Energy Efficiency Potential Assessment for 2016-2025

April 17, 2015

Prepared For

PPL Electric

The Cadmus Group, Inc.

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List of Acronyms

ACS: American Community Survey

B/C: Benefit-cost

CBECS: Commercial Building Energy Consumption Survey (Energy Information Agency)

CIS: Customer information system

EIA: Energy Information Agency

EUC: End-use consumption

EUL: Effective useful life

EUI: End-use Intensities

GWh: Gigawatt hours

GNI: Government, non-profit, institutional

MECS: Manufacturing Energy Consumption Survey (Energy Information Agency)

MW: Megawatt

MWh: Megawatt hour

NAICS: North American Industrial Classification System

kWh: Kilowatt hour

RASS: Residential Appliance Saturation Survey

RECS: Residential Energy Consumption Survey (Energy Information Agency)

SIC: Standard industrial classification

SWE: State-wide evaluator

TRC: Total resource cost

UEC: Unit energy consumption, also referred to as end-use consumption

UCT: Utility cost test

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Executive Summary

This report summarizes results from an independent study of the long-run technical, economic, achievable, program energy efficiency and demand response potential for PPL Electric (PPL) in 2016 through 2025. The results of this study will inform planning and program design for Phase III of PPL's energy efficiency programs.

The study relies on both primary and secondary data specific to PPL's service territories. Cadmus analyzed data from the Pennsylvania Statewide Evaluator's (SWE) residential and non-residential 2014 baseline studies[1], PPL's appliance saturation surveys, and PPL's Phase I and Phase II program accomplishments. Secondary data include PPL's load forecasts, long-term avoided costs (including annual energy and capacity values), line losses, and discount rates. Cadmus thoroughly reviewed the 2015 Pennsylvania Technical Reference Manual (TRM) to develop a comprehensive list of commercially available measures. We also included measures from various alternate sources including regional TRMs, American Council for an Energy-Efficient Economy (ACEEE) technical reports, ENERGY STAR calculators, and Cadmus' internal database of energy efficiency measures.

Cadmus supplemented primary and secondary data with information from secondary sources.[2] Together, they provide the foundation for estimating technical, economic, achievable, and program potential, defined as follows:

- ***Technical potential*** the total energy efficiency potential in PPL's service territory after assuming all technically feasible, energy efficiency measures may be implemented, regardless of their costs or market barriers.
- ***Economic potential*** represents a subset of technical potential, consisting only of measures meeting cost-effectiveness criteria based on the utility's avoided supply costs for delivering electricity and natural gas and avoided line losses. Cadmus determined the economic potential

[1] *P*ennsylvania Statewide Act 129 2014 Non-Residential End Use & Saturation Study. April 2014 submitted by Nexant; and 2014 Pennsylvania Statewide Act 129 Residential Baseline Study. April 2014 submitted by GDS Associates. Cadmus' analysis reflects compiled data from PPL Electric, PECO, and Duquesne.

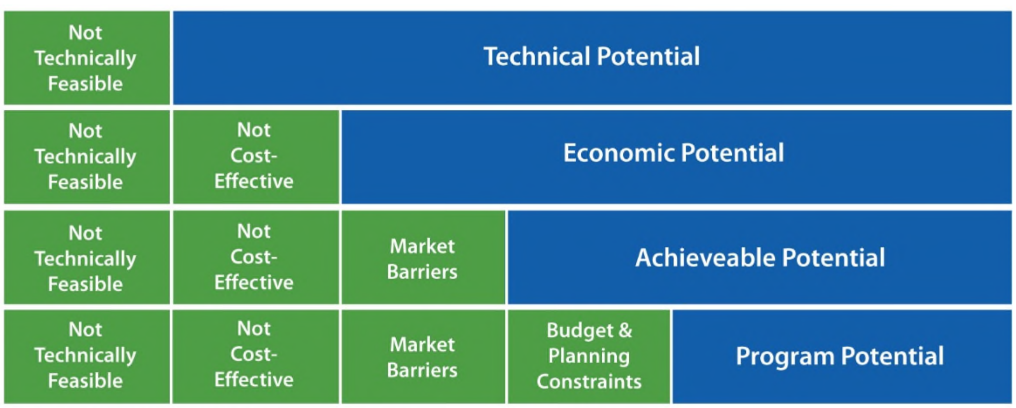
[2] Secondary sources are different from "secondary data." Secondary sources provide information not directly gathered or compiled by Cadmus, but that we consider accurate. Examples of secondary sources include the U.S. Census and Energy Information Administration websites, where we obtained supplemental technical and market data.

using a total resource cost test (TRC), which compares the net benefits of energy efficiency measures with their costs.[3]

- **Achievable potential** is defined as the portion of economic potential assumed to be reasonably achievable in the course of the planning horizon, given market barriers that may impede customers' participation in utility programs. In this study, Cadmus examined survey results from the SWE's 2014 baseline study and other willingness to pay surveys to assess the consumers' willingness to adopt energy efficiency measures at "base" (between 35% and 57.5% of the incremental cost) and "maximum" (100% of the incremental cost) incentive levels.
- **Program potential** is the portion of achievable energy efficiency potential that can realistically be acquired through programs after accounting for legislative spending requirements, low-income savings carve-outs, institutional-savings carve-outs, and other program design considerations such as measure mix, low-income expenditures, incentive levels, and the ramping of programs.

Figure 1 shows considerations for each type of energy efficiency potential.

Figure 1. Definitions of Energy Efficiency Potential



EPA – National Guide for Resource Planning

To estimate technical potential, Cadmus used the industry-standard, bottom-up approach. This approach is consistent with energy efficiency studies by Cadmus and others consultants in various jurisdictions in the United States, including the SWE's 2015 energy efficiency potential study. We began with a comprehensive review of electric energy efficiency measures applicable to each utility's sector and market segments. Using technical measure data and market characteristics, we determined likely

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3 For a description of the method for calculating the total resource costs test, see the *California Standard Practice Manual: Economic Analysis of Demand Side Management Programs*. California Public Utilities Commission. October 2001. Cadmus used a TRC benefit-cost test consistent with the Pennsylvania Public Utilities Commission's TRC orders.

long-term saturations of each measure in specific sectors and market segments. This assessment resulted in a technical potential supply curve at the measure level, which we then screened for cost-effectiveness to determine the economic potential. The study determined achievable levels of energy efficiency potential by assessing customers' willingness to pay for energy efficiency measures, based on results from the SWE's 2015 Baseline Study.

Study Objectives

This study's broad purpose is to identify energy efficiency customers eligible to participate in PPL's energy efficiency programs and inform PPL's Phase III energy efficiency program design. Specific objectives to fulfill this broad purpose include:

- Analyze primary data on the saturation of specific end uses and equipment in Pennsylvania homes and commercial facilities.
- Assess customers' willingness to participate in energy efficiency programs for specific measures at different incentive levels.
- Develop baseline "end–use" load forecasts for the residential, commercial, institutional and industrial sectors for PPL that capture the unique mixture of end-use consumption in each sector, accounts for the impact of energy building codes and federal equipment standards, and reflects the natural adoption of efficient technology.
- Characterize a comprehensive list of commercially available energy efficiency measures, which includes estimates of measure costs, savings, and applicability.
- Identify technical, economic, and achievable potential over the study horizon (2015 to 2024) for the residential, commercial, institutional, and industrial sectors.
    - Identify energy efficiency potential for market segments within each sector, such as the low-income market segment for the residential sector.
- Identify the relative savings potential for a list of energy efficiency measures. Compare measures with high savings potential to those offered through PPL's existing programs.
- Identify market segments with high-energy efficiency savings potential.
- Develop alternate program potential scenarios that reflect different expenditures on incentives, measure mix, and segment-specific carve-outs
    - Test the sensitivity of program potential to changes in program assumptions (such as measure cost, incentives, and measure mix).

While this study is meant to inform program design, it does not explicitly set program targets. Cadmus developed program scenarios which reflect broad assumptions about expenditures and the mixture of measures. We incorporated various program constraints, such as PPL's $307.5 million spending cap, low-income carve out equivalent to 5.5% of five-year program savings, an institutional carve-out equivalent to at least 3.5% of five-year savings, and the expected mix of measures for Phase III programs. These scenarios are meant to be a starting point for program design. For Phase III, PPL can use these program scenarios to guide portfolio design by identifying possible high-saving measures and other measures where potential may be depleted due to codes and standards or previous program accomplishments.

Summary of Results

This study estimates the amount of energy PPL can save across its service territory through energy efficiency measures from 2016 to 2025, with an emphasis on 2016 through 2020 (the years spanning Phase III). Estimates reflect the assessment of proven and commercially available energy efficiency technologies, while accounting for

- Changes in codes and standards (taking effect between 2016 and 2025);
- Technical feasibility (technical potential);
- Cost-effectiveness (economic potential) using the TRC;
- Consumers' willingness to adopt energy efficiency measures (achievable potential); and
- Planning constraints such as spending caps, segment-specific carve outs, and measure mix (program potential).

Table 1 shows cumulative technical and economic energy efficiency potential in 2020, by sector. Potential for government, non-profit, and institutional (GNI) customers are included in the commercial sector.

Table 1. Cumulative Technical and Economic Potential - 2020

Sector	Baseline Sales (2010)	Technical Potential - Cumulative 2020		Economic Potential - Cumulative 2020		
		MWh	% of Baseline	MWh	% of Baseline	As a % of Technical Potential
Residential	15,136,306	3,668,300	24%	2,374,011	16%	65%
Commercial	12,829,784	2,398,733	19%	1,647,682	13%	69%
Industrial	10,248,276	540,889	5%	480,149	5%	89%
Total	**38,214,366**	**6,607,922**	**17%**	**4,501,842**	**12%**	**68%**

Cumulative technically feasible energy-efficiency potential in 2020, is roughly equivalent to 6,608 GWh or 17% of 2010 baseline sales. Cumulative economic potential in 2020 equals 4,502 GWh, which is approximately equivalent to 12% of 2010 baseline sales. Economic potential captures roughly 68% of technical potential.

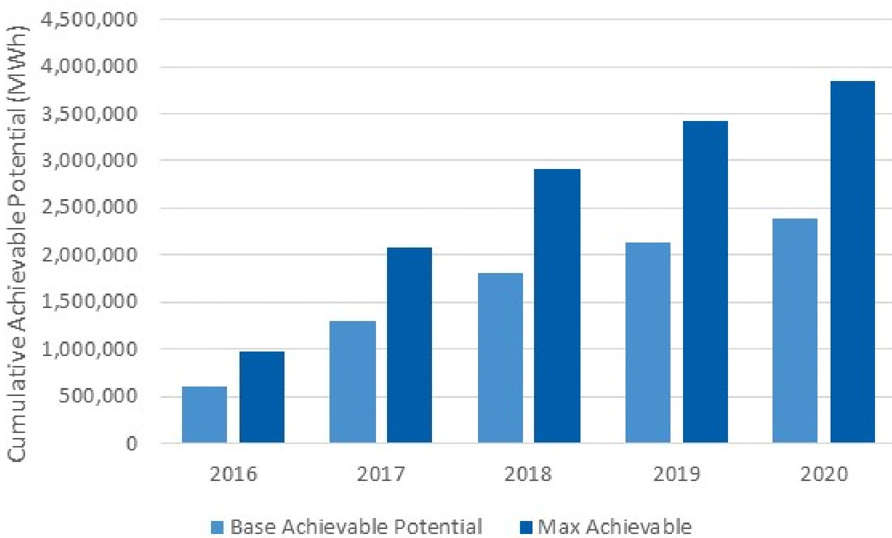
Cadmus produced two achievable potential scenarios which reflect customers' willingness-to-adopt various efficiency measures if provided different incentive levels. The "base" efficiency scenarios assumes incentive levels consistent with base scenario incentives used in the SWE's 2015 statewide potential study. These incentives equal 56% of incremental costs for the residential sector and 35% of incremental costs for the commercial, industrial, and GNI sectors. Cadmus assumed incentives equivalent to 100% of full measure costs for low income customers within the residential sector. Cadmus considered a second achievable potential scenario—maximum achievable—which sets incentive levels equivalent to 100% of either incremental or full measure costs.[4] Table 2 summarizes cumulative achievable energy efficiency potential for each scenario

Table 2. Cumulative Achievable Energy Efficiency Potential - 2020

Sector	Baseline Sales	Cumulative Base Achievable - 2020 MWh		Cumulative Max Achievable - 2020 MWh	
		MWh	% of Baseline	MWh	% of Baseline
Residential	15,136,306	1,712,718	11%	2,151,294	14%
Commercial	12,829,784	502,720	4%	1,294,306	10%
Industrial	10,248,276	177,942	2%	404,631	4%
Total	**38,214,366**	**2,393,380**	**6%**	**3,850,231**	**10%**

In 2020, cumulative achievable savings can account for between 2,393 and 3,850 GWh or approximately 6% to 10% of baseline sales for the base and max scenarios, respectively. Figure 2 shows cumulative achievable potential in 2016 through 2020 for the base and max achievable scenarios.

Figure 2. Cumulative Achievable Potential by Scenario

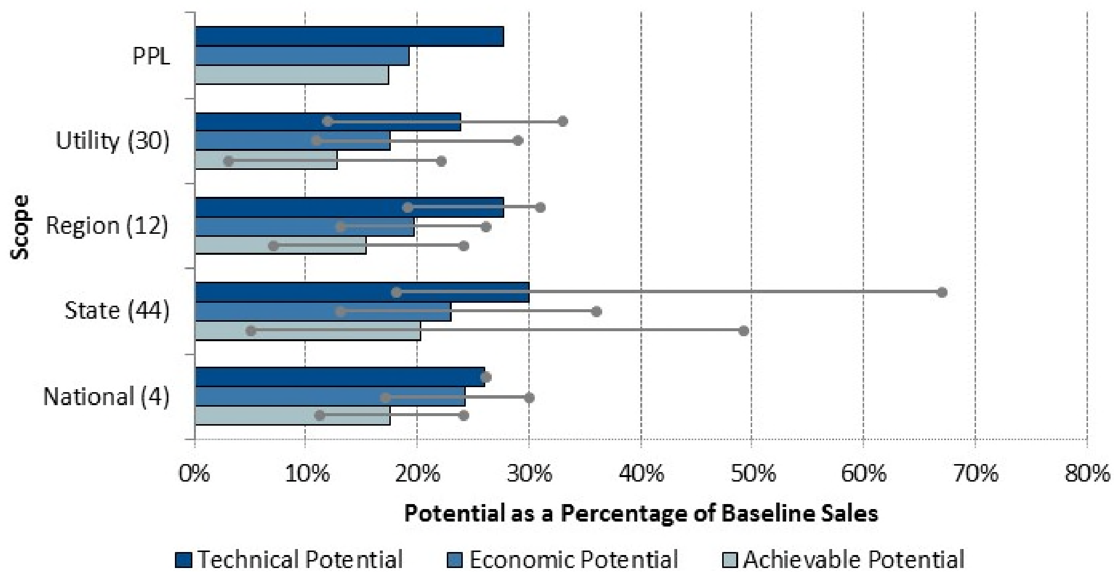


Comparison of Study Results to Other Energy Efficiency Potential Studies

[4] Cadmus used full measure costs for measures applicable to the residential low income segment. Some measures applicable to all segments are naturally full cost measures (such as weatherization and shell) because the baseline for these measures is the absence of the measure

Overall, study findings are largely consistent with similar energy-efficiency potential studies. Cadmus conducted a review of 90 studies that estimate the technical, economic, and achievable energy-efficiency potential for various regions (utility, state, region, and national). Figure 3 summarizes the results of this comparison (gray lines indicate the range of estimates). Note: values in Figure 3 exceed those in Table 1 and Table 2 because these reflect 10-year estimates of technical, economic, and achievable potential, while values in the preceding tables reflect 5-year estimates of potential. Also, PPL's potential is expressed as a portion of *historic* (2010) sales, while most comparable studies expressed potential as a fraction of forecast sales. For this reason, PPL's potential as a fraction of baseline sales may be higher than those of comparable studies.

Figure 3. Comparison of Study Results to Other Potential Studies



On average, Cadmus' overall estimate of technical potential relative to forecasted baseline sales are consistent with similar studies—technically feasible energy-efficiency can offset approximately 28% of baseline sales, which is within the range of estimates for utility sponsored studies. Economic potential as a percentage of technical potential is only slightly lower for PPL, compared to the studies Cadmus reviewed. This indicates a smaller share of technically feasible savings is cost-effective for PPL. Economic potential is largely determined by each utility's respective avoided energy and capacity costs—PPL's current avoided costs are below historic national averages, which explains why economic potential relative to technical potential is below average. Table 3 compares the ratio of economic potential to technical potential for this study to other studies.

Table 3. Comparison of Economic and Achievable Potential to Similar Studies

Scope	Economic as % of Technical (n = 42)	Max Achievable as % of Economic (n = 38)	Moderate Achievable as % of Economic (n = 22)
PPL	69%	90%	50%
Utility	73%	61%	47%
State	73%	65%	46%
Region	64%	68%	58%
National	65%	N/A	50%

Max achievable as a percentage of economic potential differed significantly from estimates included in other potential studies. This is likely due to differing definitions and assumptions for "maximum achievable" potential—in some studies the "maximum" scenario reflects current incentive levels, and not true "maximum" incentives. In this study, Cadmus assumed that maximum achievable potential reflects the scenario where PPL covers 100% of incremental measure costs. Based on results from willingness to participate surveys in the SWE 2014 residential and non-residential baseline surveys, Cadmus found that on average, 10% of customer *would not* adopt the efficient option if PPL covers 100% of the cost to upgrade.

Also, it is important that Cadmus' review of 90 similar energy-efficiency potential studies span roughly the last ten years. Over this period, natural gas prices have declined, which in turn, has led to a decline in avoided costs for many utilities. Due to declining avoided costs, the portion of technical potential that is cost-effective has generally declined.

Program Potential

Program potential is the portion of achievable energy efficiency potential that can be realistically acquired through programs, after accounting for budget and implementation constraints. In this study, Cadmus considered six program potential scenarios which incorporated different assumptions for the following:

- **Benefit-cost threshold**: Traditionally, estimates of economic, achievable, and program potential only reflect measures with a total resource cost (TRC) benefit-cost ratio equaling or exceeding 1.0. This assumption, however, does not reflect cost-effectiveness requirements in Pennsylvania. PPL may offer measures with a TRC benefit-cost ratio less than one as long as the overall energy efficiency portfolio remains cost-effective. For four program scenarios, Cadmus relaxed this benefit-cost threshold, and effectively produced estimates of program potential reflecting non-cost-effective measures bundled with cost-effective measures.
- **Measure mix**: An approach for estimating program potential involves equally "scaling down" estimates of achievable potential for all measures; so overall program budgets meet legislatively mandated spending caps. This approach assumes the distribution of savings from measures that contribute to program potential equals the distribution observed in achievable potential. An alternate approach involves estimating programming potential using only measures that a utility

expects to offer through programs. Measures with high freeridership levels or market barriers may be excluded from such estimates of program potential. We present scenarios using both approaches.

- **Treatment of low-income customers:** The PUC's tentative implementation order on Phase III programs proposes a low-income carve out where savings from low-income, direct-install programs account for at least 2% of total portfolio savings, and other low-income savings (non-direct-install) account for at least 3.5% of portfolio savings. While the SWE's estimates of program potential do not account for this carve out, Cadmus developed alternate program potential scenarios that do so. For these scenarios, low-income acquisition costs reflect PPL's actual acquisition costs from Phase II.
- **Mixture of screw-base lighting measures:** Program acquisition costs and potential remain highly responsive to the mixture of screw-base lighting measures considered—a scenario where a utility primarily offers CFLs will be much cheaper and have higher program potential than a scenario where a utility primarily offers LEDs.

Table 4 describes the key assumptions for each program scenario.

Table 4. Program Scenarios and Assumptions

Scenario Name	Acquisition Cost ($/kWh)	Description	Benefit-Cost Threshold	Measure Mix	Low Income Treatment	Low-Income Carve Out	Lighting Treatment
Traditional 1	$0.18	Scenario most comparable to the SWE potential study. This scenario includes all cost-effective measures, treats low-income similar to non-low-income, does not include a low-income carve out, and assumes a 30/70 distribution of CFLs and LEDs.	1.0	All cost-effective measures	Use incremental measure costs; incentives equivalent to approximately 50% of incremental costs	No	Declining LED prices; 30/70 CFL and LED share
Traditional 2	$0.22	This scenario is identical to Scenario 1, except it assumes incentives for low-income measures are equivalent to 100% of incremental measure costs.	1.0	All cost-effective measures	Use incremental measure costs; incentives equivalent to 100% of incremental costs	No	Declining LED prices; 30/70 CFL and LED share
Program 1—Low Cost A	$0.18	This scenario only includes PPL's preferred measures. Non-cost-effective measures are allowed and CFLs account for 100% of screw-base lighting savings.	0.75	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	Exclude LEDs (CFLs only)
Program 2—Low Cost B	$0.21	Includes PPL's preferred measures and excludes CFLs. Accounts for the low-income carve out	0.75	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	LEDs only (exclude CFLs)
Program 3—Medium Cost	$0.30	Reflects a lower benefit-cost threshold and a more balanced mixture of measures. Lighting accounts for a low to moderate share of portfolio savings.	0.5	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	LEDs only (exclude CFLs)
Program 4—High Cost	$0.39	Reflects a lower benefit cost threshold. Lighting accounts for a relatively low share of portfolio savings.	0.45	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	LEDs only (exclude CFLs)

In addition to assumptions listed in Table 4, Cadmus applied the following assumptions to each of the four program scenarios (and not the two traditional scenarios):

- The total five-year spending cap roughly equals $280 million. This reflects the demand response (DR) expenditure requirement in the PUCs implementation order, which effectively makes energy efficiency expenditures equivalent to an average of $58.5 million per year. Per PPL, we reduced this resulting budget by 3.5% to account for risk.
- Low-income, direct-install, acquisition costs approximately are $1.50 per kWh saved; acquisition costs for other low-income measures range from $0.20 per kWh to approximately $0.30 per kWh. These costs reflect PPL's actual expenditures on low-income programs.

In evaluating these different scenarios, Cadmus compared the following metrics:

- **Overall acquisition cost ($/kWh):** An acquisition cost calculated as the total five-year program budget, divided by the five-year program potential.
- **Five-year program potential (MWh):** Equals the sum of incremental savings in each program year (2016 through 2020).
- **Total Budget ($000s)**: Reflects the sum of each measures' cost per kWh (including incentives and administrative expenditures), multiplied by the sum of the five-year incremental program potential.
- **Low-income potential:** Expressed as a percentage of the total portfolio program potential.
- **Lighting potential:** Expressed as a percent of the total portfolio program potential. This metric roughly represents the diversity of the measure mix for a given scenario. Scenarios with a relatively high share of savings from lighting have a less diverse mixture of measures. Notably, the lighting share as a percent of portfolio savings may be significantly lower than the share PPL historically has observed through programs: the remaining lighting efficiency potential has greatly decreased over the last six program years, the saturation of efficient lighting has increased, and federal lighting standards have further reduced savings.
- **Weighted average program potential** as a fraction of base achievable potential: Program potential is the remaining subset of achievable potential after accounting for budget constraints. This metric shows the portion of achievable savings PPL must capture through programs to meet savings targets. Scenarios where this fraction is high could carry more risk as they require nearly all likely participants to participate.

Overview of Program Potential Results

Table 11 summarizes these key metrics for each of the six scenarios considered.

Table 5. Summary of Program Scenario Results

Scenario Name	Acquisition Cost	5-Year Program	Total Budget	Low Income Potential as a	Lighting Potential as a	Weighted Average Program Potential

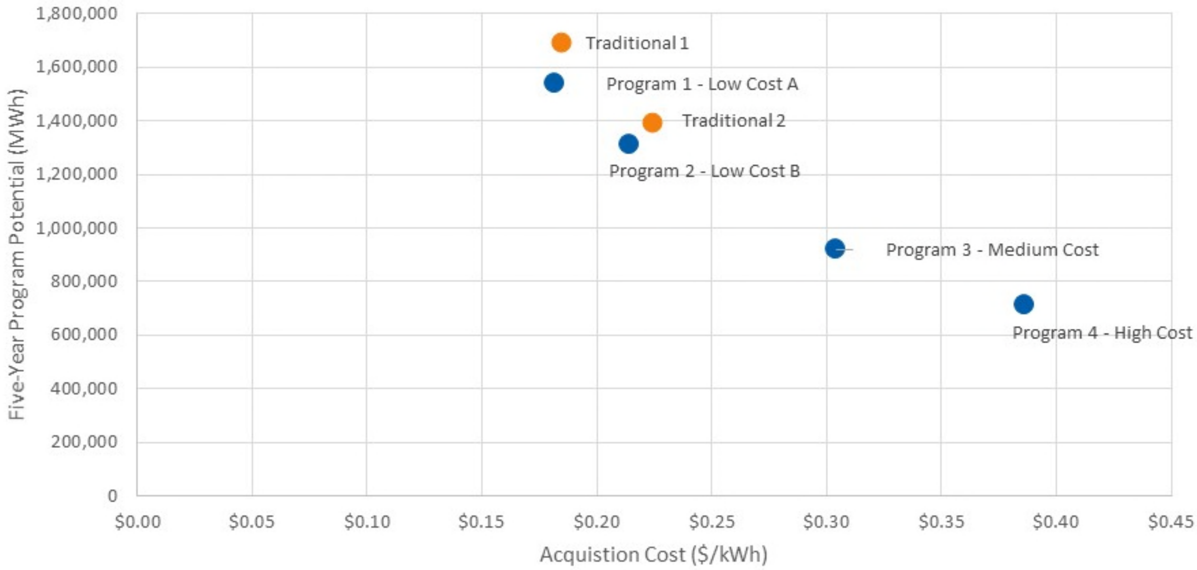
	($/kWh)	Potential (MWh)	($000s)	% of Portfolio Savings	% of Portfolio Savings	as a Fraction of Achievable
Traditional 1	$0.18	1,691,844	312,479	20%	34%	65%
Traditional 2	$0.22	1,392,280	312,559	25%	32%	43%
Program 1—Low Cost A	$0.18	1,539,137	280,370	6%	38%	91%
Program 2—Low Cost B	$0.21	1,308,016	280,501	6%	42%	76%
Program 3—Medium Cost	$0.30	920,356	279,773	6%	26%	33%
Program 4—High Cost	$0.39	712,309	275,115	6%	18%	25%

The results of the two traditional scenarios and the four program scenarios differ in two major ways:

1. The traditional scenarios do not account for actual low-income program costs (which are approximately $1.50/kWh for direct-install programs and $0.25/kWh for other programs). For Traditional 1, this means low-income customers effectively are treated akin to non-low-income customers. This approach reduces the overall acquisition cost, and it allows for low-income to account for a larger relative share of total portfolio savings (i.e., this large share would not be feasible upon assuming actual low-income acquisition costs).
2. The two traditional scenarios include a broader mixture of measures, including low-cost consumer electronics measures with low acquisition costs but subject to high freerdiership levels. Including these measures in the traditional scenarios means, after accounting for Act 129 spending caps, program potential equals a moderate share of achievable potential (65% in Traditional 1 and 43% in Traditional 2).

Acquisition costs and savings targets for each scenario can be plotted to show the relationship between a change in acquisition cost and five-year program potential (shown in Figure 4): each program scenario is subject to a fixed, five-year spending cap. Program scenarios fall on a "lower" curve as they incorporate an energy efficiency spending cap that accounts for required DR expenditures (whereas traditional scenarios do not).

Figure 4. Scenario Acquisition Costs and Five-Year Program Potential



After accounting for proposed DR expenditures requirements, program scenarios ranging from $0.18/kWh to $0.39/kWh reflect a five-year savings target between approximately 1.5 million and 0.7 million MWh.

The **Comparison of Program Scenarios** section includes a detailed discussion of each program scenario.

Organization of this Report

This report presents the study's findings in two volumes. Volume I (this document), presents the methodologies and findings, and Volume II contain the appendices and provide detailed study results and supplemental materials.

Volume I includes the following sections:

- **Methodology** provides an overview of the methodology Cadmus used to estimate technical, economic, and achievable potential.
- **Technical and Economic Potential** presents the technical and economic potential available from energy efficiency resources. This section provides detailed summaries by sector, segment, and end use, and identifies measures with high savings potential.
- **Achievable Potential** describes the basis for and results of estimating realistically achievable energy efficiency potential.
- **Program Potential** provides detailed results for each of the six program scenarios considered

Volume II includes the following Appendices

- **Appendix A: Baseline Data**
- **Appendix B: Detailed Assumption and Energy Efficiency Potential Results**
- **Appendix C: Measure Details**
- **Appendix D: Preferred Program Measures**

Methodology

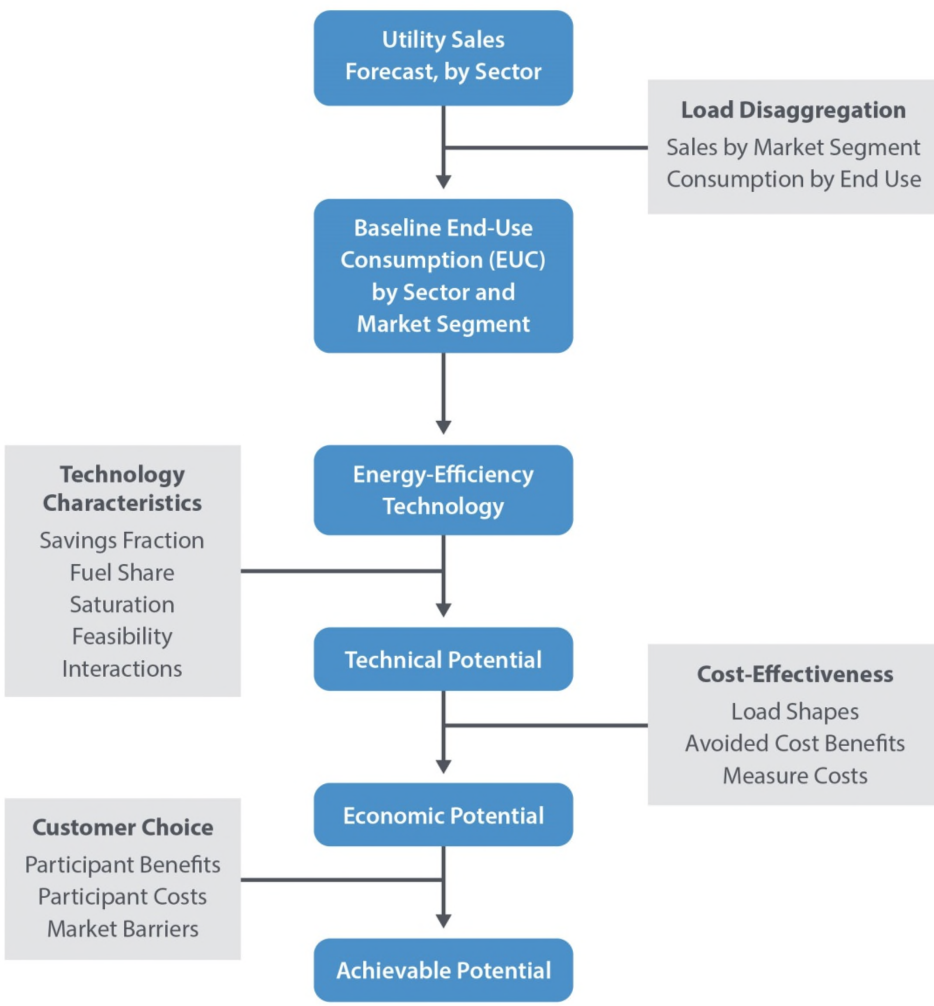
Assessing Energy Efficiency Potential

This assessment relies on industry best practices, analytic rigor, and flexible and transparent tools to accurately estimate the potential for energy savings in PPL's territory, from 2016 to 2025. This section describes each step in the assessment process and summarizes the results.

General Approach

The methodology used for estimating the technical, economic, and achievable energy efficiency potential drew upon standard industry practices. Figure 5 depicts the general methodology and illustrates how Cadmus combined baseline and efficiency data to estimate savings for each type of potential.

Figure 5. Methodology for Estimating Energy Efficiency Potential

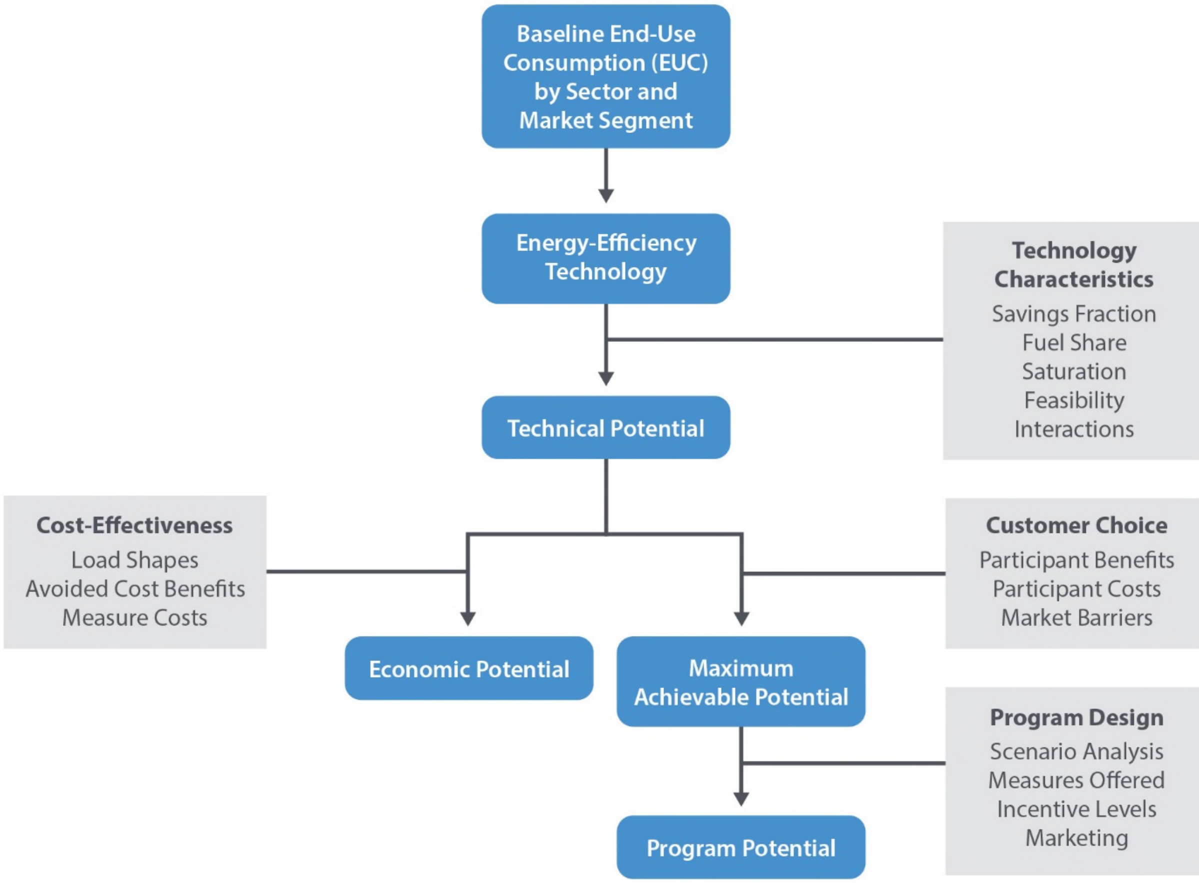


The study assessed the following four types of potential:

- ***Technical potential*** assumes all technically feasible demand side management measures will be implemented, regardless of their costs or market barriers. For energy efficiency resources, technical potential can be divided into three distinct classes: (1) retrofit opportunities in existing buildings, (2) equipment replacements in existing buildings, (3) and new construction. Customers can implement the first class, existing in current building stock, at any point in the planning horizon, while end-use equipment turnover rates and new construction rates dictate the timing of the other two classes.
- ***Economic potential*** represents a subset of technical potential, consisting only of measures meeting the cost-effectiveness criteria based on the organization's avoided energy and capacity costs. For each energy efficiency measure, the study structures the benefit-cost test as the ratio of the net present values of the measure's benefits and costs, and only measures with a benefit-to-cost ratio of 1.0 or greater will be deemed cost-effective.
- ***Achievable potential*** derives from the portion of economic potential that might be assumed reasonably achievable in the course of the planning horizon, given market barriers that might impede customer participation in utility programs. Achievable potential can vary greatly, based on program incentive structures, marketing efforts, energy costs, customer socio-economic characteristics, and other factors.
- ***Program potential*** derives from the portion of achievable potential given program budget and implementation constraints. Cadmus adopted two approaches for estimating program potential. The first, a "traditional approach", involved estimating program savings by scaling down achievable savings so total five-year program budgets equals PPL's Phase III spending cap ($307.5 million). In this approach, Cadmus only considered measures with a benefit-cost ratio that exceeds 1.0 and did not modify the mix of measures based on other program considerations (such as high levels of freeridership). This first approach is largely consistent with the one used in the SWE's 2015 potential study. The second approach, an "alternative approach," involved creating program potential scenarios that reflect a mix of measures that reflects PPL's recent programs, it accounts for potential low-income and GNI savings carve-outs, and reflects actual measure-specific expenditures on incentives and admin.

Figure 6 shows the alternative methodology for estimating program potential.

Figure 6. Alternative Program Potential Methodology



With the alternative program potential approach, Cadmus ignored the traditional definition of achievable potential, which is usually thought of a subset of economic potential where all measures have a benefit-cost ratio that exceeds 1.0. Instead, Cadmus considered both cost-effective and non-cost-effective measures, while ensuring the overall portfolio benefit-cost ratio exceeds 1.0. Note: for these program scenarios, Cadmus excluded some measures based on cost-effectiveness. Each program scenario has a minimum benefit cost-threshold (between 0.3 and 0.75)—see Table 4 for additional detail.

The traditional approach for estimating energy efficiency potential is based on a sequential analysis of various energy efficiency measures in terms of technical feasibility (technical potential), cost-effectiveness (economic potential), and expected market acceptance, considering normal barriers possibly impeding measure implementation (achievable technical potential). The traditional assessment followed four steps:

1. ***Developing baseline forecast.*** The Cadmus team determined 10-year future energy consumption by sector, market segment, and end use. The study calibrated the base year, 2015,

to PPL's forecasted sector loads. Baseline forecasts shown in this report include estimates of naturally occurring potential, such as savings due to building energy codes and federal equipment standards.

2. ***Estimating technical potential.*** We estimated technical potential using alternative forecasts that reflect impacts of technical feasible energy efficiency measures.
3. ***Estimating economic potential.*** Cadmus estimated economic potential using forecasts that reflect impacts of cost-effective energy efficiency measures.
4. ***Estimating achievable potential***. We calculated achievable potential by applying ramp rates and an achievability percentage to cost-effective measures (detailed later in this section). Achievability percentages reflected incentive scenarios where a single broad incentive rate is applied to all measures within a sector
5. ***Estimating program potential*.** For the traditional approach, we scaled down estimates of achievable potential (for all cost-effective measures), so the overall five-year expenditures match the spending cap defined in Act 129.

The alternative assessment involved the following steps:

1. ***Developing baseline forecast.***
2. ***Estimating technical potential***
3. ***Defining Program Measures.*** Cadmus and PPL reviewed the comprehensive list of energy efficiency and removed measures that PPL will not offer due to high levels of freeridership or other implementation barriers. Appendix D includes the list PPL's preferred program measures
4. ***Estimating achievable potential***. We calculated achievable potential by applying ramp rates and an achievability percentage to measures selected in step 3. Achievability percentages reflect incentive scenarios where incentive rates match PPL's current expenditures and ramp rates reflect PPL's planned acquisition rate.
5. ***Estimating program potential*.** For the alternative approach, Cadmus created four program scenarios that reflect different minimum benefit-cost thresholds and a different mixture of measures.

Developing a Baseline Forecast

Creating a baseline forecast requires multiple data inputs to accurately characterize energy consumption in PPL's service area. These key inputs include:

- Sales and customer forecasts;
- Major customer segments (e.g., residential dwelling types or commercial business types);
- End-use saturations;
- Equipment saturations;
- Fuel shares;

- Efficiency shares (the percentage of equipment below, at, and above code); and
- Annual end-use consumption estimates by efficiency level.

Data specific to PPL's service territory not only provided the basis for baseline calibration, but supported estimation of technical potential. The assessment incorporated primary data collected as a part of the SWE's 2014 residential and non-residential baseline studies. PPL also provided data on actual and forecasted sales and customers by sector. Table 6 identifies sources for key data.

Table 6. Key Data Sources

Data Type	Residential	Commercial	Industrial
Baseline Sales and Customers	PPL Actual	PPL Actual	PPL Actual
Forecasted Sales and Customers	PPL Forecasts	PPL Forecasts	PPL Forecasts
Percentage Sales by Building Type	U.S. Census Bureau's American Community Survey	PPL's Non-residential Customer Database	PPL's Non-residential Customer Database
End-Use Energy Consumption	PPL Load Forecast, Building simulations, EIA RECS, ENERGY STAR®, Pennsylvania 2015 TRM	PPL Load Forecast, EIA CBECS, Building Simulations, PA 2015 TRM	PPL Load Forecast, EIA MECS, ACEEE Reports
Saturations and Fuel Shares	SWE 2014 residential baseline study, PPL RASS, EIA RECS	SWE 2014 non-residential baseline study, EIA CBECS	N/A
Efficiency Shares	SWE 2014 residential baseline study, EIA RECS, ENERGY STAR Reports	SWE 2014 non-residential baseline study, EIA CBECS, ENERGY STAR Reports	N/A
Energy Efficiency Measures	PA 2015 TRM, Cadmus measure list	PA 2015 TRM, Cadmus measure list,	PA 2015 TRM, Cadmus measure list

Collecting Baseline Data

Measure Characterization

Cadmus developed a comprehensive database of technical and market data of energy conservation measures (ECMs) that apply to all end uses in various market segments. We included the following measures contained in our database:

- All measures identified in the 2015 Pennsylvania Technical Reference Manual
- All measures currently included in the utilities prescriptive programs;
- Efficiency tiers from Consortium for Energy Efficiency (CEE) and ENERGY STAR®;
- Measures from Cadmus' extensive measures database that includes measures in regional or national databases (e.g., DEER) and technical reference manuals; and
- Particular technologies identified by PPL as relevant to the study.

Compiling Energy Efficiency Technology Measure Database

After creating a list of electric energy efficiency measures applicable to PPL's service territory, Cadmus classified energy efficiency measures into two categories:

1. ***High-efficiency equipment measures.*** These measures directly affect end-use equipment (e.g., high-efficiency central air conditioners), which follow normal replacement patterns based on expected lifetimes.
2. ***Non-equipment measures.*** These measures affect end-use consumption without replacing end-use equipment (e.g., insulation). Such measures do not include timing constraints from equipment turnover (except for new construction) and should be considered as discretionary as savings can be acquired at any point over the planning horizon.

The following lists show the relevant inputs for each measure type:

Equipment and non-equipment measures:

- Energy savings: average annual savings attributable to installing the measure, in absolute and/or percentage terms.
- Equipment cost: full or incremental, depending on the nature of the measure and the application.
- Labor cost: the expense of installing the measure, accounting for differences in labor rates by region, urban versus rural areas, and other variables.
- Measure life: the expected life of measure equipment.

Non-equipment measures only:

- Technical feasibility: the percentage of buildings where customers can install this measure, accounting for physical constraints.
- Percentage incomplete: the percentage of buildings where customers have not installed the measure, but where it is technically feasible to install it.
- Measure competition: for mutually exclusive measures, accounting for the percentage of each measure likely installed (to avoid double-counting savings).
- Measure interaction: accounting for end-use interactions (e.g., a decrease in lighting power density causing heating loads to increase).

Cadmus derived these inputs from various sources, primarily from the 2015 Pennsylvania TRM. Table 7 lists the primary sources referenced in this study by data input.

Table 7. Key Measure Data Sources

Data	Residential	Commercial	Industrial
Energy Savings	Pennsylvania 2015 TRM, ENERGY STAR, Regional TRMs, DOE/EERE, Regional Technical Forum, Cadmus Research	Pennsylvania 2015 TRM, CBECS 2003 Microdata, ENERGY STAR, DEER, TRMs, DOE/EERE, Regional Technical Forum, Cadmus Research	Pennsylvania 2015 TRM, DOE's Industrial Assessment Center Database (IAC), Industrial Savings Potential Project (ISPP), Industrial Council Data, Cadmus Research
Equipment and Labor Costs	SWE Incremental Cost Database, National Residential Efficiency Measures Database, RSMeans, ENERGY STAR, DOE/EERE, DEER, Online Retailers, Cadmus Research	SWE Incremental Cost Database, RSMeans, ENERGY STAR, DOE/EERE, DEER, Regional Technical Forum, On-line Retailers, Cadmus Research	SWE Incremental Cost Database, DOE's Industrial Assessment Center Database (IAC), Industrial Savings Potential Project (ISPP), Industrial Council Data, Cadmus Research
Measure Life	Pennsylvania 2015 TRM, ENERGY STAR, DEER, Cadmus Research	Pennsylvania 2015 TRM, ENERGY STAR, DEER, Cadmus Research	DEER, DOE's ITP (Industrial Technologies Program), Industrial Council Data, Cadmus Research
Technical Feasibility	SWE 2014 Residential Baseline Study, Cadmus Research	SWE 2014 Non-Residential Baseline Study, Cadmus Research	SWE 2014 Non-Residential Baseline Study, Cadmus Research, Industrial Council Data
Percent Incomplete	SWE 2014 Residential Baseline Study, RECS, Cadmus Research	SWE 2014 Non-Residential Baseline Study, Cadmus Research	SWE 2014 Non-Residential Baseline Study, Cadmus Research
Measure Interaction	Pennsylvania 2015 TRM	Pennsylvania 2015 TRM	Pennsylvania 2015 TRM, Cadmus Research

Incorporating Codes and Standards

Cadmus' assessment accounts for changes in codes and standards over the planning horizon. These changes affect customers' energy consumption patterns and behaviors, but they determine which energy efficiency measures continue to produce savings over minimum requirements. Cadmus captured current efficiency requirements, including those enacted but not yet in effect.

Cadmus did not attempt to predict how energy codes and standards might change in the future; rather, only factored in enacted legislation—notably, the Energy Independence and Security Act (EISA) provisions slated to take effect over the course of the analysis.

EISA requires that general service lighting becomes approximately 30% more efficient than current incandescent technology, with standards phased in by wattage from 2012 to 2014. In addition, EISA includes a backstop provision, requiring even higher-efficiency technologies beginning in 2020.

Cadmus explicitly accounted for several other pending federal codes and standards. For the residential sector, these included appliances, HVAC, and water heating standards. For the commercial sector, these included appliances, motors, water heating, HVAC, and lighting standards. Table 8 provides a comprehensive list of codes and standards considered in this study.[5]

Table 8. Enacted or Pending Standards Accounted for In Commercial and Residential Sectors

Equipment Type	Existing (Baseline) Standard	New Standard	Study Effective Year
Appliances			
Clothes washer	Federal standard 2007	Federal standard 2015	2016*
Clothes washer	Federal standard 2007	Federal standard 2018	2018
Commercial refrigeration equipment (semi-vertical and vertical cases)	Federal standard 2012	Federal standard 2016	2017*
Dishwasher	Federal standard 2010	Federal standard 2013	2014*
Dryer	Federal standard 2011	Federal standard 2015	2015
Freezer	Federal standard 2001	Federal standard 2014	2015*
Refrigerator	Federal standard 2001	Federal standard 2014	2015*
HVAC			
Central air conditioner	Federal standard 2006	Federal standard 2015	2017**
Heat pump (air source)	Federal standard 2006	Federal standard 2015	2017**
Room air conditioners	Federal standard 2000	Federal standard 2014	2015*
Lighting			
Lighting general service lamp (EISA)	Existing conditions (no federal standard prior to EISA 2007)	Federal standard 2014 (phased in over three years)	2014
Lighting general service lamp (EISA backstop provision)	Existing conditions (no federal standard prior to EISA 2007)	Federal standard 2020	2020
Metal halide lamp fixtures	Federal standard 2009	Federal standard 2017	2018*
Motors			
Small electric motors	Federal standard 1987	Federal standard 2015	2016*
Water Heaters			

[5] All applicable standards enacted prior to 2014 have been accounted for such as 2013 commercial clothes washer standard, 2012 lighting general service fluorescent lamp standard, 2012 lighting incandescent reflector lamp standard, 2012 dehumidifier standard, 2012 cooking oven and range standard, 2010 ice maker standard, and 2010 electric motor standard.

Equipment Type	Existing (Baseline) Standard	New Standard	Study Effective Year
Water heater > 55 gallons	Federal standard 2004	Federal standard 2015	2016*
Water heater ≤ 55 gallons	Federal standard 2004	Federal standard 2015	2016*

*To estimate the potential, Cadmus assumed that standards that take effect mid-year will begin on January 1 of the following year.

**Due to the uncertainty created by the litigation, DOE will not enforce this standard until July 1, 2016

To ensure accurate assessment of the remaining potential, Cadmus accounted for the effects of future standards. Based on a strict interpretation of the legislation, Cadmus assumed that customers would replace affected equipment with more efficient alternatives meeting minimum federal standards; in other words, Cadmus assumed complete compliance.

Estimating Technical Potential

Once we fully populated the measure database, we used measure-level inputs to estimate technical potential over the planning horizon. To begin this process, our team estimated savings from all measures included in the analysis and then aggregated the results to the end use, market segment, and sector levels.

We characterized individual measure savings, first in terms of the percentage of end-use consumption. For each non-equipment measure, the study estimated absolute savings using the following equation:

$$SAVE_{ijm} = EUI_{ije} * PCTSAV_{ijem} * APP_{ijem}$$

Where:

$SAVE_{ijm}$	=	annual energy savings for measure *m* for end use *j* in customer segment *i*
EUI_{ije}	=	calibrated annual end-use energy consumption for equipment *e* for end use *j* and customer segment *i*
$PCTSAV_{ijem}$	=	the percentage savings of measure *m,* relative to the base usage for the equipment configuration *ije*, accounting for interactions among measures, such as lighting and HVAC, calibrated to annual end-use energy consumption
APP_{ijem}	=	measure applicability: a fraction representing a combination of the technical feasibility, existing measure saturation, end-use interaction, and any adjustments to account for competing measures

For example, for wall insulation saving 10% of space heating consumption, the final percentage of the end use saved would be 5%, assuming an overall applicability of 50%. This value represented the percentage of baseline consumption the measure saved in an average home.

However, capturing all applicable measures required examining many instances where multiple measures affected a single end use. To avoid overestimating total savings, we assessed cumulative impacts accounted for interactions among the various measures—a treatment called “measure stacking." The primary method to account for stacking effects establishes a rolling, reduced baseline, applied sequentially upon assessment of measures in the stack. The equations below illustrate this technique, applying measures 1, 2, and 3 to the same end use:

$$SAVE_{ij1} = EUI_{ije} * PCTSAV_{ije1} * APP_{ije1}$$

$$SAVE_{ij2} = (EUI_{ije} - SAVE_{ij1}) * PCTSAV_{ije2} * APP_{ije2}$$

$$SAVE_{ij3} = (EUI_{ije} - SAVE_{ij1} - SAVE_{ij2}) * PCTSAV_{ije3} * APP_{ije3}$$

After iterating all measures in a bundle, the final percentage of the reduced end-use consumption provided the sum of the individual measures' stacked savings, which we then divided by the original baseline consumption.

Estimating Economic Potential

Cadmus based the methodology for estimating economic potential on the methods described in the California Standard Practice Manual (SPM),[6] which establishes the procedures for economic evaluation from the perspectives of participants, utility (or program administrator), total resource cost, societal and all ratepayers. We adjusted this approach for consistency with the 2009 and 2011 Pennsylvania TRC Orders. Changes include the exclusion of secondary fuel benefits and the use of a maximum 15 year measure life.

For each measure, the application of TRC began with the valuation of the measure's benefits, as measured by the avoided long-run energy, capacity costs, and avoided line losses, and then comparing the result to the measure's costs. For equipment measures, we calculated costs based on the measure's incremental costs, compared with the cost of baseline technology. For retrofit measures, measure costs included the total installed cost of the measure. The study considered a measure cost-effective if it the net present value of its benefits exceeded the net present value of its costs as measured according to the TRC test, that is:

$$\frac{\text{TRC Benefits}}{\text{TRC Costs}} \geq 1$$

Where:

$$\text{TRC Benefits} = NPV\left(\sum_{year=1}^{measurelife}\left(\sum_{i}^{i=8760}(impact_i \times avoided\ \cos t_i)\right)\right)$$

And:

6 *California Standard Practice Manual for Economic Analysis of Demand-Side Programs and Projects*, California Public Utilities Commission, 2002.

TRC Costs = NPV (incremental -or total - installed measure cost)

Economic potential represented the savings from the subset of measures that passed the cost-effectiveness criterion according to the TRC test.

Calculating a measure's total resource benefits utilized the following data:

- **End-use load shapes:** End-use load shapes represented end-use consumption patterns by costing period, which we applied to measures to capture the time-differentiated value of energy savings and determine the amount of savings during peak periods.
- **Line losses:** Line losses represented energy lost between the generator and the customer meter. Thus, we would "gross up" the energy and capacity savings at the customer meter to capture the true value of savings.
- **Discount rate**
- **Utility avoided energy costs:** This is the utility's projections of time and seasonally differentiated electric energy costs.
- **Utility avoided capacity costs:** This the utility's projections of the cost of supplying power during peak periods.

PPL provided line loss factors, discount rates, avoided energy and avoided capacity costs for this study.

Based on the results from the cost-effectiveness analysis, and using the same method described in the technical potential section, Cadmus developed an alternate supply curve consisting of measures passing the cost-effectiveness criterion from the TRC perspective.

Economic potential can exceed technical potential when second measure that interacts with a given measure fails a benefit-cost screen. For instance, suppose a homeowner installs an efficient air conditioner that reduces our baseline cooling consumption from 1,000 kWh to 900 kWh. Then suppose the homeowner installs a weatherization measure that saves 10% off the baseline cooling consumption—the technical potential for this weatherization measure would equal 90 kWh (900*10%). Now suppose the efficient air conditioner measure is not cost-effective—the homeowner's baseline consumption will remain at 1,000 kWh. If the weatherization measure is cost-effective, the 10% savings will yield economic potential equal to 100 kWh (1,000*10%). In this case economic potential for the weatherization measure will exceed the technical potential.

Estimating Achievable Potential

This study defines "achievable" potential as the portion of economic potential that customers' would be willing-to-adopt if the financial barriers to purchasing energy-efficiency measures are reduced through incentives. Therefore, Cadmus measures and expresses achievable potential as a fraction (percent) of economic potential. While estimating technical and economic potentials remain fundamentally engineering and accounting endeavors, based on industry-standard practices and methodologies,

achievable potential is more difficult to quantify and reliably predict as it depends on a large number of behavioral factors, which tend to change unpredictably over time.

A number of factors account for the gap between economic and achievable potential, including: customer awareness; perceptions of energy efficiency's value; and energy-efficiency measures' front costs. In the case of new measures and programs, there are additional practical constraints regarding availability of delivery infrastructure. These barriers have been well documented in energy-efficiency literature.[7]

The utility can mitigate some of these market barriers through program design and delivery processes, while others remain out of a utility's reach. For example, a utility can reduce first-cost barriers by providing financial incentives to lower up-front costs and improve customer paybacks. However, since utility incentives only cover a portion of the incremental costs for most measures, incentives may not be sufficient to motivate a customer to adopt energy-efficiency measures. This particularly holds true for the commercial sector and large equipment in the residential sector, where up-front costs tend to be high. Thus, the task becomes one of assessing which barriers PPL can overcome over the course of the planning horizon, and how much economic potential can be deemed reasonably achievable.

Willingness-to-Adopt Efficiency Measures

To assess the fraction of customers who would likely adopt an energy-efficiency measure, the SWE 2014 baseline studies included a battery of questions to elicit information about customers' willingness to adopt measures under different *hypothetical* incentive scenarios. For a number of measure types (e.g., heating, cooling, lighting, weatherization), survey respondents were first asked if they would adopt efficient measures if the EDC did not provide an incentive. The SWE then asked if the customer would adopt the efficient measure if the EDC covered 50% of the measure's incremental cost (the cost to upgrade). The customer was then asked if it would adopt the efficient measure if the utility covered 75% of the incremental cost, corresponding to the high-achievable scenario. Finally, the surveys asked if a customer would adopt the efficient measure if the EDC covered 100% of the measure's incremental cost—corresponding to the max-achievable scenario.

Using the revealed relationship between incentive levels and the customers' willingness to adopt an efficiency measure, Cadmus estimated an expected long-run achievable penetration for a "base" scenario where residential expenditures on incentives, on average, are equivalent to 57.5% of incremental measures costs and non-residential expenditures are equivalent to 35% of incremental measure costs. Figure 7 and Figure 8 summarize residential and commercial willingness to participate survey results—low corresponds to incentives equal to 25% of incremental costs, base corresponds to

[7] See for example William H. Golove and Joseph H. Eto, "Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency," LBL-38059 UC-1322, March 1996.

incentives equal to 50% of incremental costs, high corresponds to incentives equal to 75% of incremental costs, and max corresponds to incentives equal 100% of incremental costs.

Figure 7. Residential Willingness-to-Participate Survey Results

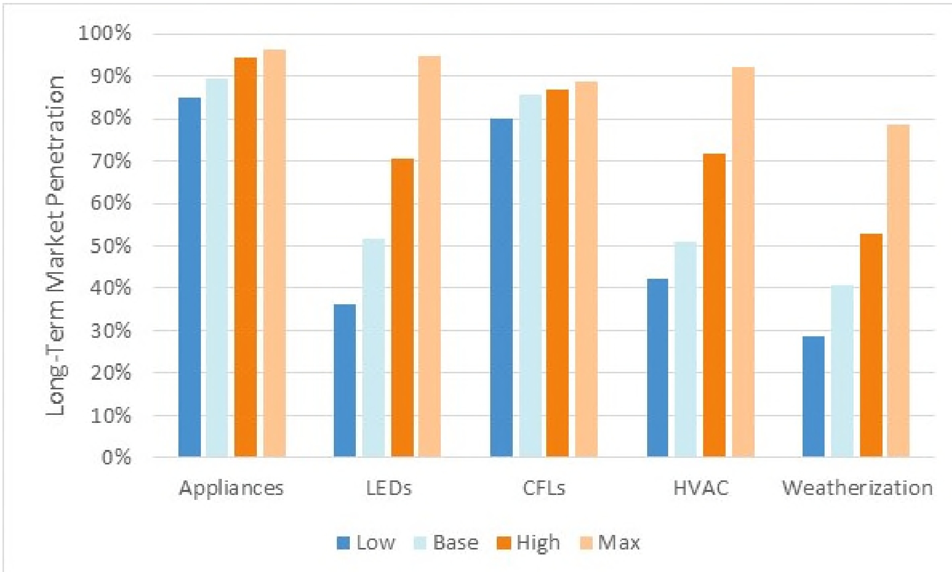
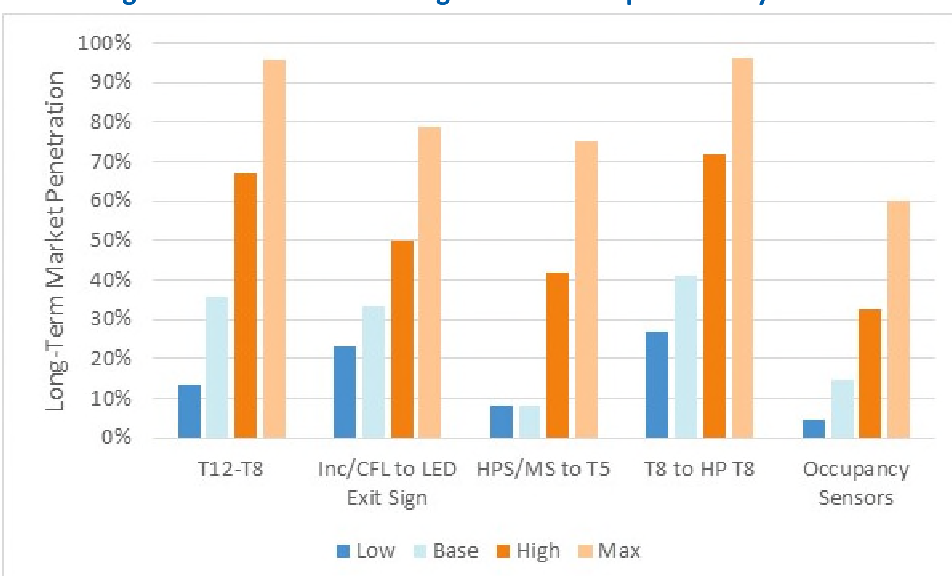


Figure 8. Commercial Willingness-to-Participate Survey Results



Ramp Rates

Energy-efficiency measures generally fall into one of two discretionary (retrofit) or non-discretionary (lost opportunity) groups. Discretionary measures (e.g. lighting upgrades in the commercial sector) may be implemented immediately, financial and practical considerations notwithstanding. Non-discretionary measures include measures that are typically implemented only on burnout of the existing equipment (normal turn-over) and new construction. The key difference between the two measures types is that unlike retrofit measures, the availability of lost-opportunity resources is determined by market forces that are outside the EDC’s control. Cadmus used a 10-year ramp rate for discretionary measures. For lost opportunity measures, natural replacement rates determine the timing of savings.

Cadmus calculated achievable energy-efficiency potential by multiplying economic potential by the percent of customers’ willing-to-adopt an efficiency measure and spreading discretionary savings over the study horizon using a 10-year ramp rate.

Detailed Energy Efficiency Potential

Scope of Analysis

Cadmus assessed the technical and economic potential for electricity savings in the residential, commercial, and industrial sectors. Within each sector-level assessment, we further distinguished among market segments, business types, vintage, and applicable end uses within each, as follows:

- Sixteen residential segments (existing and new construction for low-income and non-low income permutations of single family detached, single family attached, multifamily, and manufactured homes);
- Twenty-four commercial segments (12 building types within existing and new construction); and
- Twelve industrial market segments.

`To begin the analysis, Cadmus assessed the technical potential for 367 unique energy efficiency measures (Table 9), which represent a comprehensive set of electric energy efficiency measures applicable to the climate and customer characteristics of PPL's service territory.

Table 9. Energy Efficiency Measure Counts and Permutations

Sector	Unique Measures	Permutations by Utility, Market Segment, and Vintage
Residential	106	2,568
Commercial*	193	5,157
Industrial	68	504
Total	**367**	**8,229**

*Commercial include GNI segments

After considering all permutations of these measures across applicable customer sectors, market segments, fuels, and end uses, Cadmus compiled and analyzed the data for over 8,229 measures.

The remainder of this section provides detailed results, by sector, for each utility.

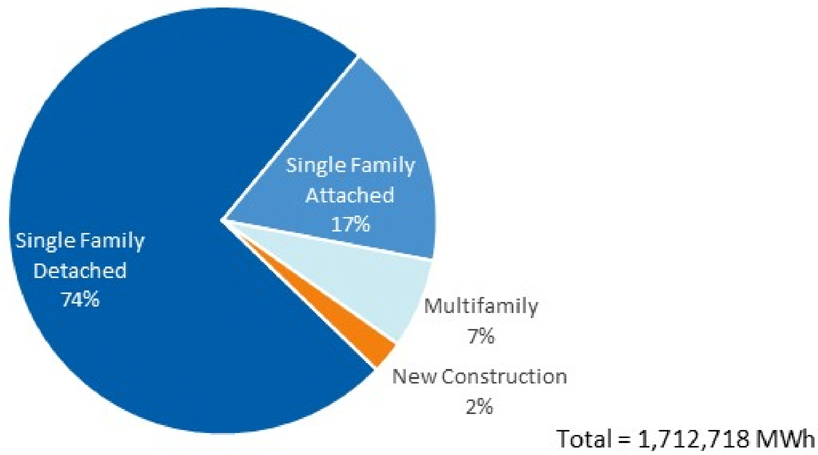
Residential

Residential customers account for nearly 40% of PPL's 2010 (base year) sales. Examples of energy efficiency measures for single family, multifamily, and manufactured homes include the following measure types

- Equipment efficiency upgrades (e.g., air conditioning, refrigerators);
- Improvements to building shells (e.g., insulation, windows, air sealing);
- Increased lighting efficiency (e.g. CFLs, LED interior lighting)

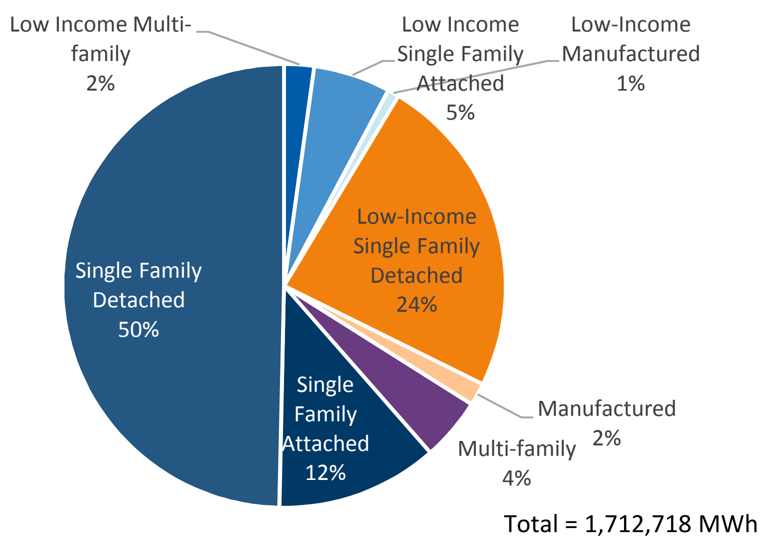
Figure 9 shows the distribution of base achievable potential by residential market segment

Figure 9. Residential Base Achievable Potential by Market Segment – Cumulative 2020 MWh



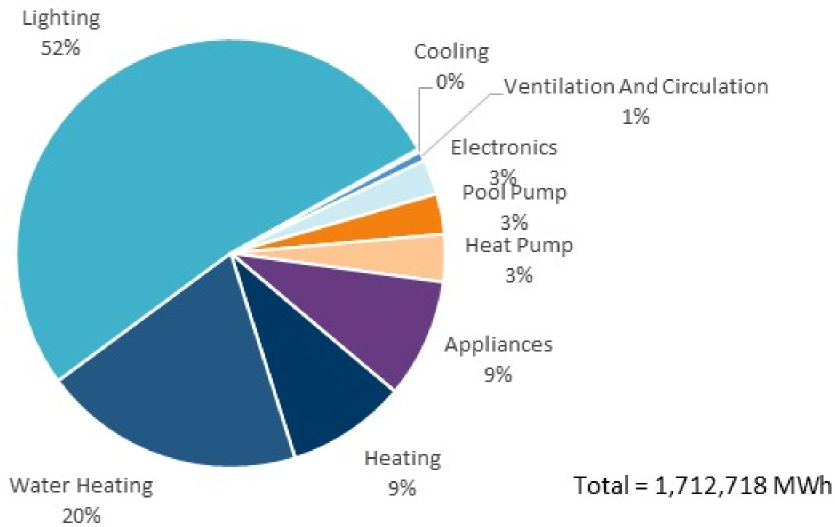
Cadmus further disaggregated residential customers according to whether or not they would qualify for low-income energy efficiency programs. Approximately 32% of households in PPL's service territory have a combined household income below the threshold required to qualify for low-income energy efficiency programs. Coincidentally, low-income households account for approximately 32% of base achievable energy efficiency potential in 2020. Figure 10 shows the distribution of residential base achievable potential in 2020 by market segment, including low income.

Figure 10. Residential Base Achievable Potential by Segment Including Low Income) – Cumulative 2020 MWh



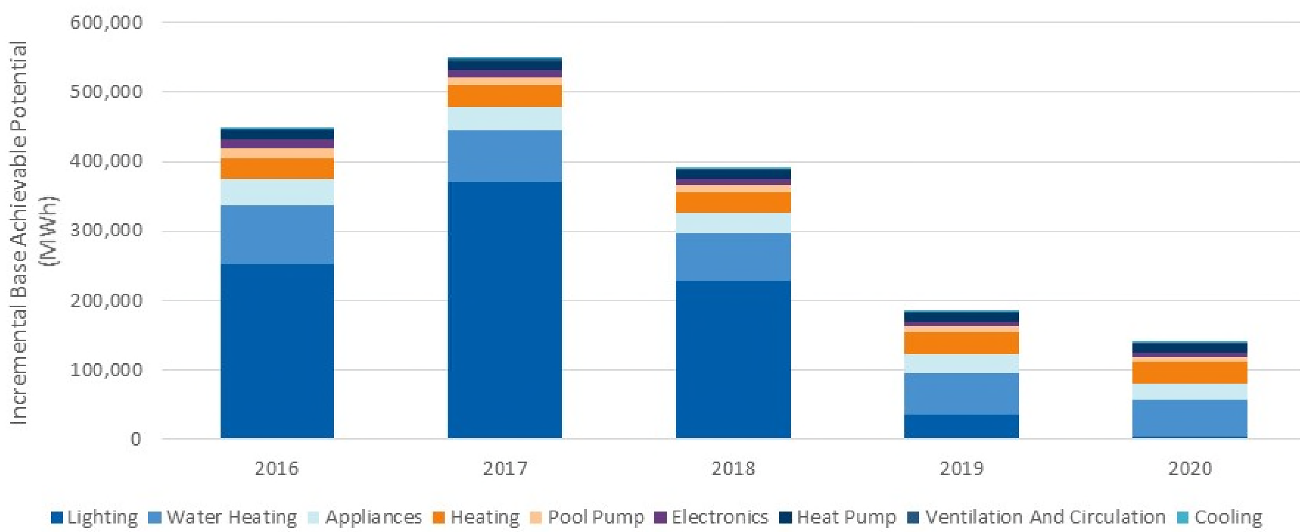
Lighting accounts for more than half (52%) of cumulative base achievable potential in the residential sector. Much of this savings comes standard and specialty CFL and LED lighting. Figure 11 shows the distribution of cumulative residential base achievable potential by end use group in 2020.

Figure 11. Residential Base Achievable Potential by End Use – Cumulative 2020 MWh



On average, incremental base achievable potential is equivalent to over 342,000 MWh per year in the residential sector. However, 84% of total 2020 cumulative achievable potential occurs within the first two years of the study (2016 and 2017). Over these two years, much of the inefficient lighting in the market (incandescent lighting) will turnover and be eligible to be replaced with efficient lighting. Once these opportunities are exhausted early in the five-year horizon, remaining savings comes from water heating, weatherization/shell, and appliances measures. Figure 12 shows residential incremental base achievable potential in 2016 through 2020 by end use.

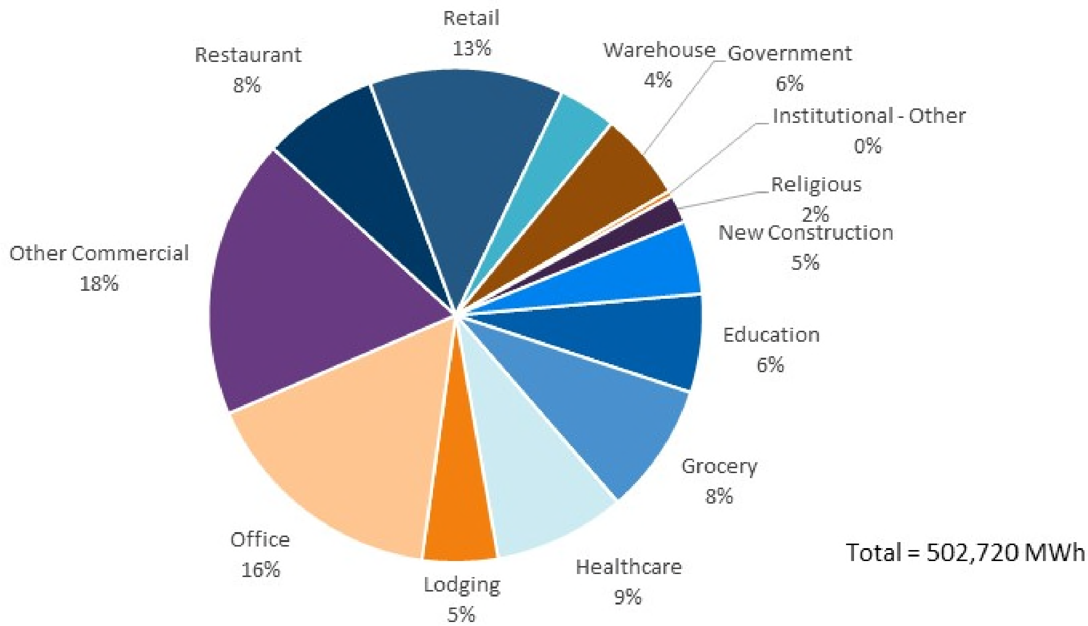
Figure 12. Residential Incremental Base Achievable Potential by End Use, 2016-2020 MWh



Commercial and GNI

Figure 13 shows the distribution of commercial and GNI cumulative base achievable potential by market segment in 2020.

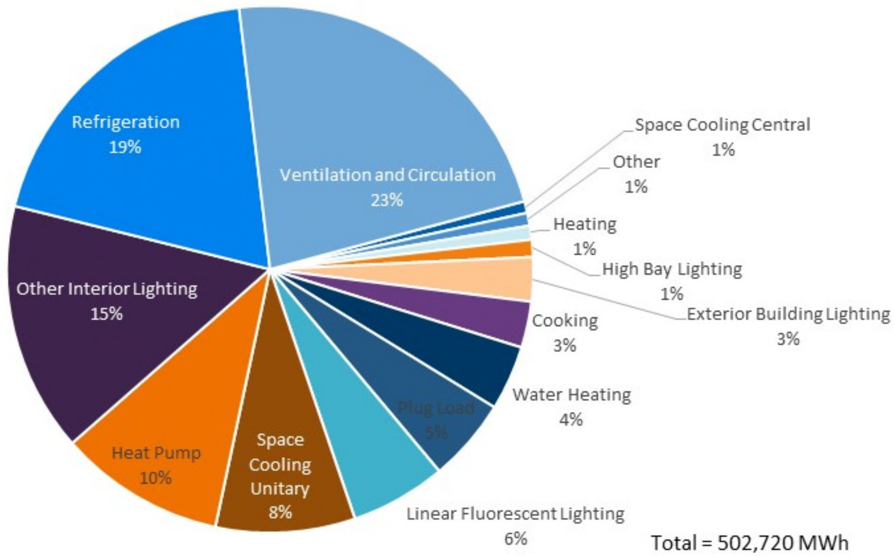
Figure 13. Commercial Base Achievable Potential by Segment – 2020 MWh



"Other commercial," offices, and retail account for more base achievable potential than other segments—overall, these three segments make up nearly half of total commercial and GNI energy efficiency potential.

Nearly one-quarter of cumulative 2020 base achievable energy efficiency potential in commercial and GNI segments is in the ventilation and circulation end use. This is primarily due to the high savings potential for variable frequency drives on HVAC fans and pumps. Figure 14 shows the distribution of cumulative base achievable potential by end use group.

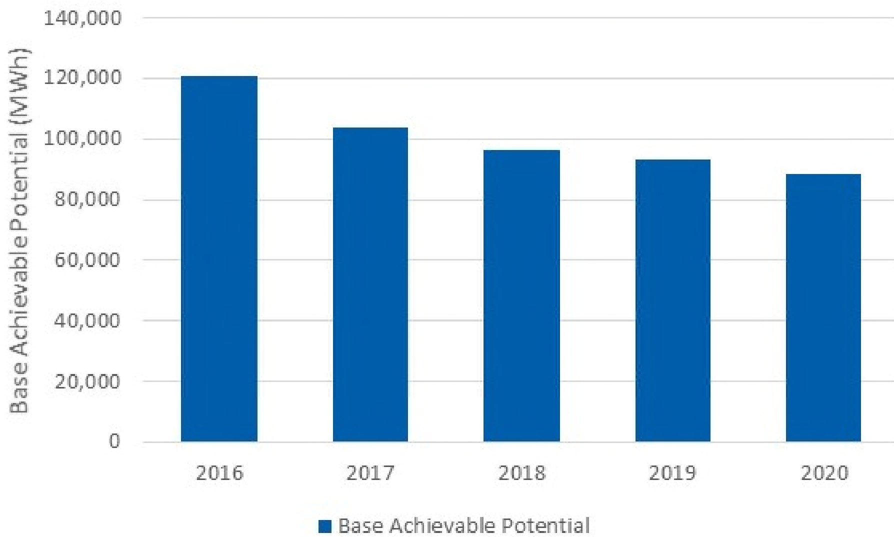
Figure 14. Commercial Base Achievable Potential by End Use Group – 2020 MWh



Refrigeration and other interior lighting (screw base and specialty lighting) account for 19% and 15% of cumulative base 2020 achievable potential, respectively. Efficient freezer doors and controls offer significant savings potential in the refrigeration end use (and primarily in grocery, restaurant, and education segments). For lighting, Cadmus found high savings potential for standard and specialty screw base CFLs and LEDs, however, much of this savings is available in the first few years of the study horizon.

On average, incremental base achievable potential in the commercial sector (including GNI) is equivalent to approximately 100,000 MWh per year. Incremental savings declines over the course of the five year planning horizon due to diminishing opportunities for lighting replacements. Figure 15 shows incremental base achievable potential from 2016 to 2020 in the commercial sector.

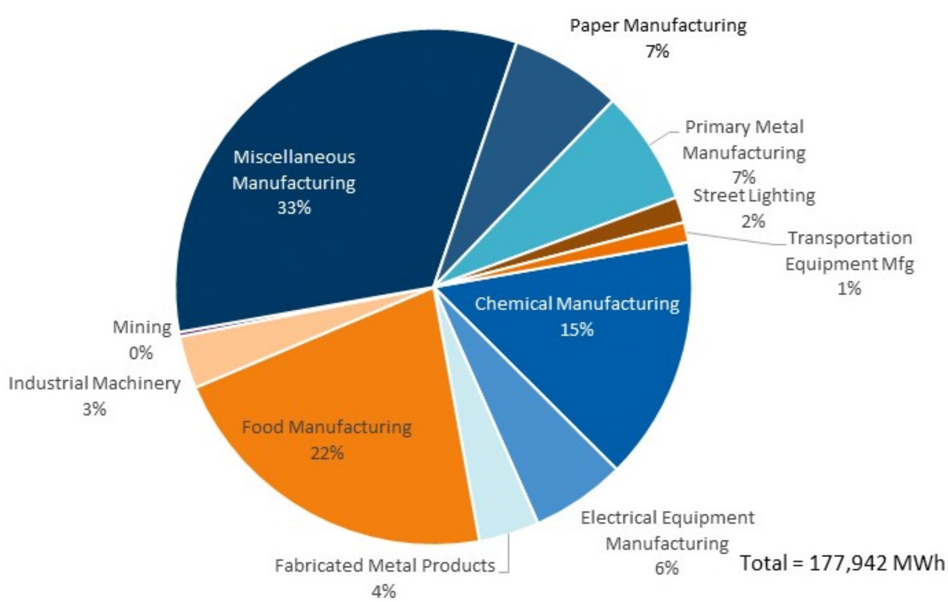
Figure 15. Commercial Incremental Base Achievable Potential, 2016-2020 - MWh



Industrial

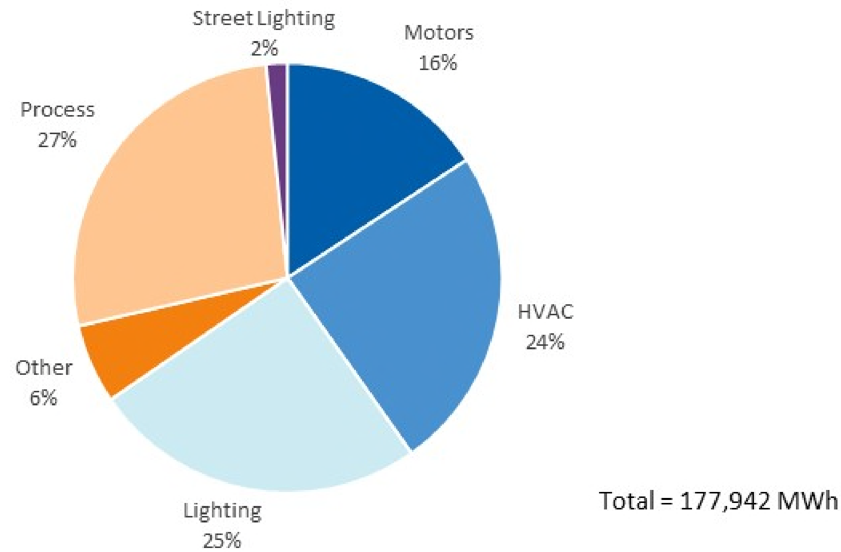
PPL's industrial sector accounts for approximately 27% of 2010 (base year) energy consumption. Major industries include various manufacturing facilities (food, chemical, and miscellaneous). Figure 16 shows cumulative base industrial achievable potential by major industrial segment.

Figure 16. Cumulative Base Industrial Achievable Potential by Segment – 2020 MWh



Industrial facilities generally have high savings potential process, lighting and HVAC end uses. Figure 17 shows the distribution of cumulative base industrial achievable potential by end use group.

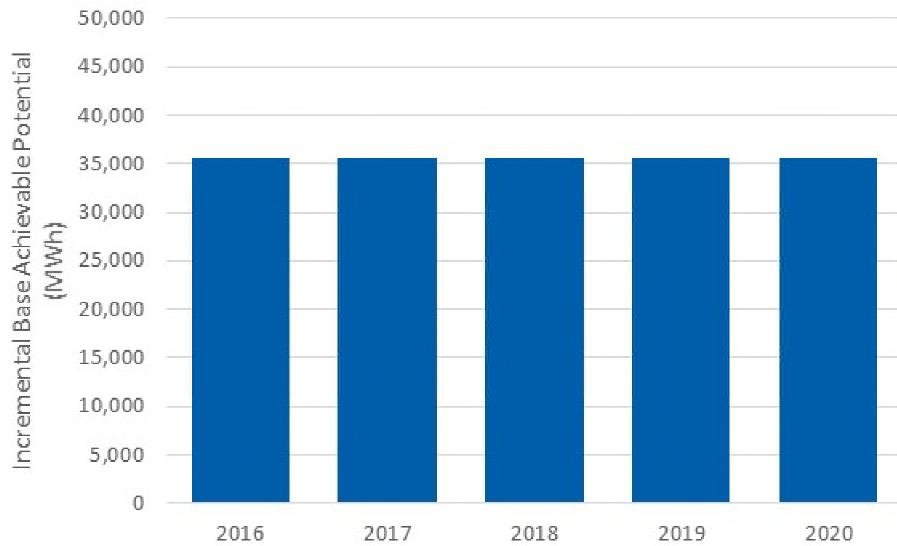
Figure 17. Cumulative Base Industrial Achievable Potential by End Use – 2020 MWh



High-saving industrial measures include HVAC equipment upgrades, reduced wattage linear fluorescent lamp packages, LED lighting packages, and air compressor optimization. Collectively, these four types of measures account for slightly over 36% of total cumulative 5-year industrial achievable potential.

Much of the industrial savings is acquired evenly over the five-year planning horizon. Average annual incremental industrial base achievable potential is equal to approximately 35,000 MWh per year in 2016 through 2020. Figure 18 shows industrial incremental base achievable potential in 2016 through 2020.

Figure 18. Incremental Industrial Base Achievable Potential in 2016-2020, MWh



Program Potential

Cadmus developed six program potential scenarios, described in Table 10. These scenarios reflect different assumptions that address the following:

- **Benefit-cost threshold**: Traditionally, estimates of economic, achievable, and program potential only reflect measures with a total resource cost (TRC) benefit-cost ratio equaling or exceeding 1.0. This assumption, however, does not reflect cost-effectiveness requirements in Pennsylvania. PPL may offer measures with a TRC benefit-cost ratio less than one as long as the overall energy efficiency portfolio remains cost-effective. For four program scenarios, Cadmus relaxed this benefit-cost threshold, and effectively produced estimates of program potential reflecting non-cost-effective measures bundled with cost-effective measures.
- **Measure mix**: An approach for estimating program potential involves equally “scaling down” estimates of achievable potential for all measures; so overall program budgets meet legislatively mandated spending caps. This approach assumes the distribution of savings from measures that contribute to program potential equals the distribution observed in achievable potential. An alternate approach involves estimating programming potential using only measures that a utility expects to offer through programs. Measures with high freeridership levels or market barriers may be excluded from such estimates of program potential. We present scenarios using both approaches.
- **Treatment of low-income customers:** The PUC’s tentative implementation order on Phase III programs proposes a low-income carve out where savings from low-income, direct-install programs account for at least 2% of total portfolio savings, and other low-income savings (non-direct-install) account for at least 3.5% of portfolio savings. While the SWE’s estimates of program potential do not account for this carve out, Cadmus developed alternate program potential scenarios that do so. For these scenarios, low-income acquisition costs reflect PPL’s actual acquisition costs from Phase II.
- **Mixture of screw-base lighting measures:** Program acquisition costs and potential remain highly responsive to the mixture of screw-base lighting measures considered—a scenario where a utility primarily offers CFLs will be much cheaper and have higher program potential than a scenario where a utility primarily offers LEDs.

Table 10. Program Scenarios and Assumptions

Scenario Name	Acquisition Cost ($/kWh)	Description	Benefit-Cost Threshold	Measure Mix	Low Income Treatment	Low-Income Carve Out	Lighting Treatment
Traditional 1	$0.18	Scenario most comparable to the SWE potential study. This scenario includes all cost-effective measures, treats low-income similar to non-low-income, does not include a low-income carve out, and assumes a 30/70 distribution of CFLs and LEDs.	1.0	All cost-effective measures	Use incremental measure costs; incentives equivalent to approximately 50% of incremental costs	No	Declining LED prices; 30/70 CFL and LED share
Traditional 2	$0.22	This scenario is identical to Scenario 1, except it assumes incentives for low-income measures are equivalent to 100% of incremental measure costs.	1.0	All cost-effective measures	Use incremental measure costs; incentives equivalent to 100% of incremental costs	No	Declining LED prices; 30/70 CFL and LED share
Program 1—Low Cost A	$0.18	This scenario only includes PPL's preferred measures. Non-cost-effective measures are allowed and CFLs account for 100% of screw-base lighting savings.	0.75	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	Exclude LEDs (CFLs only)
Program 2—Low Cost B	$0.21	Includes PPL's preferred measures and excludes CFLs. Accounts for the low-income carve out	0.75	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	LEDs only (exclude CFLs)
Program 3—Medium Cost	$0.30	Reflects a lower benefit-cost threshold and a more balanced mixture of measures. Lighting accounts for a low to moderate share of portfolio savings.	0.5	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	LEDs only (exclude CFLs)
Program 4—High Cost	$0.39	Reflects a lower benefit cost threshold. Lighting accounts for a relatively low share of portfolio savings.	0.45	PPL's preferred measure mix; excludes measures with high freeridership	Use full measure costs; incentives equivalent to 100% of full costs	Yes	LEDs only (exclude CFLs)

In addition to assumptions listed in Table 10, Cadmus applied the following assumptions to each of the four program scenarios (and not the two traditional scenarios):

- The total five-year spending cap roughly equals $280 million. This reflects the demand response (DR) expenditure requirement in the PUCs implementation order, which effectively makes energy efficiency expenditures equivalent to an average of $58.5 million per year. Per PPL, we reduced this resulting budget by 3.5% to account for risk.
- Low-income, direct-install, acquisition costs approximately are $1.50 per kWh saved; acquisition costs for other low-income measures range from $0.20 per kWh to approximately $0.30 per kWh. These costs reflect PPL's actual expenditures on low-income programs.

In evaluating these different scenarios, Cadmus compared the following metrics:

- **Overall acquisition cost ($/kWh):** An acquisition cost calculated as the total five-year program budget, divided by the five-year program potential.
- **Five-year program potential (MWh):** Equals the sum of incremental savings in each program year (2016 through 2020).
- **Total Budget ($000s)**: Reflects the sum of each measures' cost per kWh (including incentives and administrative expenditures), multiplied by the sum of the five-year incremental program potential.
- **Low-income potential:** Expressed as a percentage of the total portfolio program potential.
- **Lighting potential:** Expressed as a percent of the total portfolio program potential. This metric roughly represents the diversity of the measure mix for a given scenario. Scenarios with a relatively high share of savings from lighting have a less diverse mixture of measures. Notably, the lighting share as a percent of portfolio savings may be significantly lower than the share PPL historically has observed through programs: the remaining lighting efficiency potential has greatly decreased over the last six program years, the saturation of efficient lighting has increased, and federal lighting standards have further reduced savings.
- **Weighted average program potential as a fraction of base achievable potential:** Program potential is the remaining subset of achievable potential after accounting for budget constraints. This metric shows the portion of achievable savings PPL must capture through programs to meet savings targets. Scenarios where this fraction is high could carry more risk as they require nearly all likely participants to participate.

Overview of Results

Table 11 summarizes these key metrics for each of the six scenarios considered.

Table 11. Summary of Scenario Results

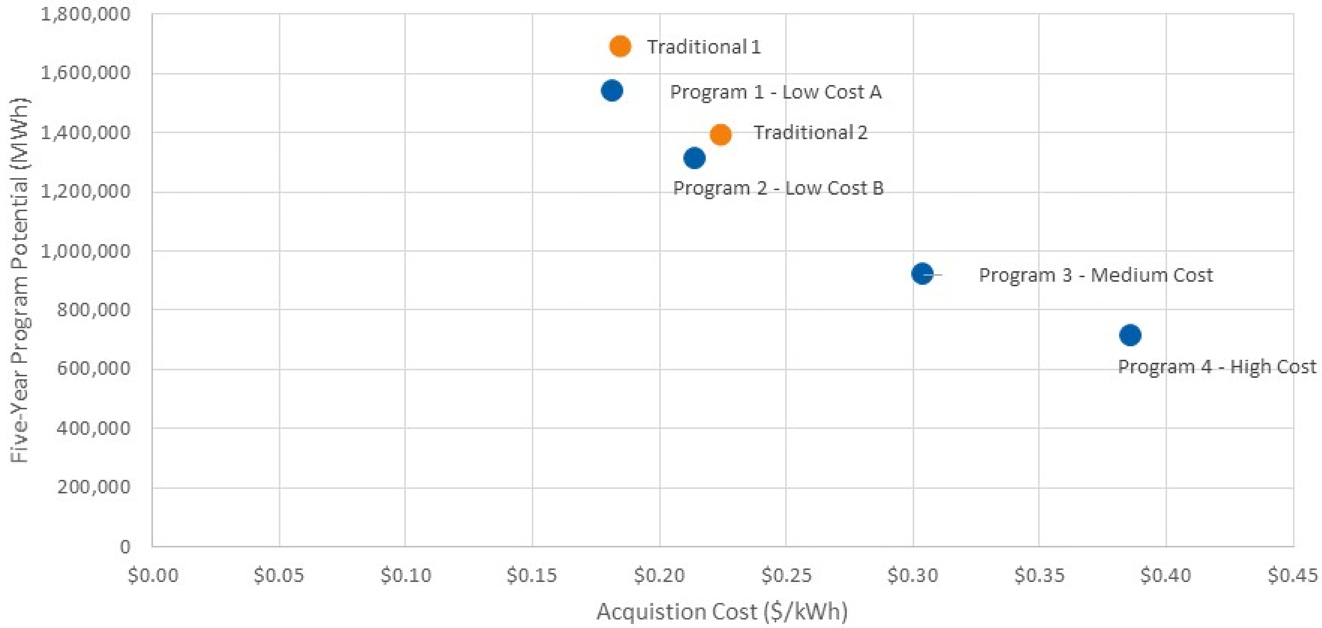
Scenario Name	Acquisition Cost ($/kWh)	5-Year Program Potential (MWh)	Total Budget ($000s)	Low Income Potential as a % of Portfolio Savings	Lighting Potential as a % of Portfolio Savings	Weighted Average Program Potential as a Fraction of Achievable
Traditional 1	$0.18	1,691,844	312,479	20%	34%	65%
Traditional 2	$0.22	1,392,280	312,559	25%	32%	43%
Program 1—Low Cost A	$0.18	1,539,137	280,370	6%	38%	91%
Program 2—Low Cost B	$0.21	1,308,016	280,501	6%	42%	76%
Program 3—Medium Cost	$0.30	920,356	279,773	6%	26%	33%
Program 4—High Cost	$0.39	712,309	275,115	6%	18%	25%

The results of the two traditional scenarios and the four program scenarios differ in two major ways:

1. The traditional scenarios do not account for actual low-income program costs (which are approximately $1.50/kWh for direct-install programs and $0.25/kWh for other programs). For Traditional 1, this means low-income customers effectively are treated akin to non-low-income customers. This approach reduces the overall acquisition cost, and it allows for low-income to account for a larger relative share of total portfolio savings (i.e., this large share would not be feasible upon assuming actual low-income acquisition costs).
2. The two traditional scenarios include a broader mixture of measures, including low-cost consumer electronics measures with low acquisition costs but subject to high freerdiership levels. Including these measures in the traditional scenarios means, after accounting for Act 129 spending caps, program potential equals a moderate share of achievable potential (65% in Traditional 1 and 43% in Traditional 2).

Acquisition costs and savings targets for each scenario can be plotted to show the relationship between a change in acquisition cost and five-year program potential (shown in Figure 19): each program scenario is subject to a fixed, five-year spending cap. Program scenarios fall on a “lower” curve as they incorporate an energy efficiency spending cap that accounts for required DR expenditures (whereas traditional scenarios do not).

Figure 19. Scenario Acquisition Costs and Five-Year Program Potential



After accounting for proposed DR expenditures requirements, program scenarios ranging from $0.18/kWh to $0.39/kWh reflect a five-year savings target between approximately 1.5 million and 0.7 million MWh.

Comparison of Program Scenarios

To evaluate each program scenario, we compared them based on acquisition costs, mix of measures, and weighted average program potential as a fraction of achievable potential. We excluded traditional scenarios from this comparison as these scenarios do not use low, realistic, low-income assumptions and include measures that EDCs would unlikely offer due to high freeridership and market barriers.

Program 1—Low Cost A

At $0.18 per kWh saved, this scenario has the lowest acquisition cost of the four program scenarios, and is the only program scenario with an overall acquisition cost approximately equal to the acquisition cost included in the SWE's estimate of program potential.

The scenario, however, presents significant drawbacks. After accurately accounting for low-income costs, the scenario must depend heavily on low-cost measures, including CFLs. The scenario must exclude LEDs, and all screw-base lighting savings derive from CFLs.

By relying heavily on CFL savings to reach an overall $0.18 per kWh acquisition cost, we assume exclusion of measures with a low benefit-cost ratio excluded and actual acquisition of a high share of achievable potential through programs. In this scenario, we assume 91% of achievable potential acquired through programs and savings reflecting measures with a benefit-cost ratio exceeding 0.75.

While a low cost scenario, it presents higher risks as it assumes programs can capture nearly all savings estimated as achievable. Also, due to the relatively high benefit-cost threshold, this scenario reflects a less diverse mixture of measures.

Table 12 (at the end of this report) summarizes costs, benefits, budgets, and savings for the Program 1 scenario. Figure 20 shows the distribution of program potential by segment for the Program 1 scenario. The majority of savings derive from the residential sector.

Figure 20. Distribution of Program Potential by Segment—Program 1 Scenario

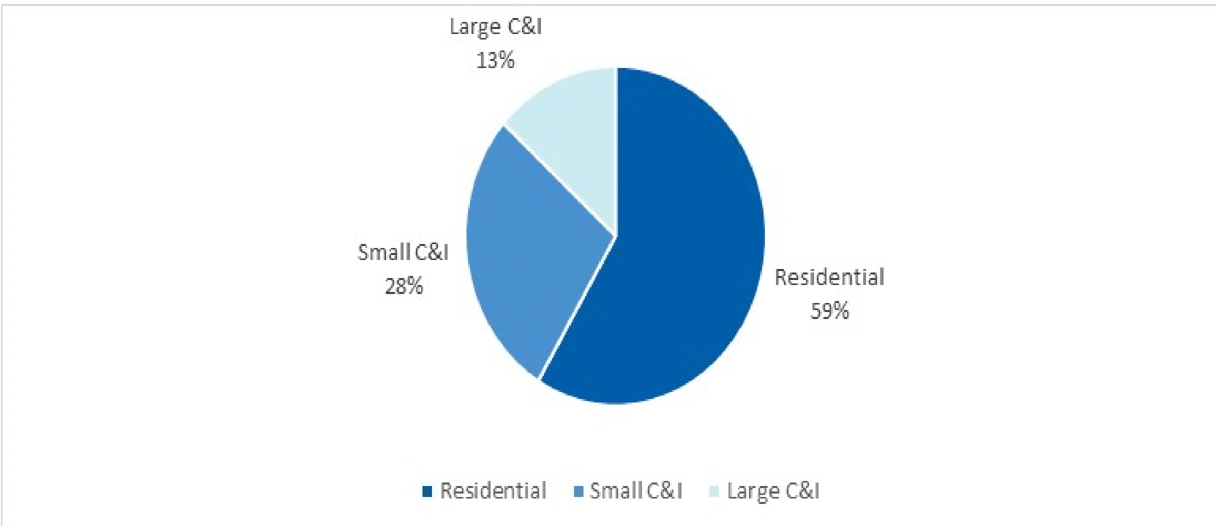


Figure 21 and Figure 22 show the respective distributions of residential and commercial savings by measure groups. The majority of residential savings derive from CFL lighting.

Figure 21. Distribution of Residential Program Potential by Measure Group–Program 1 Scenario

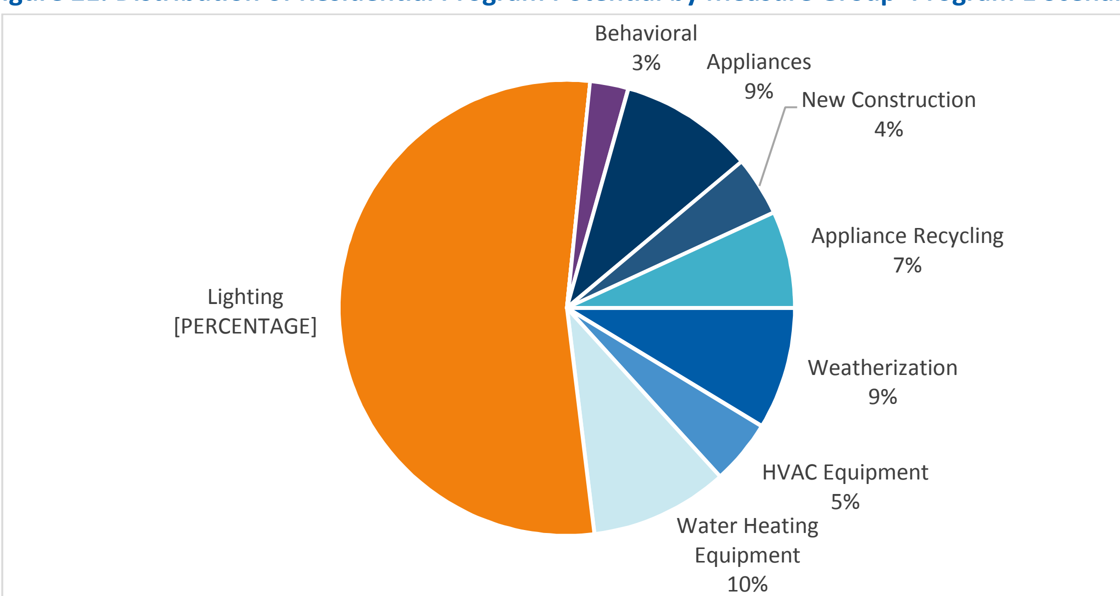


Figure 22. Distribution of Commercial Program Potential by Measure Group

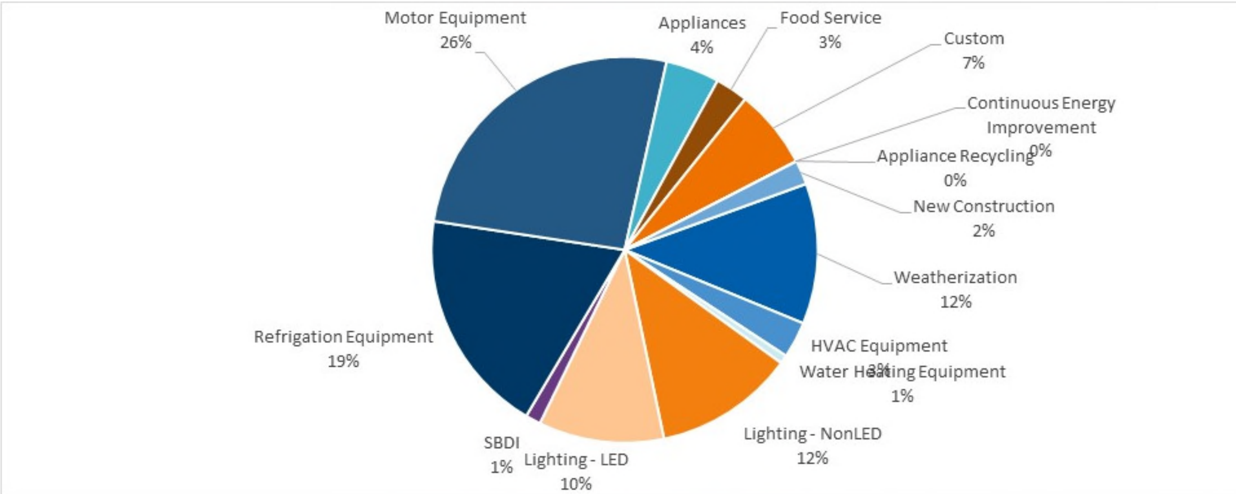


Figure 23 shows the incremental achievable potential for the Program 1 scenario in each year (2016 through 2020). Due to the high concentration of savings from screw-base lighting measures and the short baseline measure life, many savings concentrate in the study's earlier year, when incandescent and halogens bulbs are expected to burn out and be replaced with CFLs. Consequently, savings drop off in 2019 and 2020. Except for 2020, savings in each year account for 15% or more of total five-year savings. In 2020, savings account for approximately 12% of total five-year savings. Average incremental savings as a fraction of 2010 sales equals 0.8% of 2010 sales.

Figure 23. Incremental Achievable Potential—Program 1 Scenario

Program 2—Low Cost B

This scenario's $0.21/kWh acquisition cost is the second lowest of the four scenarios. Though similar to the first low-cost program scenario in that it uses a minimum benefit-cost threshold of 0.75, it largely excludes CFLs and includes screw-base LEDs in the residential sector. To preserve acquisition near $0.20 per kWh and to include LED lighting, relatively low-cost lighting and behavioral measures must account for a high share of savings, while more expensive weatherization and efficient equipment measures must account for a smaller share of savings. Overall, lighting accounts for 42% of cumulative, five-year savings and 67% of total residential savings.

The scenario presents two main disadvantages: it includes lower measure diversity rates and assumes a high share of potential lighting and behavioral savings can be achieved through programs. In this scenario, we assume 100% of achievable behavioral savings acquired through programs and 85% of achievable lighting savings acquired. In contrast, we assume approximately 25% of potential water heating equipment, HVAC equipment, weatherization, new construction, and appliances savings acquired through programs over the five-year planning horizon.

Table 13 (at the end of this report) summarizes savings, costs, benefits, budgets, and acquisition costs for program Scenario 2, and Figure 24 shows the distribution of program potential by segment. Compared to Scenario 1, C&I accounts for a larger share of five-year program potential. C&I savings generally are lower cost than residential savings; to achieve a near $0.20 acquisition cost, while including LED lighting in the residential sector, C&I must account for a higher share of program potential.

Figure 24. Distribution of Program Potential by Segment—Program 2 Scenario

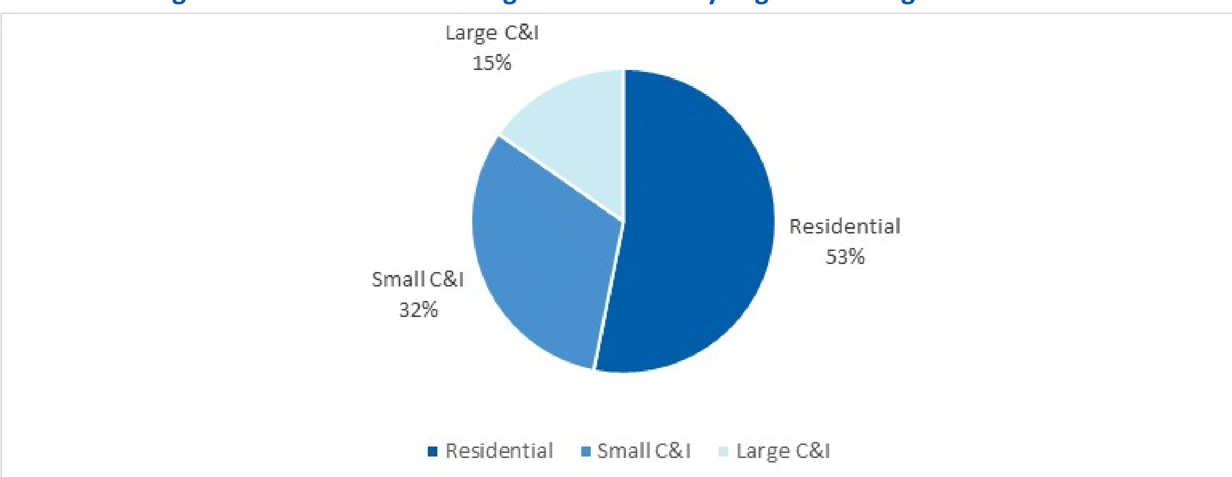


Figure 25 and Figure 26 show distributions of residential and commercial program potential by measure group. In this scenario, residential lighting accounts for a much larger share of residential program potential. More expensive groups of measures, such as HVAC equipment, weatherization, new construction, and water heating equipment account for a smaller share of savings.

Figure 25. Distribution of Residential Program Potential by Measure Group—Program 2 Scenario

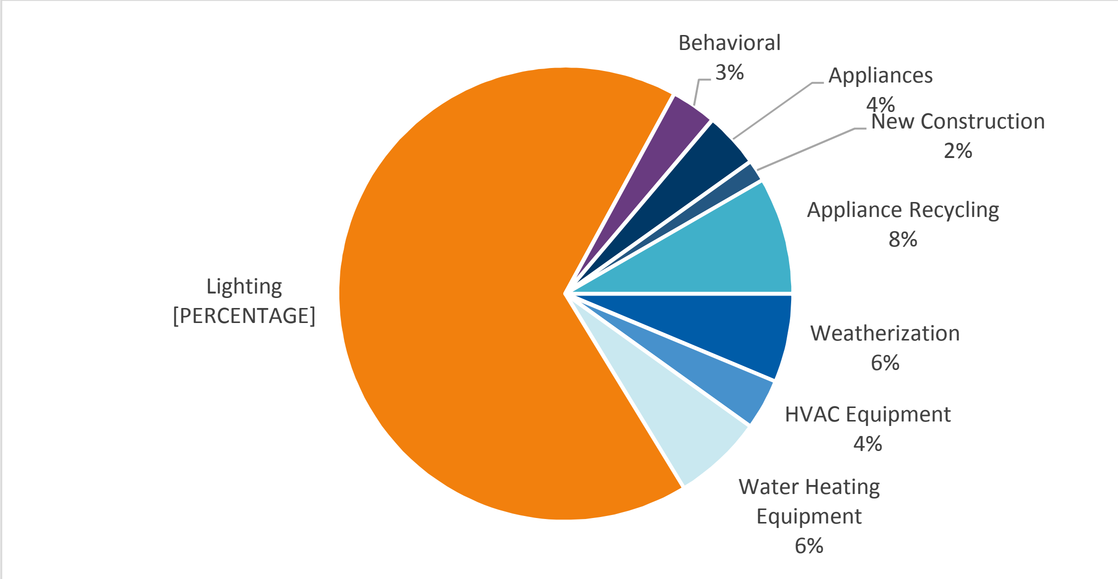


Figure 26. Distribution of Commercial Program Potential by Measure Group—Program 2 Scenario

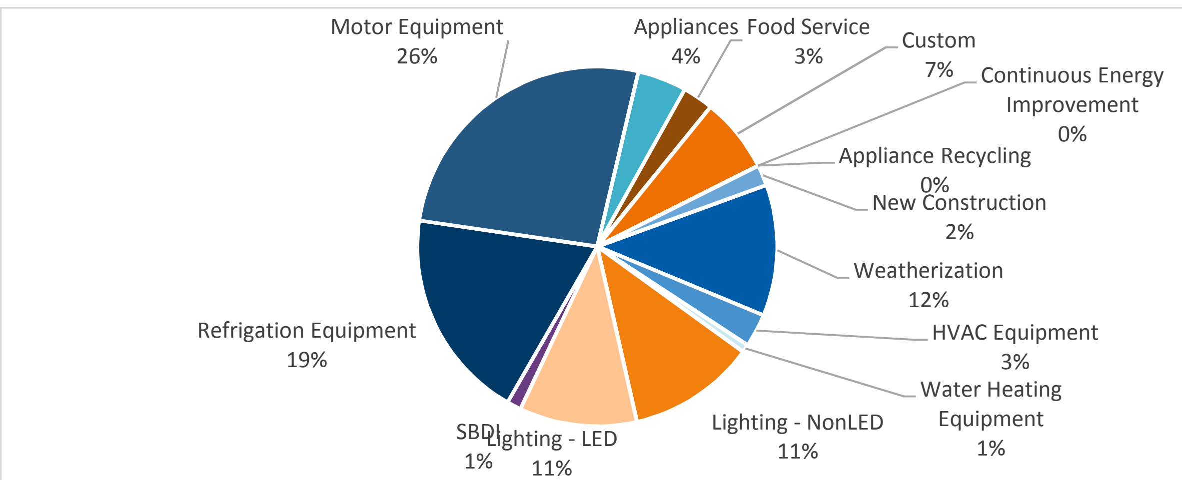
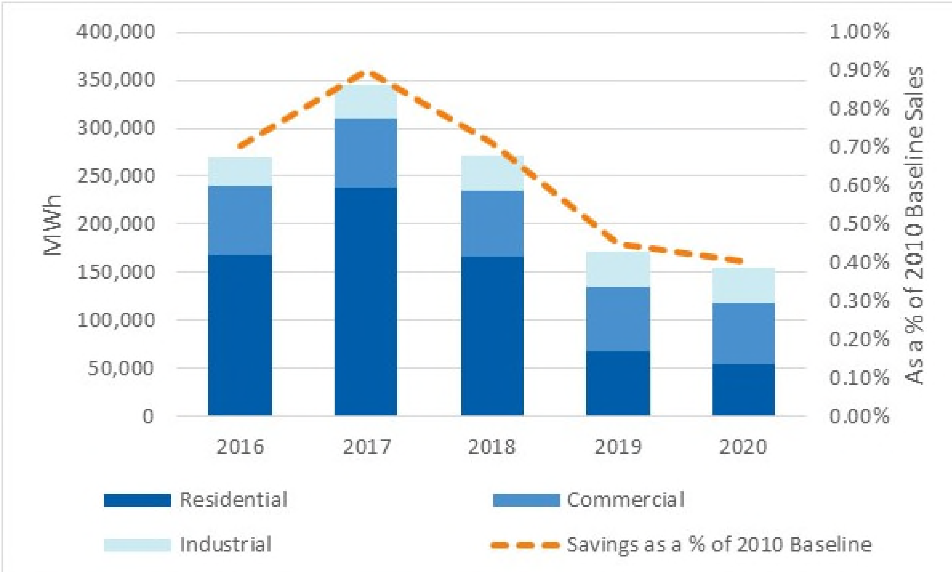


Figure 27 shows incremental program potential for the Program 2 scenario for each year of the planning horizon (2016 through 2020). Similar to Program Scenario 1, Program Scenario 2 is a lighting-heavy scenario, with high savings in early years and diminishing savings in 2019 and 2020. Potential incremental savings in 2019 and 2020 each account for less than 15% of total five-year program potential. In these later years, commercial and industrial programs must account for the majority of savings. Average annual incremental savings approximately equal 0.6% of 2010 baseline sales in each year.

Figure 27. Incremental Achievable Potential—Program 2 Scenario



Program 3—Medium Cost

The third program scenario (Program 3) includes the second-highest acquisition cost of each of the four program scenarios ($0.30/kWh), a greater diversity of measures, and uses a lower benefit-cost threshold (0.5). Though this scenario depends less on residential screw-base lighting, due to the higher acquisition cost, it has a much lower five-year program potential. In this scenario, lighting accounts for 26% of five-year program potential (compared to 38% and 42% in the first and second low-cost scenarios, respectively).

The scenario includes a much more balanced mixture of measures—it assumes approximately 33% of achievable potential acquired through programs. The residential sector still accounts for roughly one-half of the total five-year program potential; however, a smaller share of residential savings comes from lighting measures.

Table 14 (at the end of this report) summarizes the potential savings, costs, benefits, budgets, and acquisition costs for the Program 3 scenario. Figure 28 shows the distribution of program potential by sector.

Figure 28. Distribution of Program Potential by Sector—Program 3 Scenario

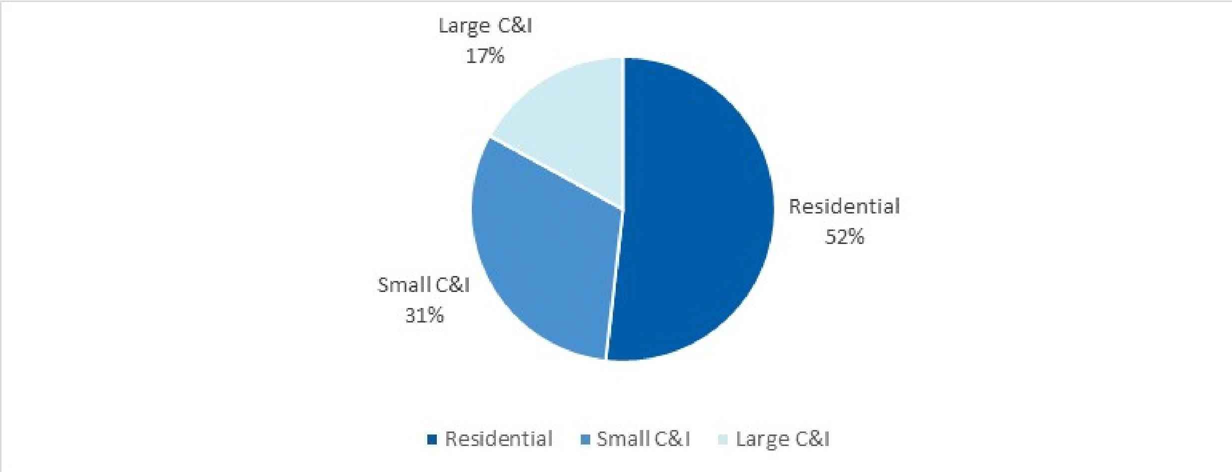


Figure 29 and Figure 30 show the distribution of residential and commercial program potential by measure group. Residential lighting savings only account for 40% of total residential savings in this scenario. Compared to Scenarios 1 and 2, Scenario 3 relies on higher savings from HVAC equipment, water heating equipment, and weatherization measures.

Figure 29. Distribution of Residential Program Potential by Measure Group—Program 3 Scenario

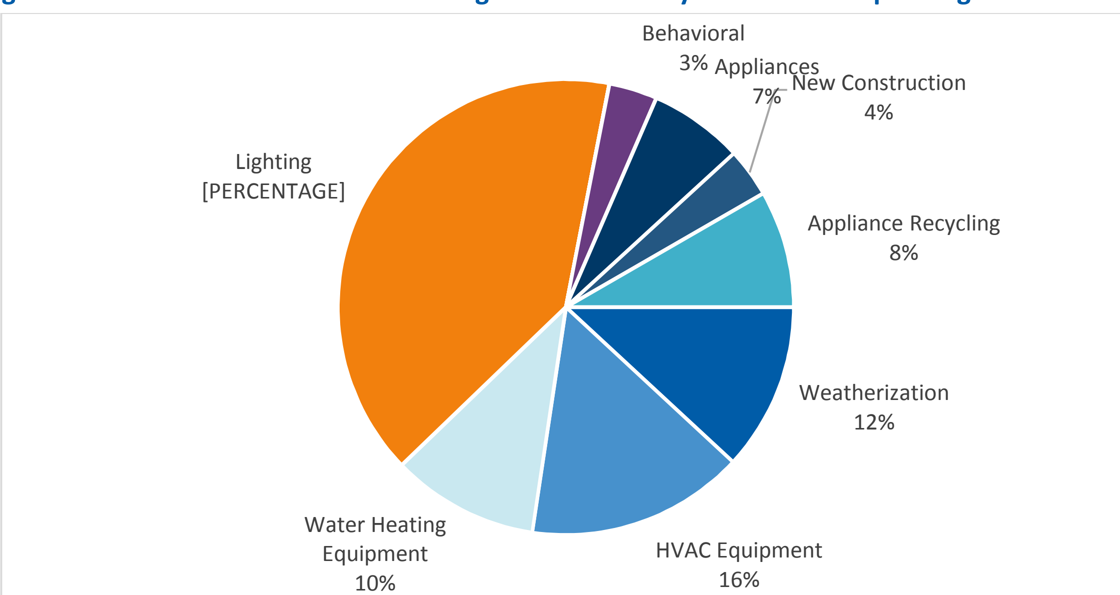
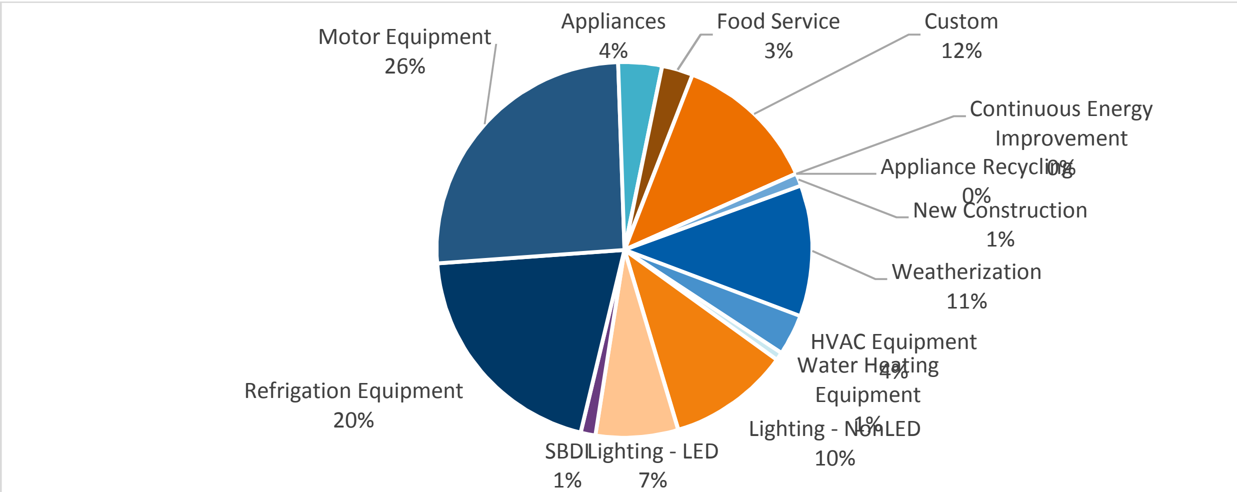
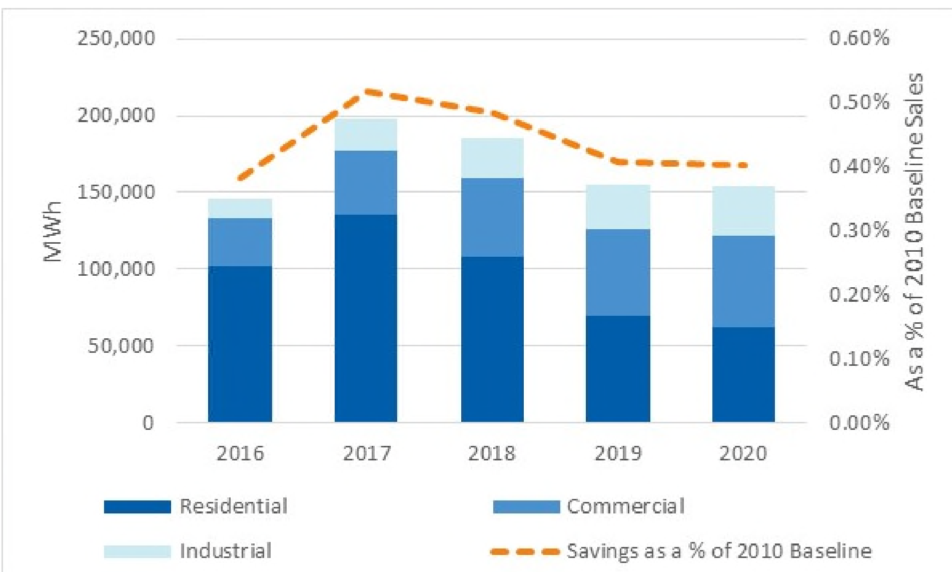


Figure 30. Distribution of Commercial Program Potential by Measure Group—Program 3 Scenario



Due to lower reliance on lighting savings, incremental savings spread more evenly across the five program years in Scenario 3 (as shown in Figure 31). Incremental savings in each year account for greater than 15% of cumulative five-year savings. Average annual incremental savings, expressed as a fraction of 2010 sales, approximately equals 0.45%.

Figure 31. Incremental Program Potential—Scenario 3



Program 4 Scenario – High Cost

The final program scenario (Program 4) reflects a diverse mixture measures, relatively low lighting savings, and a high overall acquisition cost ($0.39/kWh saved). This scenario includes the greatest diversity of measures and reflects a minimum benefit-cost ratio threshold of 0.45. Program potential in this scenario is equivalent to roughly 25% of five-year achievable potential. Table 15 (at the end of this report) summarizes potential savings, costs, benefits, budgets, and acquisition costs for program Scenario 4.

In program Scenario 4, a relatively high share of savings comes from the residential sector (63%), as shown in Figure 32.

Figure 32. Distribution of Potential by Sector—Program Scenario 4

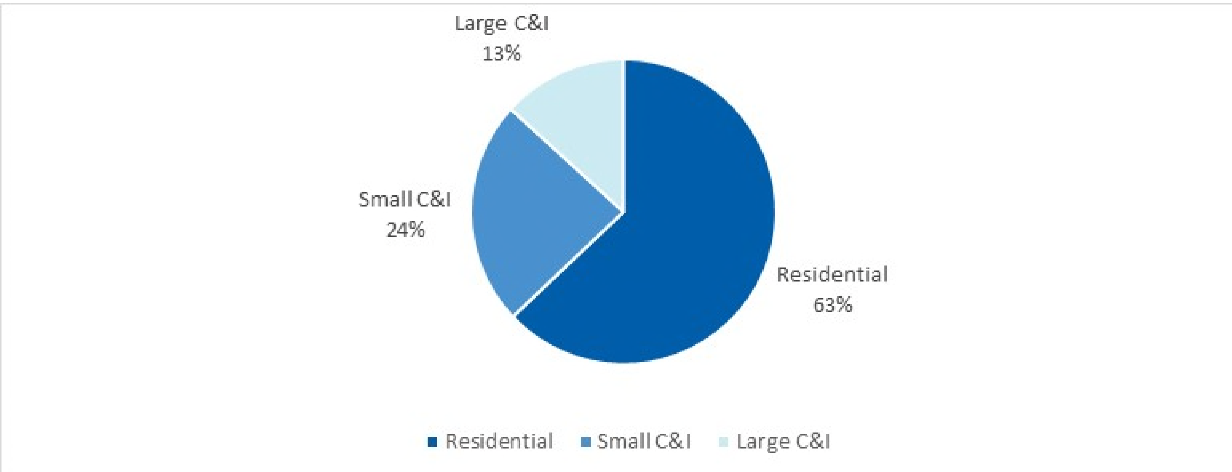


Figure 33 and Figure 34 show the distribution of residential and commercial program potential by measure group. Lighting only accounts for 23% of residential potential in this scenario, while HVAC equipment, water heating equipment, appliances, and weatherization collectively account for 65% of potential residential savings.

Figure 33. Distribution of Residential Program Potential by Measure Group—Scenario 4

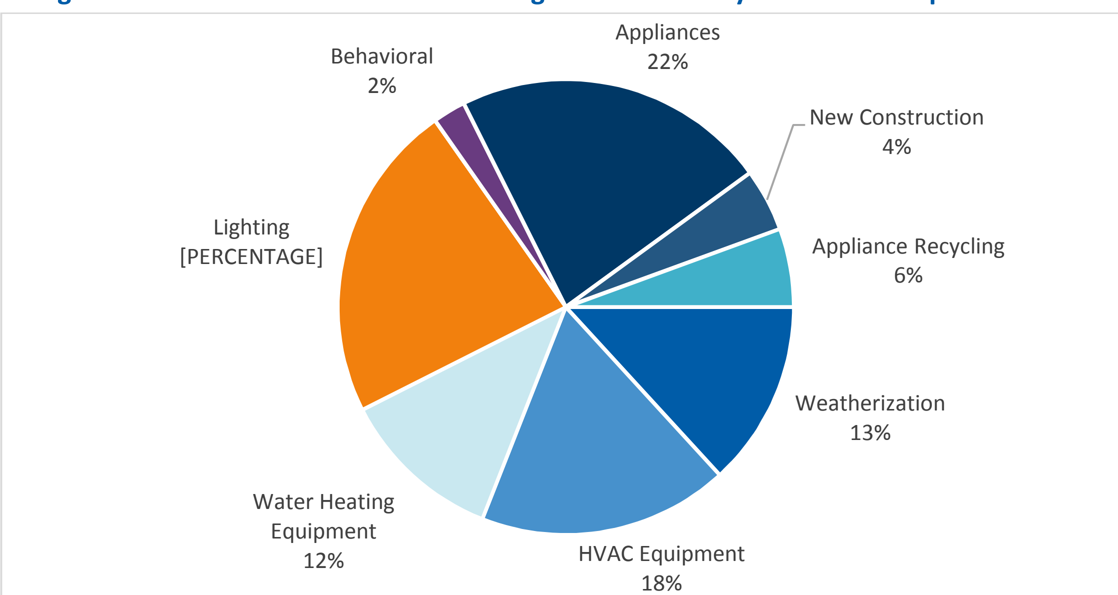


Figure 34. Distribution of Commercial Program Potential by Measure Group—Scenario 4

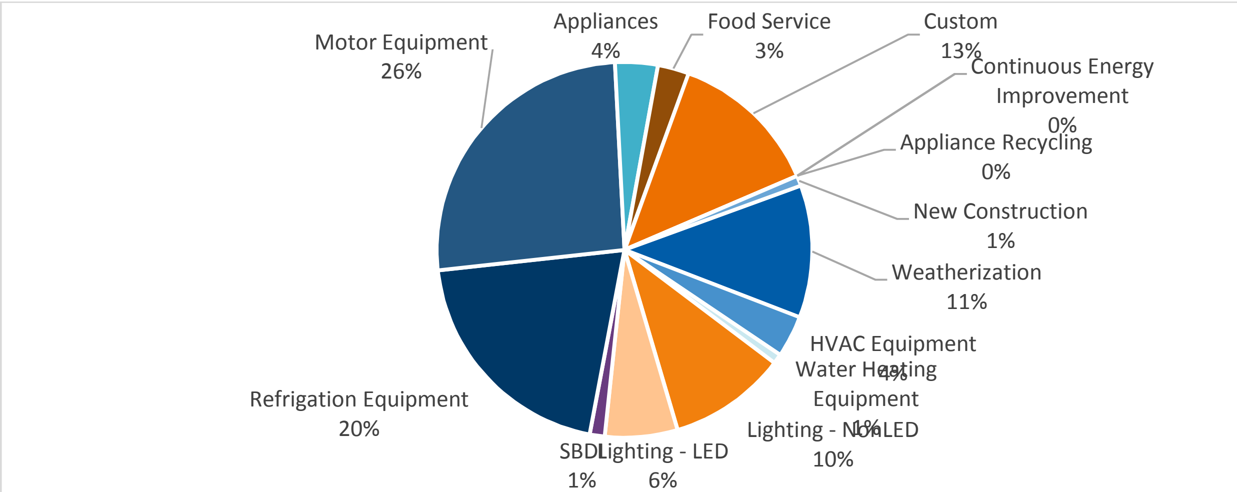
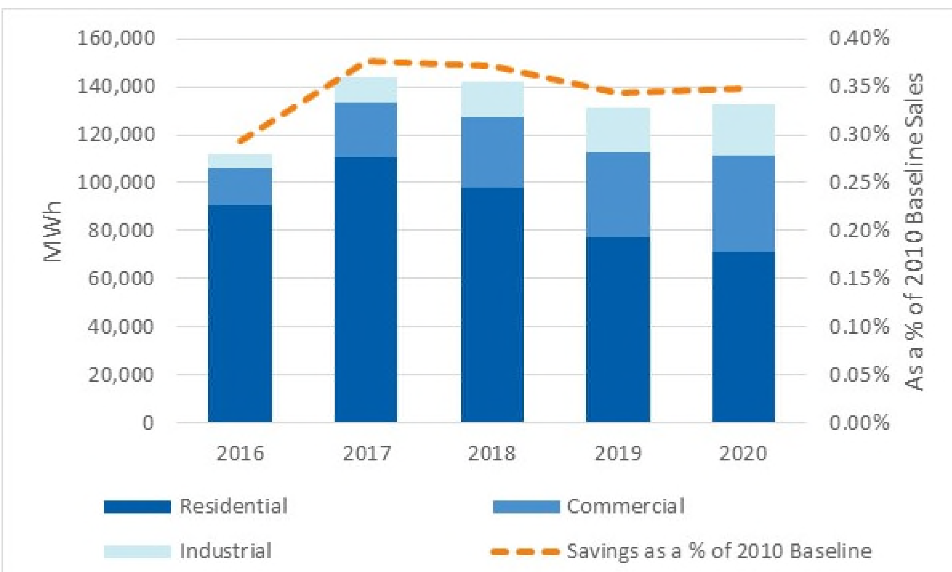


Figure 35 shows incremental program potential in each year of the planning horizon for program Scenario 4. Compared to Scenarios 1 through 3, incremental savings in each year remains relatively flat due to the lower share of lighting savings, which tends to be acquired in the first three years of the planning horizon.

Figure 35. Incremental Program Potential—Scenario 4



Program Summary Tables

Table 12, Table 13, Table 14, and Table 15 show the program potential, benefits, costs, budgets, and acquisition costs for each of the four program scenarios.

Table 12. Program 1 Scenario Summary

Sector	Program Potential - 5 Year	TRC NPV Benefits ($000s)	TRC NPV Costs ($000s)	Program TRC B/C Ratio	Incentive Budget - 5 Year ($000)	Admin Budget - 5 Year ($000)	Budget - 5 Year ($000)	Incentive Acquisition Cost - $/kWh	Admin Acquisition Cost $/kWh	Acquisition Costs ($/1st Yr kWh Saved)
Residential	902,464	$890,606	$640,775	1.39	$144,572	$52,688	$197,260	$0.16	$0.06	$0.22
Small C&I	430,050	$513,539	$220,613	2.33	$35,845	$20,483	$56,328	$0.08	$0.05	$0.13
Large C&I	206,623	$224,876	$103,537	2.17	$17,044	$9,739	$26,783	$0.08	$0.05	$0.13
Total	1,539,137	$1,629,021	$964,925	1.69	$197,460	$82,910	$280,370	$0.13	$0.05	$0.18

Table 13. Program 2 Scenario Summary

Sector	Program Potential - 5 Year	TRC NPV Benefits ($000s)	TRC NPV Costs ($000s)	Program TRC B/C Ratio	Incentive Budget - 5 Year ($000)	Admin Budget - 5 Year ($000)	Budget - 5 Year ($000)	Incentive Acquisition Cost - $/kWh	Admin Acquisition Cost $/kWh	Acquisition Costs ($/1st Yr kWh Saved)
Residential	695,157	$691,600	$467,451	1.48	$145,469	$52,632	$198,101	$0.21	$0.08	$0.28
Small C&I	412,635	$499,871	$214,517	2.33	$35,922	$20,527	$56,449	$0.09	$0.05	$0.14
Large C&I	200,223	$221,030	$101,764	2.17	$16,515	$9,437	$25,952	$0.08	$0.05	$0.13
Total	1,308,016	$1,412,502	$783,732	1.80	$197,905	$82,596	$280,501	$0.15	$0.06	$0.21

Table 14. Program 3 Scenario Summary

Sector	Program Potential - Potential - 5 Year	TRC NPV Benefits ($000s)	TRC NPV Costs ($000s)	Program TRC B/C Ratio	Incentive Budget - 5 Year ($000)	Admin Budget - 5 Year ($000)	Budget - 5 Year ($000)	Incentive Acquisition Cost - $/kWh	Admin Acquisition Cost $/kWh	Acquisition Costs ($/1st Yr kWh Saved)
Residential	477,003	$549,554	$494,652	1.11	$142,310	$52,358	$194,668	$0.30	$0.11	$0.41
Small C&I	286,978	$422,158	$243,000	1.74	$34,094	$19,482	$53,576	$0.12	$0.07	$0.19
Large C&I	156,375	$213,837	$147,176	1.45	$20,064	$11,465	$31,529	$0.13	$0.07	$0.20
Total	920,356	$1,185,549	$884,827	1.34	$196,468	$83,305	$279,773	$0.21	$0.09	$0.30

Table 15. Program 4 Scenario Summary

Sector	Program Potential - 5 Year	TRC NPV Benefits ($000s)	TRC NPV Costs ($000s)	Program TRC B/C Ratio	Incentive Budget - 5 Year ($000)	Admin Budget - 5 Year ($000)	Budget - 5 Year ($000)	Incentive Acquisition Cost - $/kWh	Admin Acquisition Cost $/kWh	Acquisition Costs ($/1st Yr kWh Saved)
Residential	448,312	$528,494	$584,134	0.90	$161,897	$61,143	$223,040	$0.36	$0.14	$0.50
Small C&I	169,687	$291,960	$172,309	1.69	$20,762	$11,864	$32,627	$0.12	$0.07	$0.19
Large C&I	94,310	$150,948	$106,017	1.42	$12,377	$7,072	$19,449	$0.13	$0.07	$0.21
Total	712,309	$971,402	$862,460	1.13	$195,036	$80,079	$275,115	$0.27	$0.11	$0.39