measures. For example, the source equipment aggregate measure in the hot water end-use bin also contains a drain water heat recovery system component measure. Because heat recovery can be installed in addition to any efficient generation source, the savings increase the overall savings captured by the aggregate measure. However, due to measure interactions the increased savings will be less than the total of the individual savings from these technologies. The weighting factor for each augmentative component measure reflects this interaction.

We developed two sets of individual component weighting factors, one for the “lost opportunity” market (natural replacement and new construction/renovation) and one for the retrofit market, in part because the characteristics of the building stock in each market warrant different assumptions about the baseline and distribution of individual component measures in any given aggregate measure. Once the weighting factors were complete, savings and measure lives for the each aggregate measure were calculated from the component measures.

Emerging technologies are important to the long-term potential emphasized by the 20-year study. The table below highlights some of the emerging technologies that were considered and analyzed as part of the measure characterization process.

Table 20. Commercial Emerging Technologies and Trends.

End-Use	Emerging Technologies and Trends
Lighting	• SSL: Efficacy of conventional tech (fluorescent, incandescent, HID) approaching theoretical maximum; however, major improvements expected for LED and OLED tech (>230 lm/W have been achieved in lab tests) • SSL costs continue to fall as conventional tech costs remain the same or increase • LED will become cost-effective for more applications (ambient lighting, high/low bay, troffers, A-lamps) • Emerging: scotopic (spectrally enhanced) lighting; retrofit networked lighting controls, integrated daylighting systems
Space Comfort / Shell	• Incremental improvements to conventional refrigeration technologies (“Advanced RTU”); EERs continue to improve, but plateauing; improvements in part load performance • Ductless mini-split AC and HP, variable refrigerant flow (VRF) systems (mature tech but relatively new to US market) • Envelope improvements: tighter, more insulated; retrofit air sealing opportunities (8 Aeroseal contractors in NYS), exterior retrofits • Emerging: Cold-climate heat pumps, GSHPs, Energy recovery ventilation, Acoustic cooling, Solid-state cooling
Motors/Drives	• Limited economic opportunities from addition efficiency improvements beyond NEMA Premium--shift focus to systems and optimization • Variable speed pumps and fans; ECM, VFD costs continue to fall – increasing opportunities
Water Heating	• Heat pumps and condensing systems; solar • Increased integration (e.g. combined space and water heater)
Appliance and Plug Loads	• Smart Controls
Other	• Improved Data Center Design; Variable-Speed CRAC Compressors • Data Center “data furnaces” • Fault Detection and Diagnostics (e.g. RTU), “Continuous commissioning” • Occupant feedback systems/behavioral programs

The last step in preparing the aggregate measure characterizations was to develop time-varying adjustments to reflect changes in codes and standards and emerging new technologies. We accomplished this by developing a set of adjustment factors that increase or diminish specific aspects of aggregate measures, as necessary, over a specified period of years. For instance, an aggregate measure might include an individual component measure for an emerging technology with a low weighting factor. The adjustment factors are used to incrementally increase the savings and costs for the aggregate measure during the period of years that the emerging technology will come online. In another example, where a pending code increase is likely to take effect, an adjustment factor is applied to decrease the potential savings for the aggregate measure starting in the year that the code change comes into effect.

Some measures apply to multiple end uses, such as building envelope measures that have savings for both cooling and heating. For these measures we characterized separate component measures for each end use, so that savings could be reported by end use. However, such measures were evaluated for cost-effectiveness as a unit, by adding up the costs and benefits of the end-use components to determine the cost-effectiveness of the overall measure.

For most end uses we did not find compelling data to indicate how measure costs and savings would vary over the study period. The on-going high level of innovation for energy efficiency leads us to believe that emerging technologies will continue to keep pace with rising baselines as they have in recent decades. However, characterization of the commercial lighting end use is expected to change over time, driven by two major factors:

- Large increases in source efficacy and cost reduction with LED technology
- Technological advancements and cost reductions with lighting controls.

LED technology will continue to become more efficient, as efficacy improves from current levels of about 100 lumens per watt to a projected efficacy of 162 lumens per watt in 2015, and 224 lumens per watt in 2020.[16] As the efficacy improves, the cost per kilolumen (klm) is also expected to decline from the current levels of about $8.00/klm to $2.30/klm in 2015, and to $0.70/klm in 2020. We expect these improvements in efficacy and reductions in price will lead to new efficiency opportunities with lighting at a pace that will exceed lighting opportunities of the past, across all lighting applications.

Lighting Controls will also offer increased lighting savings potential into the future, largely driven by technological advancements such as wireless controls, improved sensors, and system integration. We also expect cost reductions as lighting controls become more prevalent in the marketplace. New systems will allow multiple layers of control strategies to be installed on a lighting system, optimizing the control and efficiency of the lighting system. These control strategies include occupancy control, daylight control, scheduling, personal control, high-end trim, lumen maintenance dimming, among others. Software-based control systems and addressable lighting will allow all of these control strategies to work together, and open-source components and systems will allow for commoditization of lighting controls.

16 U.S. Department of Energy. 2012. *Solid State Lighting Research and Development: Multi-Year Program Plan*. Prepared by Bardsley Consulting, Navigant Consulting, Inc., Radcliffe Advisors, Inc., SB Consulting, and Solid State Lighting Services, Inc. for the U.S. Department of Energy, Lighting Research and Development. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2012_web.pdf. Accessed July 2013.

A total of 63 aggregate measures were included in the analysis and characterized for:

- up to three applicable markets (new construction/renovation, natural replacement, and retrofit), and
- up to 12 applicable building types (Office, Retail, Grocery, Warehouse, Education, Health, Lodging, Restaurant, Data Center, Multifamily, Street Lighting, and Other).

This resulted in a total of 1,114 measures for each of the four regional analysis zones including the end-use component measures noted above. Not all of these measures passed the cost-effectiveness test. Many measures were cost-effective in some building types but not others, due mainly to the different hours of use associated with different building types.

Appendix D in Volume 4 provides the full list of commercial measures with their characterizations.

4.5 Market Characterization

The commercial market characterizations include the measure applicability, feasibility, and non-complete factors, which are estimated for each building type. These market factors are described above under the General Approach section.

4.6 Analysis of Economic Potential

The commercial sector analysis assumed that retrofit penetrations increased to 10% per year over the first three years, then held steady at 10% per year through year 11. This results in capturing all retrofit opportunities over a period of about 11 years, after which we assumed a low level of retrofit penetrations to apply to measures installed in earlier years that would again become available for retrofits. With these assumptions the economic potential essentially captures all available cost-effective efficiency potential by the end of the study period.

4.7 Analysis of Achievable Potential

The achievable potential was analyzed using the top-down methodology described above under the Overview and Approach section, and the approach to measure penetrations and program costs described under the Achievable Potential section.

4.7.1 Program Costs

Table 21 shows the commercial sector program costs for the achievable scenario by market for select years through 2030.

Table 21. Commercial Sector Program Costs by Market, Achievable Scenario (Non-Discounted Million 2012$).

Market	2013	2015	2017	2020	2025	2030
New Construction	$132	$165	$196	$249	$241	$248
Incentive Costs	$87	$109	$130	$164	$159	$164
Non-Incentive Costs	$45	$56	$67	$85	$82	$84
Equipment Replacement	$145	$166	$198	$225	$208	$240
Incentive Costs	$96	$110	$131	$148	$137	$158
Non-Incentive Costs	$49	$57	$68	$77	$71	$82
Retrofit	$416	$427	$345	$291	$258	$280
Incentive Costs	$275	$282	$227	$192	$170	$185
Non-Incentive Costs	$142	$145	$117	$99	$88	$95
Commercial Sector Total	**$693**	**$758**	**$740**	**$765**	**$708**	**$768**
Incentive Costs	$457	$500	$488	$505	$467	$507
Non-Incentive Costs	$236	$258	$252	$260	$241	$261

4.8 Detailed Results for the Commercial Sector

This section provides detailed results for the economic and achievable scenarios for the commercial sector, including results by end-use and building type.

4.8.1 Commercial Economic and Achievable Electric Potential

As shown in Table 22, the end-use with the greatest efficiency potential for the commercial sector is indoor lighting, accounting for about 35% of the total achievable electric opportunities. This is consistent with many other studies and also with many efficiency portfolios. Cooling accounts for the next highest share with 24% of achievable opportunities, followed by ventilation and refrigeration with 13% each.

Table 22. Distribution of Commercial Economic Electric Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (GWh)	% of Total	Savings (GWh)	% of Total
Indoor Lighting	22,464	38%	8,976	35%
Cooling	14,640	25%	6,022	24%
Ventilation	7,428	13%	3,430	14%
Refrigeration	6,405	11%	3,420	13%
Office Equipment	4,282	7%	1,966	8%
Outdoor Lighting	2,537	4%	1,317	5%
Space Heating	417	1%	128	1%
Water Heating	369	1%	145	1%
Food Preparation	7	0%	2	0%
Total	**58,550**	**100%**	**25,407**	**100%**

Table 23 shows the breakdown by building type of electric savings potential for the economic and achievable scenarios in 2030. As is typical with most potential studies, offices offer the largest opportunities, accounting for 29% of the total achievable potential. This is followed by "other" and retail, accounting for 14% and 10%, respectively. Multifamily accounts for only a minimal portion of the commercial potential since most multifamily electric usage and efficiency potential are in the residential sector.

Table 23. Distribution of Commercial Electric Efficiency by Building Type, Economic and Achievable Scenarios, 2030.

"Other" building type includes buildings with commercial activity that do not fit into any other category (e.g. airplane hangars, crematoriums, laboratories, etc.)

Building Type	Economic		Achievable	
	Savings (GWh)	% of Total	Savings (GWh)	% of Total
Office	18,227	31%	7,493	29%
Other	8,834	15%	3,664	14%
Retail	5,990	10%	2,608	10%
Grocery	5,101	9%	2,470	10%
Education	5,075	9%	2,309	9%
Restaurant	4,630	8%	2,032	8%
Health	4,610	8%	1,918	8%
Warehouse	2,786	5%	1,326	5%
Lodging	2,046	3%	907	4%
Data Center	964	2%	474	2%
Streetlighting	199	0%	162	1%
Multifamily	88	0%	44	0%
Total	**58,550**	**100%**	**25,407**	**100%**

4.8.2 Commercial Economic and Achievable Natural Gas Potential

As shown in Table 24, the end-uses with the greatest natural gas potential in the commercial sector are water and space heating, respectively accounting for 50% and 45% of the total achievable gas opportunities.

Table 24. Distribution of Commercial Natural Gas Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Water Heating	64,697	47%	23,522	50%
Space Heating	64,194	47%	21,199	45%
Food Preparation	6,202	5%	1,762	4%
Cooling	1,700	1%	485	1%
Total	**136,793**	**100%**	**46,968**	**100%**

Table 25 shows the breakdown by building type of economic and achievable natural gas savings potential in 2030. As is typical with most potential studies, office buildings offer the largest opportunities, accounting for 22% of the total. This is closely followed by multifamily buildings with large central systems categorized under commercial. Retail, health and education account for 14%, 13% and 10%, respectively.

Table 25. Distribution of Commercial Natural Gas Efficiency by Building Type, Economic and Achievable Scenarios, 2030.

“Other” building type includes buildings with commercial activity that do not fit into any other category (e.g. airplane hangars, crematoriums, laboratories, etc.)

Building Type	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Office	30,394	22%	10,458	22%
Multifamily	28,987	21%	9,786	21%
Retail	19,527	14%	6,623	14%
Health	17,548	13%	6,324	13%
Education	13,436	10%	4,677	10%
Restaurant	8,590	6%	2,884	6%
Other*	6,840	5%	2,275	5%
Lodging	5,772	4%	1,930	4%
Grocery	2,861	2%	1,177	3%
Warehouse	2,542	2%	834	2%
Data Center	297	<0.5%	0	0%
Total	**136,793**	**100%**	**46,968**	**100%**

4.8.3 Commercial Economic and Achievable Petroleum Fuels Potential

Table 26 provides the end-use breakdown of petroleum fuel savings potential for the economic and achievable scenarios in 2030. Space and water heating respectively account for 51% and 49% of the total achievable petroleum opportunities. Food preparation accounts for less than 0.5% of the potential.

Table 26. Distribution of Commercial Petroleum Fuels Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Water Heating	21,384	47%	7,829	51%
Space Heating	23,595	52%	7,496	49%
Food Preparation	130	<0.5%	33	<0.5%
Total	**45,109**	**100%**	**15,358**	**100%**

Table 27 shows the breakdown by building type of petroleum fuel savings for the economic and achievable scenarios in 2030. As is typical with most potential studies, offices offer the largest opportunities, accounting for 23% of the total. This is closely followed by multifamily buildings (17%) with large central systems categorized under commercial. Retail, health and education account for 16%, 14% and 9%, respectively. These figures are very similar to the natural gas breakdown by building type.

Table 27. Distribution of Commercial Petroleum Fuels Efficiency by Building Type, Economic and Achievable Scenarios, 2030.

“Other” building type includes buildings with commercial activity that do not fit into any other category (e.g. airplane hangars, crematoriums, laboratories, etc.)

Building Type	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Office	10,288	23%	3,497	23%
Multifamily	7,814	17%	2,576	17%
Retail	7,345	16%	2,475	16%
Health	5,759	13%	2,104	14%
Education	4,132	9%	1,436	9%
Restaurant	3,404	8%	1,157	8%
Other*	2,098	5%	688	4%
Grocery	1,583	4%	609	4%
Lodging	1,803	4%	598	4%
Warehouse	756	2%	218	1%
Data Center	127	0%	0	0%
Total	**45,109**	**100%**	**15,358**	**100%**

5 Industrial Efficiency

This section presents detailed results of the industrial sector economic and achievable efficiency potential, as well as explanations of the industrial methodology and major inputs and assumptions.

5.1 Summary of Results

Figure 20 shows the total industrial sector achievable scenario potential in 2030 for each fuel and region. For electricity New York City and Upstate regions each account for about a third of the statewide potential, similar to the commercial sector. Long Island and Hudson Valley account for the remainder, representing a little more than 10% each. For natural gas and petroleum Upstate accounts for by far the largest share of potential, consistent with most of the larger and heavier industries relying on high levels of fossil fuel usage being located in this region. The vast majority of industrial fossil fuel potential is associated with natural gas usage. This is driven by large energy intensive industries locating in places that have gas service, and often relying on dual fuel burners that provide the flexibility to switch between gas and oil. Given the current large favorable price differential for gas as compared to oil, large heavy industries have generally reduced petroleum consumption dramatically. Of course, because of dual fuel capability, this relationship could shift over time if the price advantage currently enjoyed by the natural gas industry were to disappear or reverse. However, the underlying forecasts do not expect this to be the case during the study period.

Figure 20. Distribution of Industrial Efficiency by Region and Fuel Type, Achievable Scenario, 2030.

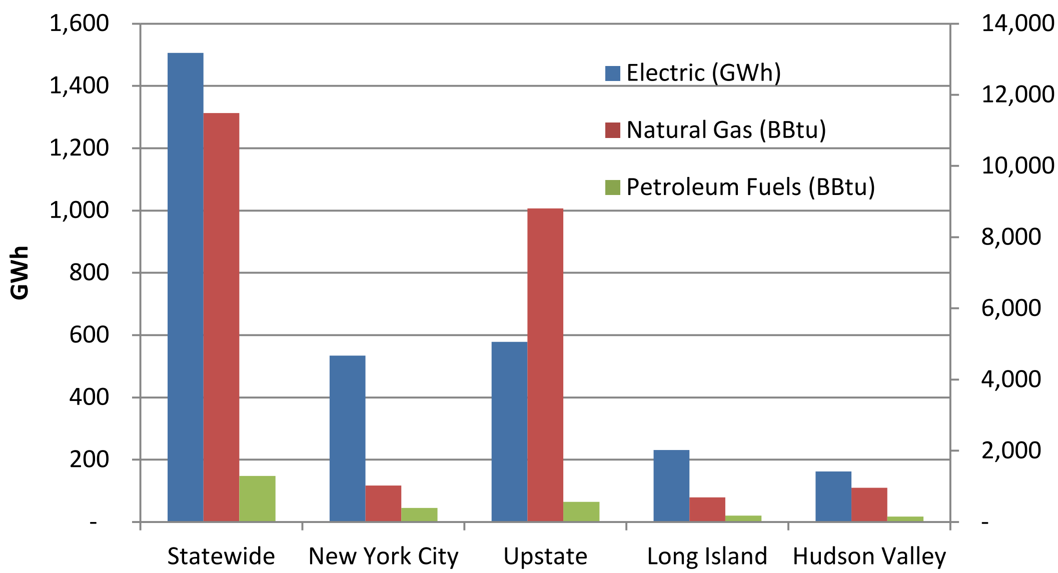


Table 28 shows the industrial sector savings, by fuel, for the economic and achievable scenarios. Unlike the residential and commercial sectors, the industrial sector is not divided into separate markets for analysis. This is because the industrial sector is smaller and generally doesn't require a targeted approach by market segment.

Table 28. Industrial Sector Economic and Achievable Savings, 2030.

Scenario	Electric Savings (GWh)	Natural Gas Savings (BBtu)	Petrol Fuels Savings (BBtu)
Economic	4,753	35,672	2,560
Achievable	1,506	11,486	1,296

Table 29 provides economic impacts for the industrial sector for the economic and achievable scenarios. Overall, capture of the achievable potential would result in $3 billion in gross benefits for an investment of about $1.3 billion, or a benefit-cost ratio of about 3.3. New York's economy would capture about $1.8 billion in present value net benefits by 2032. Note this is just the direct net benefits accruing from reduced energy purchases, and ignores the significant economic multiplier effects associated with significantly reducing industrial energy costs, enhancing competitiveness, and increasing industrial profits and jobs in New York.

Table 29. Industrial Sector Cost-Effectiveness Results, Economic and Achievable Scenarios, Total for 2013-2032 (Present Value Million 2012$).

Scenario	Costs (Million$)	Benefits (Million$)	Net Benefits (Million$)	BCR
Economic	$2,357	$7,817	$5,460	3.32
Achievable	$1,330	$3,142	$1,813	2.36

5.2 Overview of Approach

Due to the diversity of the industrial sector, particularly the many different processes and other end uses of each manufacturing subsector, we developed a model to estimate the energy use of each of these subsectors from a base year of 2007 through 2032, the final study year. This methodology is described in the "Energy Sales Disaggregation" section below. We then applied the measures described in the Measure Characterization section to those subsector-specific end uses to develop the overall energy efficiency potential for each measure and for the industrial sector overall.

5.3 Energy Sales Disaggregation

The industrial sector is made up of a diverse group of economic entities spanning agriculture, mining, construction and manufacturing. Significant diversity exists within most of these industry sub-sectors, with the greatest diversity within manufacturing. The various product categories within manufacturing are classified using the North American Industrial Classification System (NAICS).

Comprehensive, highly-disaggregated electricity, natural gas, or petroleum data for the industrial sector are not available at the state level. To estimate the energy consumption, this study drew upon a number of resources, all using the NAICS system and a consistent sample methodology. Fortunately, a conjunction of the various economic censuses for each state allows us to use a common base-year of 2007.

We then used national industry energy intensities derived from industry group electricity, natural gas, and petroleum consumption data reported in the *2010 Annual Energy Outlook* (AEO)[17] and value of shipments data reported in the *2007 Annual Survey of Manufacturing* (ASM)[18] to apportion total industrial energy consumption to each sub-sector. These energy consumption estimates were then used to estimate the share of the industrial sector energy consumption for each sub-sector.

As is the case for state-level energy consumption data, no state-level disaggregated energy consumption forecasts are publicly available. Future energy consumption for each industry is a function of three things: the base-year energy consumption, change in economic output, and change in energy intensity.

Because state-level disaggregated economic growth projections are not publicly available, we used data from Moody's (economy.com). We estimated the average growth rates for specific industrial-subsectors in New York based on Moody's estimates of gross state product (GSP) for those sub-sectors. We then applied the annual percent change in GSP for each subsector to the base-year energy consumption. The AEO includes a forecast of national-level energy intensities for each sub-sector, which are also applied to the base-year energy consumption estimate. The energy use by each industrial subsector calculated by this methodology was then scaled so that total industrial energy consumption matched the forecast of industrial energy consumption used by this study.

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17 U.S. Energy Information Administration. 2010 "Annual Energy Outlook." infousa.state.gov/economy/technology/docs/0383.pdf. Accessed July 2013.

18 U.S. Census Bureau. 2007. "Annual Survey of Manufacturers." http://www.census.gov/manufacturing/asm/index.html. Accessed July 2013.

The industry sector is comprised of four sub-sectors: Manufacturing, Mining, Agriculture, and Construction. The manufacturing subsector is further broken down into 21 subsectors, defined by three digit NAICS codes. In order to most closely match available data from the ASM and AEO, three subsectors were further broken down to four digit NAICS codes: chemical manufacturing, nonmetallic mineral product manufacturing, and primary metal manufacturing. Table 30 shows the estimated electrical, natural gas, and petroleum consumption for all major subsectors in New York for 2013.

Table 30. Industrial Energy Consumption by Source and Subsector, 2013.

Sector	NAICS Code	Electricity		Natural Gas		Petroleum	
		(GWH)	(%)	(BBtu)	(%)	(BBtu)	%
Agriculture	11	116	0.8%	461	0.5%	928	3.4%
Mining	21	27	0.2%	141	0.1%	56	0.2%
Construction	23	766	5.0%	8,314	8.2%	18,349	67.6%
Total Manufacturing	**33**	**14,329**	**94.0%**	**92,085**	**91.2%**	**7,824**	**28.8%**
Food mfg	311	414	3%	3,794	4%	37	0%
Paper mfg	322	363	2%	2,128	2%	213	1%
Chemical mfg	325	6,093	40%	62,290	62%	2,579	9%
Pharmaceutical & medicine mfg	*3254*	3,190	21%	32,614	32%	1,350	5%
All other chemical products	*325x*	2,903	19%	29,676	29%	1,229	5%
Plastics & rubber products mfg	326	629	4%	1,496	1%	45	0%
Nonmetallic mineral products mfg	327	1,220	8%	5,565	6%	2,704	10%
Cement & concrete product mfg	*3273*	877	6%	616	1%	2,118	8%
Other minerals (including glass)	*327x*	344	2%	4,949	5%	586	2%
Primarily metal mfg	331	3,264	21%	6,653	7%	1,158	4%
Alumina and Aluminum	*3313*	1,505	10%	2,392	2%	545	2%
Nonferrous Metals except Aluminum	*3314*	1,535	10%	2,439	2%	555	2%
Other Metal mfg (incl iron & steel)	*331x*	223	1%	1,822	2%	58	0%
Fabricated metal product mfg	332	363	2%	1,782	2%	29	0%
All other manufacturing	3xx	1,983	13%	8,376	8%	1,059	4%
Total Industrial Sector		**15,239**	**100%**	**101,000**	**100%**	**27,156**	**100%**

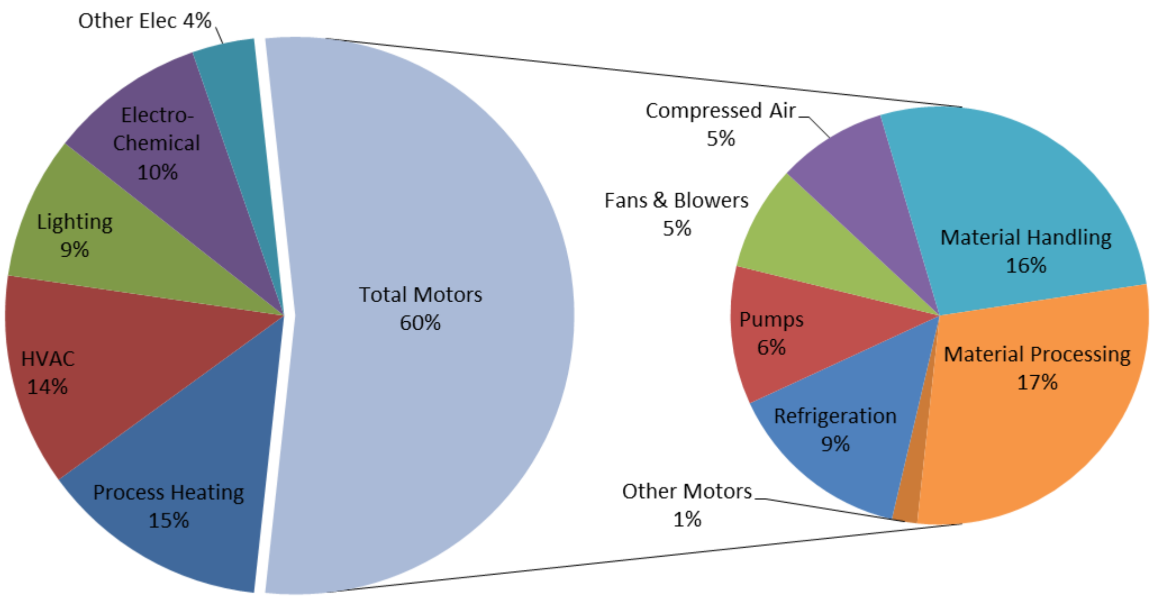
As shown in the table above, the chemical industry is the largest user of energy across the board, consuming nearly 10% of industrial petroleum, 40% of electricity, and over 60% of natural gas. Over two-thirds of the industrial petroleum is consumed by the construction sector. Other major industries are primary metal manufacturing, which consumes over 20% of industrial electricity and 7% of industrial natural gas, and non-metallic mineral manufacturing (mostly cement and concrete), which consumes 6% of industrial natural gas.

Much of the energy consumed by industry is directly involved in processes required to produce various products. Electricity accounts for almost a quarter of the primary energy used by industries. Electricity is used for many purposes, the most important being to run motors, provide lighting, provide heating, and to drive electrochemical processes.

While detailed end-use data are only available for each manufacturing sub-sector and group through the MECS survey, motor systems are estimated to consume 60% of the industrial electricity.[19]

Motors are used for many diverse applications from fluid applications (pumps, fans, and air and refrigeration compressors), to materials handling and processing (conveyors, machine tools and other processing equipment). The distribution of these motor uses varies significantly by industry, with material processing being the largest consumer in the sector. The figure below shows the total weighted average of end-use industrial electricity consumption in New York with a breakdown of the motors end use.

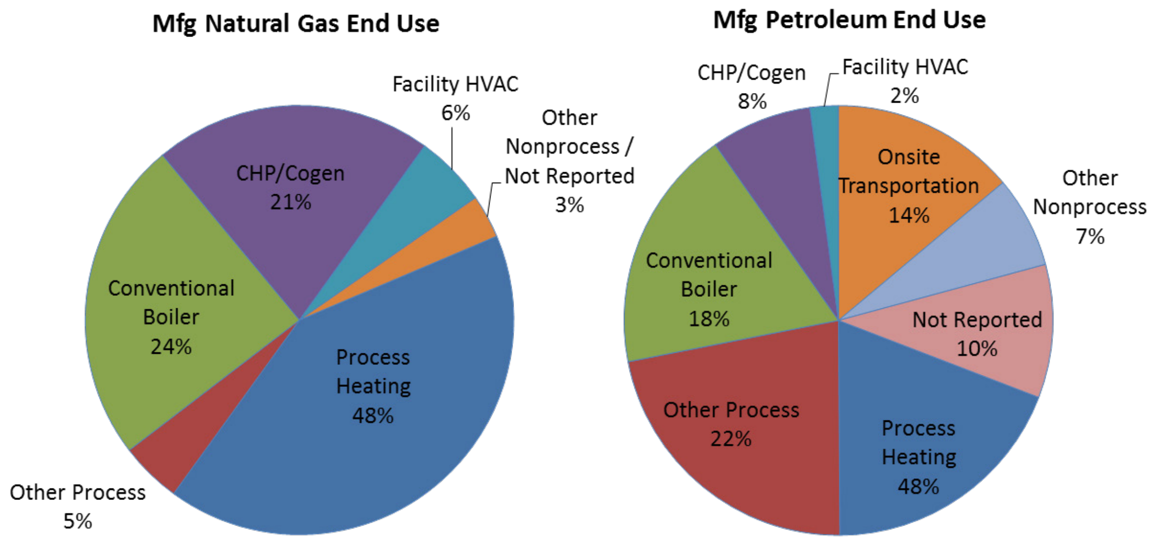
Figure 21. Weighted Average of Total Industrial Electricity End-Uses in New York, 2013.



A similar methodology was used to determine industrial natural gas and petroleum end use. The MECS survey (EIA 2010) provided both end use categories and nationwide consumption by industry, which was then applied to the actual industry mix in New York. Figure 22 shows the natural gas and petroleum fuel usage by end-use for the manufacturing sector (note that an end-use breakdown for construction, which accounts for nearly two-thirds of industrial petroleum consumption, is not available).

[19] XENERGY, Inc. 1998. *United States Industrial Electric Motor Systems Market Opportunities Assessment*. Prepared for the U.S. Department of Energy's Office of Industrial Technology and Oak Ridge National Laboratory. http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/mtrmkt.pdf. Accessed July 2013.

Figure 22. New York Manufacturing Natural Gas and Petroleum End Use, 2013.



5.4 Measure Characterization

For the industrial electric analysis, we used a suite of 40 industrial measures characterized and combined into 14 aggregate measures. The cost and performance of these measures has been developed over the past decade by ACEEE from research into the individual measures and review of past project performance. The costs of many of these measures has increased in recent years as a result of significant increases in key commodity costs such as copper, steel, and aluminum, as well as overall manufacturing costs due to energy prices and market pressures. These recent cost increases are reflected in the measure characterizations.

For the natural gas and petroleum fuel end uses we identified 36 fuel measures that were combined into 18 aggregate measures each for analysis. The cost and performance of these measures were largely drawn from a 2006 Itron report[20] , with applicable updates to measure costs.

Industrial measure costs and savings are assumed to remain fairly constant over the time span of this study. Particularly with aggregate measures, as measures penetrate the market, newer measures continue to enter and replace them as the new opportunity, often at a similar cost in nominal dollars.[21]

The table below highlights some of the emerging technologies and trends in industrial energy efficiency. These technologies and practices are either included in or enabled by the aggregate measures analyzed for the industrial sector.

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20 Itron, Inc. and KEMA, Inc. 2008. *California Energy Efficiency Potential Study*. Prepared for Pacific Gas & Electric Company. http://www.calmac.org/publications/PGE0264_Final_Report.pdf. Accessed July 2013.

21 Shipley, Anna Monis, R. Neal Elliott. 2006. *Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector?*. ACEEE Report Number IE061. http://www.aceee.org/research-report/ie061. Accessed July 2013.

Table 31. Industrial Emerging Technologies and Trends.

Application	Emerging Technologies and Trends
Advanced Manufacturing Processes	• Advanced motor systems (including pump, fan, and air compressor technology and system design) • Process heating (infrared, microwave, e-beam, radio frequency) • Heat recovery, boiler optimization, and combustion controls
Smart Manufacturing	• Sensors and submetering • Plant-wide data and energy information systems • Process integration and utility (compressed air, steam, etc.) automation • Energy management systems (e.g., ISO 50001)
Supply Chain Integration	• Lean Energy • Supplier data systems and energy goals • Flexible Manufacturing and redundant processing

Due to limited data for efficiency measures applicable to non-manufacturing industrial sectors (agricultural, mining, and construction), few of the electricity measures and none of the natural gas and petroleum measures apply to non-manufacturing industry. Non-manufacturing industry accounts for about 6% of industrial electricity, 9% of industrial natural gas, and 71% of industrial petroleum use in New York over the period of this study. While this doesn't significantly impact the bounded technical potential for electricity or natural gas, it largely accounts for the relatively low savings potential for petroleum, as construction accounts for over two-thirds of the industrial petroleum use in New York, and efficiency programs do not target that sector.

Appendix D in Volume 4 provides the full list of industrial measures with their characterizations.

5.5 Market Characterization

As mentioned above, manufacturing accounts for the vast majority of industrial energy in New York, with agriculture, mining, and construction making up the rest. Manufacturing energy varies by end use, and end uses vary greatly between subsectors. Table 28 in the previous section lays out the energy consumption in key subsectors.

5.6 Analysis of Economic Potential

For the industrial analysis we assumed penetration rates increased by a steady implementation ramp up of 10% to 30% per year until measures reach their full economic potential. Implementation then slows down or stops until previously-installed measures are retired, when replacement measures are installed.

5.7 Analysis of Achievable Potential

The achievable scenario takes into account the market barriers that account for how aware end users are of the costs and benefits of each measure as well as how willing they would be to implement them. The awareness barrier is important in manufacturing, because while some companies are relatively savvy at identifying efficient technologies and new trends in energy management, many companies have little or no focus on energy. Energy is often considered a fixed cost and not part of the company's core competency. For these companies, outreach and education are key to overcoming the awareness barrier. The willingness barrier is significant in all industry, regardless of how savvy industrial energy managers may be regarding new technologies and practices. Many manufacturing energy efficiency opportunities require an interruption of key processes or supporting equipment such as compressed air or boilers. Additionally, any changes to a manufacturing processes or supporting equipment are seen as an extra risk of failure. The willingness barrier accounts for manufacturers who understand the benefits of energy efficiency measures but may not be willing to install them.

The achievable scenario assumed that on average the incentives paid across all cost-effective measures represented 50% of the incremental measure costs. Instead of a flat 50% incentive for each measure, the incentives assumed for the achievable scenario ranged from 20% to 75% based on the benefit-cost ratio (BCR) of each measure, reflecting each measure's cost-effectiveness. The assumed incentives are shown in the following table.

Table 32. Industrial Measure Incentive Levels for the Achievable Scenario.

BCR	Incentive % of Incremental Cost
< 1.5	75%
≥ 1.5 and < 5	50%
≥ 5 and < 10	30%
≥ 10	20%

The hurdle of high initial costs for energy efficiency projects is an especially significant barrier to the adoption energy efficiency in manufacturing and other industry. In many cases a manufacturing plant's energy bills are often paid (and hence savings accrued) through the operations and maintenance budget, while investment comes out of the capital budget. This not only creates a disconnect between those managing the energy and capital budgets, but it pits energy efficiency project investments against all possible investments the company could make. Energy projects are generally considered less valuable than, for example, investments in production increases. These in-house barriers were considered when developing measure penetrations for the achievable scenario.

5.7.1 Program Costs

Program costs were developed relative to the incentive levels assumed for the achievable scenario. Program administration, marketing and other outlays were based largely on program spending data collected by the Northeast Energy Efficiency Partnerships' (NEEP) Regional Energy Efficiency Database (REED). Table 33 presents the industrial sector program costs for select years through 2030, broken out by incentive and non-incentive costs.

Table 33. Industrial Sector Program Costs, Achievable Scenario (Non-Discounted Million 2012$).

Market	2013	2015	2017	2020	2025	2030
Total Industrial Costs	$14	$92	$140	$42	$27	$26
Incentive Costs	$9	$57	$87	$26	$17	$16
Non-Incentive Costs	$5	$35	$53	$16	$10	$10

5.8 Detailed Results for the Industrial Sector

This section provides detailed results for the economic and achievable scenarios for the industrial sector that show how savings break out by end-use.

5.8.1 Industrial Economic and Achievable Electric Potential

As shown in Table 34, the end-use with the greatest electric efficiency potential in the industrial sector is process, accounting for 66% of the total achievable opportunities. This is consistent with many other studies and also with many efficiency portfolios.[22, 23] Other end uses account for the next highest share with 19% of the achievable opportunities, followed by lighting with 14%. Overall, the 2030 achievable potential of 1,506 GWh is about 32% of the economic potential.

[22] Eldridge, Maggie, Steve Nadel, Amanda Korane, John A. "Skip" Laitner, Vanessa McKinney, Max Neubauer, and Jacob Talbot. 2009. *Potential for Energy Efficiency, Demand Response, and Onsite Solar Energy in Pennsylvania*. ACEEE Report Number E093. http://aceee.org/research-report/e093. Accessed July 2013.

[23] Navigant Consulting, Inc. and Heschong Mahone Group. 2011. *Analysis to Update Energy Efficiency Potential, Goals, and Targets for 2013 and Beyond: Track 1 Statewide Investor Owned Utility Energy Efficiency Potential Study*. Prepared for California Public Utilities Commission.

Table 34. Distribution of Industrial Electric Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

Other end uses include HVAC, non-process water heating, miscellaneous plug loads, etc.

End Use	Economic		Achievable	
	Savings (GWh)	% of Total	Savings (GWh)	% of Total
Process	2,827	59%	1,000	66%
Other	1,002	21%	290	19%
Lighting	924	19%	216	14%
Total	**4,753**	**100%**	**1,506**	**100%**

5.8.2 Industrial Economic and Achievable Natural Gas Potential

As shown in Table 35, the end-use with the greatest natural gas efficiency potential in the industrial sector is boilers, accounting for about 60% of the total achievable gas opportunities. Process accounts for most of the remainder usage. Note that the vast majority of "boiler" savings are for process steam or hot water thermal energy (as opposed to space conditioning). However, because boilers alone account for such a large portion we differentiate here between boilers and other process energy use. This is consistent with many other studies and also with many efficiency portfolios. Overall, the 2030 achievable potential of 11,486 BBtu is about 32% of the economic potential.

Table 35. Distribution of Industrial Natural Gas Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Boiler	25,100	70%	6,917	60%
Process	9,906	28%	4,340	38%
HVAC	666	2%	229	2%
Total	**35,672**	**100%**	**11,486**	**100%**

5.8.3 Industrial Economic and Achievable Petroleum Fuels Potential

Table 36 shows the industrial petroleum fuels efficiency potential by end-use. Similar to the natural gas breakdown, the vast majority of opportunities are from boilers, at 56% of achievable savings, with virtually all the remainder for non-boiler process usage. Similar to the gas efficiency, we separate out boiler process use from non-boiler process usage because of the very large opportunities associated with these single systems. Overall, the 2030 achievable potential of 1,296 BBtu is about 51% of the economic potential.

Table 36. Distribution of Industrial Petroleum Fuels Efficiency by End-Use, Economic and Achievable Scenarios, 2030.

End Use	Economic		Achievable	
	Savings (BBtu)	% of Total	Savings (BBtu)	% of Total
Boiler	1,181	46%	720	56%
Process	1,355	53%	560	43%
HVAC	23	1%	16	1%
Total	**2,560**	**100%**	**1,296**	**100%**

6 Heat Pumps Research Module

6.1 Introduction

Heat pumps are a group of space conditioning devices that can extract heat from a cold reservoir and move it to a hot reservoir. As such, heat pumps are basically air conditioners that can run in reverse in the winter in order to provide heating. Because heat pumps move heat as opposed to creating it, they can achieve a coefficient of performance (COP)[24] many times higher than 1.0, which is the theoretical maximum efficiency for typical combustion heat sources and traditional electric resistance heat.

Heat pumps are often grouped into two distinct categories – air source heat pumps (ASHP) and ground source heat pumps (GSHP). Air source heat pumps use outdoor air as a thermal reservoir. This allows for simpler and less expensive installations, but ASHPs are also highly susceptible to reduced performance at lower air temperatures. Because the efficiency of heat pumps is inversely proportional to the difference in temperature between the hot and cold reservoirs, the heat pumps become less efficient as the temperature difference becomes larger. The difference in temperature between inside and outside is typically higher in the winter than in the summer, so this problem mainly impacts the heating season. In fact, for climates in most of New York, heat pumps need an auxiliary heat source for the coldest nights. Conventional air source heat pumps, designed for mild climates, for example, have a COP barely above 1 at 50 degrees Fahrenheit, and a lower temperature limit of 45 degrees Fahrenheit. However, heat pumps designed for improved cold weather performance has significantly increased in recent years, and now some ASHP models can provide space heating at a COP of 1.75 at 5 degrees Fahrenheit, and lower limit temperatures as low as -25 degrees Celsius (-13 degrees Fahrenheit).[25]

Ground source heat pumps attempt to address the problem of cold weather performance by using the ground soil or a body of water as a heat reservoir, instead of the outdoor air. Ground temperatures in the US stay at a fairly constant temperature throughout the year of between, depending on latitude, 45 degrees to 75 degrees Fahrenheit.[26] Since the temperature difference between the ground and the desired setpoint remains fairly small all year, ground source heat pumps are able to achieve higher seasonal efficiencies than air source heat pumps. However, extra piping and digging expenses also mean that the installation costs for GSHPs are much higher than those for ASHPs.

Within each of these two broad categories, there are several distinct types of heat pumps. This report will review several of these types of heat pumps, giving an overview of the technology, the market status and ideal site characteristics for installation, barriers preventing market adoption, and a high level estimate of energy savings potential.

24 The coefficient of performance (COP) is the ratio of the heating or cooling energy pumped between reservoirs to the energy consumed.

25 ETSAP and IRENA, p. 1 (see the bibliography at the end of this research module for full citations).

26 DOE Website, June 24, 2012.

6.2 Selected Technologies

6.2.1 Ductless Mini-Split

6.2.1.1 Overview

Ductless mini-splits are a type of air-source heat pump used primarily in residential and small commercial settings. Like standard central air conditioning (AC) units, ductless mini-splits have an outdoor compressor and an indoor air handler/evaporator connected by refrigerant lines. However, no ductwork is needed – instead, the evaporator units are typically located directly in the space to be cooled. Multiple indoor units can be connected to the same outdoor unit, allowing easy multi-zone control. Further, ductless mini-split units typically use inverter-driven variable speed compressors and multi-speed fans which allows for efficient part-load operation. This means less cycling and thus a tighter indoor temperature range. The eliminated duct losses, efficient part load operation, and easy zone control combine to allow ductless mini-splits to achieve higher seasonal efficiencies than traditional central ACs; units can reach as high as a 26 SEER. The lack of duct losses that often degrade the system efficiency in ducted systems contribute to additional energy savings. On the heating side, with seasonal average COPs reaching 3.5, ductless mini-splits provide significant advantages over electric resistance heat, and potentially even over fossil fuel boilers and furnaces, for which the highest efficiencies are in the upper nineties not including any duct losses.

In most areas of New York supplemental heating would likely be needed with ductless mini-splits. However, recent years have seen large advancements in cold-climate mini-splits, and units have recently become available that provide full heating capacity at 5 degrees Fahrenheit with COPs in the range of 1.5-1.8.[27]

6.2.1.2 Market Trends and Ideal Site Characteristics

Internationally, ductless mini-split heat pumps (DMSHPs) are not a new market, and in fact they are estimated to make up as much as 98% of the Asian residential HVAC market, and 50-70% of the European market.[28] Despite the international popularity, they have been slow to take hold in the US market, and are thought to make up less than 5% of the residential market. However, US adoption has recently been picking up, with an average annual growth rate of 12% for the past 5 years, despite a contracting overall Unitary HVAC market.[29]

Part of the reason for the slower uptake in the US market is that ductless mini-splits have a higher first-cost than a traditional AC and furnace. A pilot program in Connecticut and Massachusetts found an average cost per ton of cooling for a ductless mini-split retrofit of $2,715.[30] This agrees closely with a case study done by the US Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE) in Austin, which found a cost of

27 Roth, Sehgal and Akers, 2013.
28 NAHB Research Center, 2008.
29 Landwehr, 2012.
30 KEMA Inc., 2009.

$2,922 per ton.[31] The EERE study also found an incremental cost of $275 per ton, assuming both the furnace and the AC need to be retrofit in the base case. A comprehensive study in the Pacific Northwest finds a slightly higher incremental cost, estimating a 30% premium for DMSHPs.[32] However, given that a large portion of the costs for DMSHPs are for labor and their relatively low acceptance in the marketplace, it is reasonable to expect that costs will come down as the technology becomes more well-known. Further, DMSHP systems are likely already cheaper than traditional ducted systems for retrofit add-ons in houses with pre-existing non-ducted systems, or for room additions or renovations where it is infeasible to extend the existing ductwork.

6.2.1.3 Market Barriers

As evidenced by very high penetration rates of DMSHPs in Europe and Asia, the market barriers preventing US adoption of the technology should be addressable. These barriers include:

- **High first cost**: as mentioned above, first costs for DMSHPs are often higher than for traditional ducted systems when replacing existing equipment. However, the incremental cost will likely fall as DMSHPs gain more acceptance in the US.
- **Aesthetic concerns**: Many US homeowners do not like the aesthetics of having the indoor air handling unit right in the conditioned space, preferring to have the conditioned air enter through the nearly invisible vents typical of a ducted system. These concerns are likely to be mitigated with increased knowledge of the other comfort benefits of DMSHPs. In the CT/MA pilot project, for example, 31 of 40 participants indicated that the DMSHP system worked better than their old one. Surveys for pilot projects have found that although many customers complain about the sight of the system at first, they gradually grew accustomed. Further, many high-end residential homes are now putting in DMSHPs with short ductwork in order to address these concerns.
- **Lack of awareness**: In the past, manufacturers have directed marketing materials exclusively to trade contractors. This means consumer awareness of the product is still very low.
- **Low temperature heating**: In the past, the low-temperature performance has been a significant barrier to adoption in cold climates. However, as discussed above, this performance has improved significantly in recent years, and will likely continue to improve.
- **Uncertainty and lack of installers**: Many builders are reluctant to install DMSHPs due to uncertainty of market acceptance. Builders who do want to install DMSHPs often report having trouble finding an installer.[33]
- **Lack of contractor training**: DMSHPs require specialized training for proper installation, including how to size the system properly, and where to install the indoor AHUs. If this is not done properly, there will likely be issues with temperature and humidity control. Further, contractors are typically much more comfortable working with ducts than with refrigerant lines.

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31 Roth, Sehgal and Akers, 2013.
32 NAHB Research Center, 2008.
33 *Ibid.*

6.2.1.4 Potential in New York

This section provides a high-level estimate of the technical potential for ductless mini-split heat pumps. The estimate represents the total energy savings potential from replacing existing electric heating equipment with heat pumps, without consideration of the time it would realistically require to capture the full potential. We assume that 70% of New York homes with electric heat have a resistance heater with a COP of 1, and the other 30% have standard heat pumps, with a seasonal COP of 2.3. These assumptions imply that a ductless mini-split heat pump provides 61% energy savings over a baseline of electric heat during winter, and 39% savings over a central air conditioner in summer. We further assume that DMSHPs are feasible in 80% of New York homes. Finally, due New York's heating dominated climate, GSHPs do not make sense as a fuel switching measure from a source MMBtu basis, despite large site MMBtu savings. This is because a site-to-source ratio for electricity of 3.14 implies that 3.14 units of energy are needed for every unit of energy consumed on site. Thus even efficiency gains for heating of 50-60% are not enough to compensate for the increased losses throughout the electric generation and transmission system. We therefore assume that only buildings currently using electric heat are candidates for installation. However, it important to note that site-specific considerations may drive significant heat pump adoption despite this fact. For example, given current high costs of fuel oil, the customers without access to natural gas have a strong financial incentive to switch to heat pumps – a typical Vermont household can save about $1,000/year by switching from a fuel oil boiler or furnace to a cold climate heat pump. Further, heat pumps may still have environmental benefits; where the electric system has higher than average rates of hydro or other renewable sources, air pollution may decrease from switching to electricity, despite higher energy demands.

Using the above assumptions, the total meter-level electricity reduction potential for ductless mini-split heat pumps in New York is 1,244,243 MWh.

6.2.2 Variable Refrigerant Flow Systems

6.2.2.1 Overview

Variable refrigerant flow (VRF) heat pumps are similar to mini-splits in that one outdoor compressor is connected to multiple indoor air handlers/evaporators. However, where mini-split (and multi-split) systems require separate refrigerant lines for each indoor unit, the variable refrigerant flow capability allows all indoor units to connect to the compressor via the same two refrigerant lines. Further, by adding an extra refrigerant line, VRF systems are able to use heat recovery, enabling simultaneous heating and cooling by zone. With heat recovery, VRF systems will typically use three refrigerant lines – a liquid line, a hot gas line, and a suction line. An indoor unit requiring cooling will open the liquid and suction lines, and act as an evaporator, and a unit requiring heating will open its hot gas line and liquid line, and act as a condenser. Heat exchangers in the indoor units will transfer reject heat from units being cooled to the refrigerant line that is going to the zone to be heated. The waste heat can also potentially go to heat domestic hot water, or hot water for a separate hydronic heating system. Since the heat recovery gives energy savings to both the heated zones and the cooled zones, the effective COP may increase significantly.[34]

6.2.2.2 Market Status and Ideal Site Characteristics

Due to the VRF system's ability to efficiently provide tight zone-level temperature control to buildings with many zones, they are best suited to larger commercial and residential buildings that benefit from a high degree of individual zone control. This includes offices, hospitals, large multifamily buildings, nursing homes, strip malls, and schools. If zones in the building are expected to have highly variable cooling/heating loads, or if heat for DHW is desired, it may be worth paying a premium for a VRF system with heat recovery. Costs for VRF systems are highly variable, and depend on many site specific conditions. However, studies indicate that a VRF system typically costs 5-20% more than an equivalent standard HVAC system.[35] VRF systems are also a highly cost-effective retrofit on commercial buildings without a current cooling system.

Like ductless mini-split systems, the larger VRF systems also have much higher usage in Asia and Europe than in the US. In Japan, for example, VRF systems are used in about 50% of medium sized commercial buildings, and 33% of large commercial buildings (greater than 70,000 sf). Although US penetration is starting to increase in sectors such as luxury high rises in New York, overall market share is very low. In 2007, less than 10,000 VRF systems were installed in the U.S.[36]

6.2.2.3 Market Barriers

Market Barriers to widespread adoption of VRF systems in the US include:

- **High first cost**: In countries where VRF systems are well established, the higher equipment costs from VRFs are somewhat offset by lower labor costs. This is less true in the US, where most contractors are not familiar with VRFs.
- **Poor understanding of savings:** There is not much reliable third-party data available examining the performance and cost data of VRF systems in the United States. Until this data is more widely available and accepted, risk-averse contractors and builders are unlikely to specify a VRF system.
- **Concerns about refrigerant leaks**: Since VRF systems have long lengths of refrigerant pipes, there has been concern relating to the potential for leaks. Installation must be performed in accordance with ASHRAE Standard 15-2007. As more contractors gain experience safely installing long refrigerant lines, this barrier should diminish in importance.
- **Manufacturer presence:** US manufacturer presence and support for VRF systems has traditionally been very limited. This seems to be changing in recent years as Japanese manufactures have moved into the US market space.

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[34] Bhatia, 2011.
[35] *Ibid.*
[36] Amarnath and Blatt, 2008.

- **Ventilation Requirements**: Depending on the design, a building with a VRF system may also need a dedicated ventilation system in order to comply with ASHRAE standard 62 requirements. This offsets part of the advantage of using a VRF system.
- **Lack of test rating procedures:** While Japan and Europe have well established rating systems for VRFs, there are no code compliance procedures certified by the ARI and approved by US DOE.

6.2.2.4 Potential in New York

This section provides high-level estimates of the technical potential for variable refrigerant flow heat pumps. The estimates represent the total energy savings potential from replacing existing electric heating equipment with heat pumps, without consideration of the time it would realistically require to capture the full potential. Due to the site-specific nature of VRFs and a lack of third-party field data, savings from VRFs are highly uncertain. The following studies provide an indication if the potential for energy savings:[37]

- EnergyPlus modeling of a 10-story office building in Shanghai showed 20% energy savings compared to a VAV system, and 10% compared to a fan coil system.
- Manufacturers suggest that a VRF could achieve 30-40% savings compared to a chiller based system.
- A pilot study of 14 building in Italy done by a VRF manufacturer found that the VRF system used 35% less energy and had 40% lower maintenance costs.
- A modeling study done in Brazil shows 30% savings in summer and over 60% in winter. However, the study suggested that savings of 5-15% were more likely in a US climate.

Since the savings are so uncertain, and since large parts of New York State have a cold climate, this potential estimate assumes savings on the low end of the range found in the above studies, at 10% of heating and cooling usage. Further, we assume that it is technically feasible to reach Japanese levels of penetration, at 50% of mid-sized buildings and 33% of large buildings. Finally, given these conservative savings estimates and the New York climate, fuel switching applications are assumed to be not desirable for replacing fossil fuel heating. We therefore limit the below potential to buildings with electric heat; however, there likely are individual instances in which VRF systems make sense as a fuel switching measure – especially downstate where the cooling load is smaller.

With these assumptions, new construction meter-level electricity reduction potential is 6,250 MWh per year. The total retrofit potential is 211,892 MWh.

[37] *Ibid.*

6.2.3 Ground Source Heat Pumps

6.2.3.1 Overview

Ground-source heat pumps (GSHPs) use either the ground, or a nearby lake or other body of water as a heat reservoir. Since the ground temperature is relatively stable throughout the year, GSHPs provide an efficiency advantage over air-source heat pumps and have much better cold climate performance than air-source heat pumps. This is demonstrated by their popularity in Scandinavian countries – 30% of Swedish houses have GSHPs, and there are an estimated 15,000 GSHP systems in Norway and 46,000 in Finland.[38]

There are two broad categories of GSHPs: open-loop systems and closed-loop systems. Open-loop systems pump water from a nearby lake, ocean, or river into a heat exchanger in the heat pump, and then discharge the water into the same body of water. While installation costs are typically cheaper than for closed-loop systems, the site must be situated nearby an appropriate body of water, and local codes regarding groundwater discharge may further restrict possible installation sites.

A closed-loop system pumps a fluid with a low freezing temperature through the ground or body of water. As the fluid gets pumped through the pipe, it exchanges heat with the surrounding ground. The longer the pipe, the more heat will be exchanged; typical estimates call for 720-1040 feet per ton of heat pump capacity. Closed-loop GSHPs can be further broken down into horizontal and vertical systems. Horizontal systems are generally cheaper to install, and more cost-effective for residential installations, if sufficient space is available. In these systems, the piping is installed over a fairly large area, at a depth of between four and six feet below ground. Cold climate installations may need to go in at the deeper end of this range in order to avoid ground frost in the winter. Vertical systems are used more often for larger systems, where the amount of land area required for a horizontal system would be prohibitive. Vertical systems are far more expensive than horizontal systems, as they require piping to depths of 100 to 400 feet.

In recent years, direct exchange (DX) ground-source heat pumps have been gaining popularity. DX systems pump refrigerant directly through the ground loop, instead of using a secondary water/glycol loop. DX systems eliminate the water-to-refrigerant heat exchanger as well as water loop pumping, making them generally cheaper and more efficient than traditional GSHPs. However, there are potentially serious environmental concerns relating to the potential leakage of refrigerant into the groundwater, and the high cost of repairing such leaks.

Desuperheaters: A desuperheater is an auxiliary heat exchanger that captures heat from the hot refrigerant as it leaves the heat pump compressor and transfers it to the domestic hot water. While there are desuperheaters available for standard air source heat pumps and even central AC units, they most commonly come with GSHPs. Desuperheaters deliver more heat in the summer, as there is more waste heat to spare, but also contribute to hot

[38] Denali Commission, 2011.

water heat in the winter. Since desuperheaters typically need auxiliary electric resistance heat, they only make sense in a building with electric water heat. Desuperheater costs range from around $400-$700, and meet 20-40% of annual water heating demand.[39,40]

6.2.3.2 Market Status and Ideal Site Characteristics

GSHP installations in the US have been rising rapidly in recent years. In 2005, there were only about 600,000 GHP units installed in the US; however 2008 and 2009 both saw annual shipments of over 100,000, equaling more than 400,000 tons of capacity per year.[41, 42] Ground source heat pumps are more common in residential and small commercial installations, as the amount of pipe needed to cool very large commercial and industrial spaces is often prohibitive. It is rare to see GSHPs in buildings over 100,000 square feet.

Despite the increase in installations, high first cost continues to be a significant barrier to GSHP penetration. Costs for GSHPs are highly variable, and dependent both on the soil type in the area, and on the availability of drillers with the type of experience needed to drill for GSHP systems. Also, incremental costs tend to get smaller as the system gets larger (for the same type of GSHP system) – a survey of the market in the Pacific Northwest found costs for a 2,000-square-foot (sf) home between $10,000 and $14,000, and costs for a larger 4,000 sf home at $12,000 to $18,000.[43] For this reason, most systems installed are going into homes larger than 3,000 sf. However, the same survey found that, if equipment were sold at cost, GSHPs would only be slightly more expensive than ASHPs for homes as small as 2,000 sf. In contrast, a 2010 ORNL study estimates the incremental cost of retrofitting a 3-ton GSHP system at more than double the costs of installing a CAC and gas furnace.[44]

Commercial installations of GSHPs are rarer than residential installations, due to more complex systems and higher costs. Cost premiums for commercial installations are also highly variable, but estimated at between 0 and 100%.[45] An ASHRAE study of a sample of GSHPs in commercial installation found an average installed cost of $7,694 per ton. However, the study also found that the ground loop portion only made up 25.5% of the total costs, implying that there is likely significant room for cost reduction on the actual HVAC components of GSHPs.

6.2.3.3 Market Barriers

The largest barrier to GSHP adoption is high first costs, as discussed above. The two main factors contributing to higher first costs are complexities associated with the ground loop, and limited production volume of the other parts. One would expect both of these two go down as GSHPs gain market acceptance. Other barriers include:

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39 Builder Guide, 2003.
40 Olszewski and Fontana, 1983.
41 Liu, 2010.
42 Navigant Consulting, Inc., 2012.
43 Regional Economic Research, Inc., 2010.
44 Liu, 2010.
45 Regional Economic Research, Inc., 2010.

- **Complexity**: The need for a ground loop adds significant complexity and risk to GSHP installations, and necessitates site-specific design. It also typically means site-specific feasibility studies have to be done, and creates uncertainty in cost estimating.
- **Variations in ground temperature**: Depending on the site, the ground temperature often varies in practice more than it does in theory, thus limiting the efficiency gains from GSHPs.
- **Economics compared to ASHPs**: Top of the line ASHPs may have more attractive economics than GSHPs, despite higher total savings from GSHPs. This is especially true as advances in ASHPs make them more suitable for colder climates. The lifetime and payback period for GSHPs are also longer than for ASHPs.
- **Site limitations**: GSHP installation may be infeasible for a specific location, based on soil type, proximately to water, space constraints, and availability of drillers.
- **Limited number of qualified, trained installers**.
- **Potential for glycol or refrigerant leaks**.

6.2.3.4 Potential in New York

This section provides high-level estimates of the technical potential for variable refrigerant flow heat pumps. The estimates represent the total energy savings potential from replacing existing electric heating equipment with heat pumps, without consideration of the time it would realistically require to capture the full potential.

There is far more research and literature on GSHPs in the US than there is for VRF systems. Some studies include:

- A comprehensive Department of Energy (DOE) overview that finds Mid-Atlantic residential primary savings of 55% compared to a gas furnace/AC (or a standard ASHP) and commercial savings of 48% compared to a typical ASHP.[46]
- A residential technical potential study by the National Energy Policy Institute that finds space heating savings for the Mid-Atlantic region of 65%-84% and cooling savings of 74%-77%, depending on the baseline.[47]

This potential estimate assumes savings levels equivalent to the EERE estimates for the Mid-Atlantic census region, at 55% for residential, and 48% for commercial. It also assumes that GSHPs are only feasible for smaller commercial buildings of under 100,000 square feet, and feasible for 50% of properties. As discussed under the ductless mini-split section, due to New York's heating dominated climate, GSHPs do not make sense as a fuel switching measure from a source MMBtu basis, despite large site MMBtu savings. We therefore assume that this measure only applies to buildings currently using electric heat.

In total, we estimate total residential meter-level electricity savings potential of 729,051 MWh. The commercial potential is 2,324,010 MWh. If all GSHPs installed are assumed to have desuperheaters that offset electric DHW use, there are additional residential savings of 516,820 MWh, and commercial savings of 292,892 MWh. This gives total residential and commercial meter-level electricity savings potential from GSHPs of about 4,000 GWh.

[46] Navigant Consulting, Inc., 2009.
[47] Liu, 2010.

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