B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

BPA Conservation Potential Assessment

2020 – 2039

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Acronyms and Abbreviations

aMW	average Megawatt
BPA	Bonneville Power Administration
CBSA	*Commercial Building Stock Assessment*
Council	Northwest Power and Conservation Council
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EUL	effective useful life
HVAC	heating, ventilation, and air conditioning
IOUs	investor-owned utilities
kWh	kilowatt-hour
MWh	Megawatt-hour
O&M	operations and maintenance
RBSA	*Residential Building Stock Assessment*
RTF	Regional Technical Forum
TRC	total resource cost test
UCT	utility cost test
UES	unit energy savings
USDA ERS RUCC	U.S. Department of Agriculture Economic Research Service's *Rural-Urban Continuum Codes*

Executive Summary

Overview

The Bonneville Power Administration (BPA) contracted with Cadmus and EES Consulting (the Cadmus Team) to develop estimates of the magnitude, timing, and costs of conservation resources within BPA's service territory over a 20-year horizon, beginning in 2020. This study identifies all of two types of conservation potential—technical and achievable technical—in each major customer sector (residential, commercial, industrial, agricultural, and distribution efficiency).

The Cadmus Team's primary objective was to develop the necessary conservation supply curves for achievable technical potential to inform the BPA Resource Program's optimization modeling, which determines the amount of conservation potential that can be expected to meet BPA's economic resource selection criteria. This involved quantifying two of the three types of potential commonly identified by conservation potential studies. The three types of potential are defined below and illustrated in **Figure 1**:

- ***Technical potential*** (identified in this study) assumes that all technically feasible resource opportunities may be captured, regardless of their costs or other market barriers. It represents the total conservation potential in BPA's service territory, after accounting for purely technical constraints.
- ***Achievable technical potential*** (identified in this study) is the portion of technical potential that is assumed to be achievable during the study's 20-year forecast regardless of their sources, which include utility-sponsored programs, improved building codes and equipment standards, and market transformation.
- ***Achievable economic potential*** *(not included in this study)* is the portion of achievable technical portion determined to be cost-effective by the Resource Program optimization modeling, in which either bundles or individual conservation potential measures are selected based on cost and savings. The cumulative potential for these selected measures or bundles constitutes achievable economic potential.

Figure 1. Types of Conservation Potential

For this study, the Cadmus Team used methods consistent with the Northwest Power and Conservation Council's (the Council) *Seventh Power Plan*, while incorporating up-to-date assumptions and BPA-specific data from regional stock assessments, BPA's Power Customers, and financial assumptions. Examples of BPA-specific data include measure saturations derived from a BPA-specific subset of the 2017 *Residential Building Stock Assessment* (RBSA), unit forecasts derived from BPA and member-utility data, and various financial assumptions (such as discount rates and avoided costs) provided by BPA's Resource Program staff. In addition, the Cadmus Team adjusted the estimates of conservation potential to account for BPA's recent and planned program accomplishments from 2016-2019, modified ramp rates to align with the 2020-2039 study horizon, incorporated new equipment standards, and used the latest costs and savings estimates for energy conservation measures approved by the Regional Technical Forum (RTF) as of September 2017.

Scope of the Analysis

For this study, the Cadmus Team analyzed conservation potential for existing and new construction in five sectors and the associated building types:

Residential: Single-family, multifamily, and manufactured homes

Commercial: Eighteen commercial segments, including offices and retail space

Industrial: Energy-intensive manufacturing and (primarily) process-driven customers

Agricultural: Considered measures applicable to primarily dairy and irrigation segments

Distribution efficiency: Improving the utility distribution system's efficiency

For each sector, the Cadmus Team characterized the savings, per-unit costs, and applicability of commercially available energy conservation measures. We considered measures that provide savings to nearly every end use in each sector, and modeled different applications of each measure, including normal replacement on burnout, retrofit, and new construction:

- ***Natural replacement (lost opportunity) measures*** are assumed to be installed when the equipment it replaces reaches the end of its effective useful life (EUL). Examples are appliances, such as clothes washers and refrigerators, and HVAC equipment, such as heat pumps and chillers.
- ***New construction (lost opportunity) measures*** were installed in newly constructed homes and buildings. Building energy codes affect the baselines for new construction measures, and the timing of these savings is constrained by new construction rates.
- ***Retrofit (discretionary)*** measures encompass upgrades to existing equipment or buildings, and which can theoretically be completed at any time over the study forecast. Unlike natural replacement measures, the timing of retrofit savings is not subject to turnover rates. Examples of retrofit measures include weatherization and controls.

The Cadmus Team developed forecasts of conservation potential over a 20-year (2020 to 2039) planning horizon. This timeframe matches that of the Resource Program and allowed BPA to jointly evaluate the conservation and supply-side resources of its Resource Program.

Study Limitations

Conservation potential studies require complex analyses based on large amounts of data from multiple primary and secondary sources. Estimates are inherently limited by the quality of that data and by the complexity of the analytic procedures used. While the Cadmus Team made every effort to use only the best and most recent data, we recognize the uncertainties inherent in the data, especially those obtained through statistical sampling. For this study, the Cadmus Team used BPA-specific primary data only when that data could produce estimates of acceptable statistical rigor. In addition, while the measure list for this study includes most commercially available measures, it is not exhaustive. We recognize that new technologies continue to emerge, and while not currently commercially viable or vetted, these technologies could produce additional savings over the 20-year study period.

Summary of Results

Overview

The Cadmus Team identified 1,812 aMW of technically achievable conservation potential through the end of the forecast horizon in 2039. The residential sector accounts for approximately 51% of this potential, and the commercial, industrial, utility, and agricultural sectors account for 30%, 13%, 4%, and 2%, respectively. **Table 1** shows 20-year cumulative achievable technical potential by sector.

Table 1. Achievable Technical Potential by Sector

Sector	20-Year Cumulative Achievable Technical Potential - aMW
Agriculture	39
Commercial	542
Utility	67
Industrial	243
Residential	920
Total	**1,812**

The Cadmus Team applied measure-specific ramp rates to determine incremental (annual) and cumulative savings in each year of the study. The assumed ramp rates are the same as those used in the 2017 *Seventh Power Plan*, adjusted to account for this study's start year of 2020[1]. Specifically, discretionary measures used 7th Plan ramp rates shifted so the first year aligns with 2020 (instead of 2016)—this ensured that 100% of discretionary potential is captured within the 20 years. Lost Opportunity measures used the same ramp rates as the 7th Plan, starting in 2020—the Team did not shift lost opportunity ramp rates. For example, if a 7th Plan ramp rate indicate that 50% of lost opportunity savings can be achieved in 2020, this study's ramp rates reflected the

[1] The **Forecast Achievable Technical Potential** section of this report describes are approach for assigning and adjusting both lost opportunity and retrofit ramp rates.

same assumption. **Figure 2** illustrates annual incremental achievable technical potential and **Figure 3** illustrates annual cumulative achievable potential.[2]

Figure 2. Incremental Achievable Technical Potential Forecast

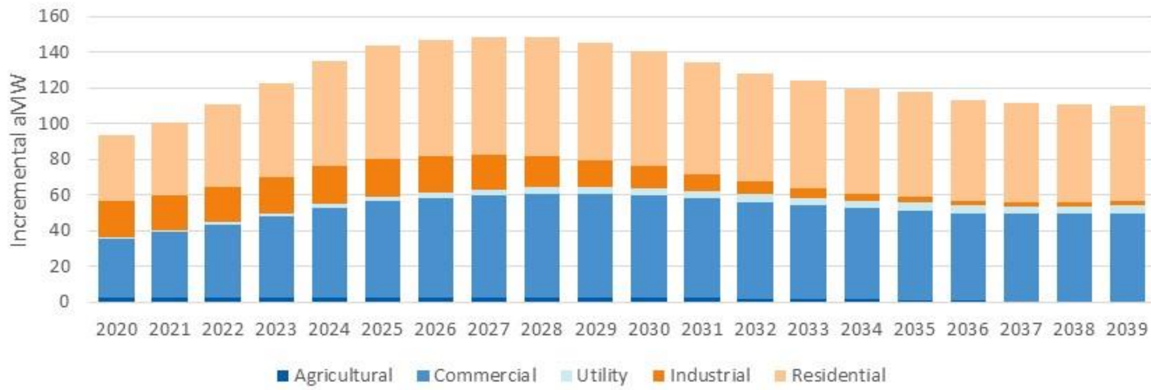
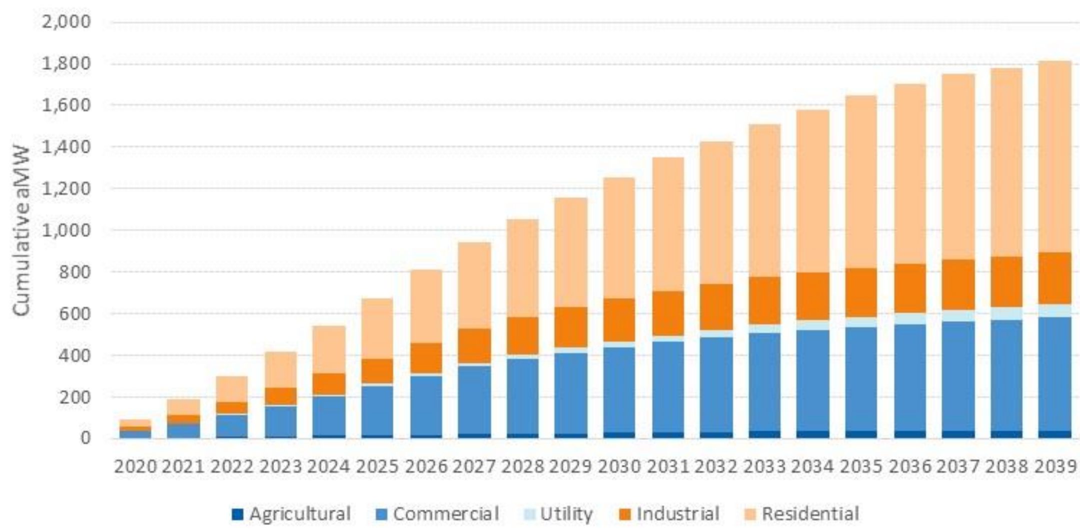


Figure 3. Cumulative Achievable Technical Potential Forecast



Cumulative achievable technical energy conservation potential is equivalent to approximately 7.1% of BPA's forecasted load in 2025 and 18.4% of forecasted load in 2039. In other words, acquiring all the achievable technical potential savings identified in this study would lower BPA's forecasted 2039 load by 18.4%, as **Table 2** and **Figure 4** illustrate. Capturing all the economic potential, which will be determined by the Resource Program, will result in a smaller reduction to BPA's forecast.

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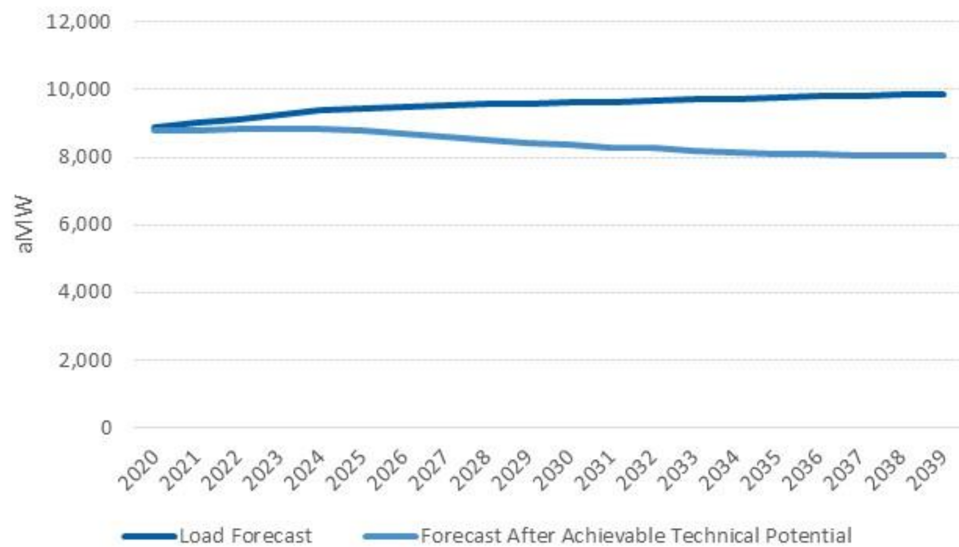
[2] Annual **incremental** achievable potential represents the annual energy savings from measures installed in each year. This also includes normal replacement of the measure on burnout. Measures with an EUL of less than 20 years are assumed to be re-installed at the end of their EUL. Annual **cumulative** savings represent the total annual energy savings from measures installed in each year and all previous years.

Table 2. Cumulative Achievable Technical Potential as Percentage of BPA Load Forecast

Sector	Cumulative 20-Year Achievable Potential (through 2039) - aMW	Percentage of Baseline
All	1,812	18.4%

Figure 4. Load Forecast Adjusted for Achievable Technical Potential



As part of this study, the Cadmus Team developed estimates of the per-unit levelized cost of savings ($/MWh) for each measure, based on the measure's *net* total resource cost (TRC).[3] This information, in conjunction with each measure's incremental savings, produces price-quantity points for a conservation supply curve, illustrated in **Figure 5**. BPA's Resource Program uses this information to determine the cost-effective amount of conservation. As the figure shows, approximately 1,088 aMW (or 60% of the total 1,812 aMW) is expected to be available at a levelized costs of $35 per MWh or less. Figure 6 **Figure 6** shows the cumulative achievable technical potential at different levelized cost points.

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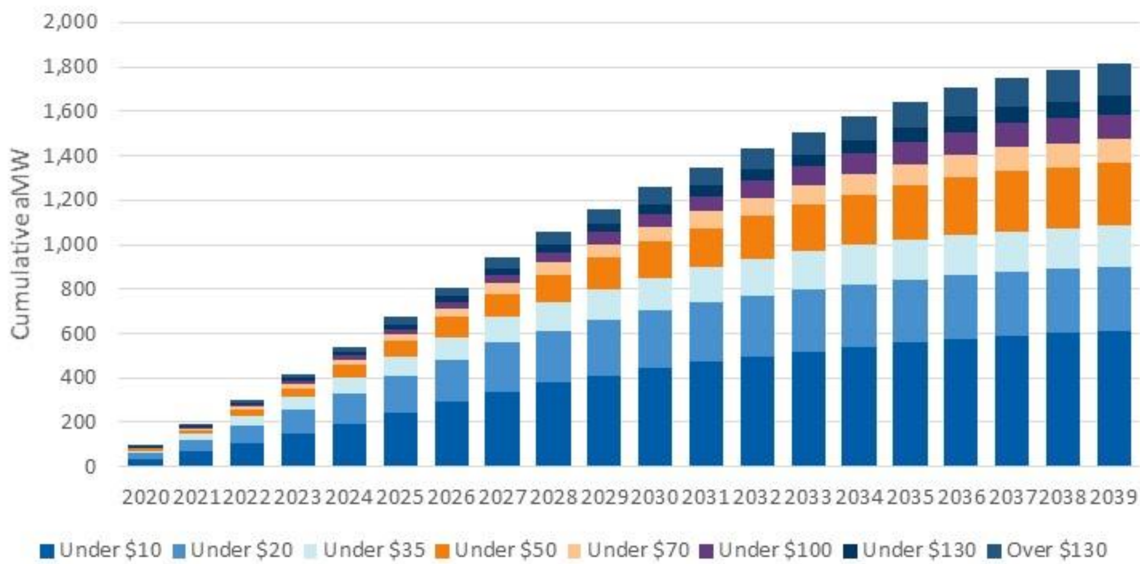
[3] Net TRC levelized costs reflect most of the quantifiable costs and benefits that can be attributed to the energy conservation measure. Costs include the incremental capital, administrative, operations and maintenance (O&M), and avoided periodic replacements, and are levelized over the 20-year study. Benefits include avoided transmission, non-energy benefits, and natural gas. Levelized costs do not include benefits from avoided distribution capacity costs.

Figure 5. Supply Curve of Achievable Technical Potential by Levelized Cost Category

Figure 6. Cumulative Achievable Technical Potential Forecast by Levelized Cost



Summary of Key Findings

The following sections highlight key findings in each sector. Refer to the *Detailed Results* section for more in-depth discussion of sector-specific results.

Residential Sector

The residential sector accounts for approximately 51% (920 aMW) of the total 20-year cumulative achievable technical potential. High-saving measure include heat pump water heaters, weatherization, and ductless heat pumps. While the residential sector has notable potential, these highest saving measures are generally high cost as well. **Table 3** shows the five residential measures with the highest saving, the range of levelized costs for different applications of these measures, and the weighted average levelized cost of all applications of these measures, weighted by 20-year cumulative achievable potential.

Table 3. Top Five Residential Measures

Measure Category	Cumulative 20-Year Achievable Technical Potential (aMW)	TRC Levelized Cost ($/MWh)		
		Weighted Average[a]	Minimum	Maximum
Heat Pump Water Heaters	255	$107	-$4	$805
Weatherization	138	$57	-$5	$275
Ductless Heat Pump	79	$91	$59	$93
Lighting	60	-$11[b]	-$47	$228
Advanced Power Strips	63	$9	$1	$59

[a] Weighted by 20-year cumulative achievable technical potential.

[b] The negative resource cost for lighting is a result of measure costs being offset by relatively large non-energy benefits and avoided periodic replacements.

The high potential for heat pump water heaters, weatherization, and ductless heat pumps reflects the relatively high saturation of electric space heating and water heating end uses within BPA's service territory. For instance, approximately one-third of single-family homes in BPA's service territory use electricity for their primary heat source (either electric zonal heat or an electric furnace). A higher saturation of these homes results in higher weatherization and ductless heat pump potential than in utility service territories which have higher saturations of homes with a natural gas furnace.

Commercial Sector

The commercial sector accounts for approximately 30% of achievable technical conservation potential, and most of these savings come from lighting, data center, and HVAC measures. Compared to the residential sector measures, the high-saving commercial measures are relatively low cost. Interior lighting represents the highest saving measures, and costs range from below $0 per MWh to $343 per MWh. On average, commercial interior lighting measures cost approximately $19 per MWh. **Table 4** shows 20-year cumulative potential and levelized cost for the highest-saving commercial measures.

Table 4. Top Five Commercial Measures

Measure Category	Cumulative 20-Year Achievable Technical Potential (aMW)	TRC Levelized Cost ($/MWh)		
		Weighted Average	Minimum	Maximum
Interior Lighting Package	99	$19	-$58	$343
Embedded Data Center Upgrades	65	$6	$3	$11
Exterior Building Lighting	49	$8	-$39	$111
Advanced Rooftop Controller	48	$19	$7	$49
Variable Refrigerant Flow	33	$41	$28	$75

Industrial Sector

The industrial sector's achievable technical potential is 243 aMW, which accounts for approximately 13% of total energy conservation potential is BPA's service area. As **Table 5** shows five measures account for nearly two-thirds of the industrial sector's total achievable technical potential. Industrial measures are generally low cost, with the five highest-saving measures costing between approximately $0 per MWh and $23 per MWh. Considerable savings are expected to be available from energy management measures, such as energy management and integrated plant energy management. Other high-saving measures include pumps and fans for industrial processes, as well as refrigerated food storage improvements.

Table 5. Top Five Industrial Measures

Measure Category	Cumulative 20-Year Achievable Technical Potential (aMW)	TRC Levelized Cost ($/MWh)		
		Weighted Average	Minimum	Maximum
Energy Project Management	37	$23	$23	$23
Pumps	36	$8	-$8	$22
Integrated Plant Energy Management	33	-$1	-$1	-$1
Refrigerated Food Storage	28	$12	$4	$9,999
Fans	25	$13	$7	$19

Agricultural Sector

Savings potential in the agricultural sector are expected to be relatively small, representing about 2% (39 aMW) of the total identified potential. **Table 6** illustrates the five highest-savings agricultural measures, much of which comes from irrigation system efficiency improvements, including upgrades to the hardware, water pressure regulation, and system efficiency. A small amount of potential is also expected from outdoor lighting upgrades.

Table 6. Top Five Agricultural Measures

Measure Category	Cumulative 20-Year Achievable Technical Potential (aMW)	TRC Levelized Cost ($/MWh)		
		Weighted Average	Minimum	Maximum
Irrigation Hardware	20	$11	$1	$160
Irrigation Pressure	9	$17	$4	$89
Irrigation Efficiency	7	$6	$6	$6
Lighting	3	$23	$10	$46
Irrigation Motor	1	$19	$16	$22

Utility Sector (Distribution Efficiency)

The results of this study indicate 67 aMW of achievable technical potential in the utility sector from distribution efficiency improvements. These improvements include volt-var optimization, phase load balancing, and feeder load balancing using various voltage control methods. Overall, this potential represents nearly 4% of the total conservation potential in BPA's service territory.

Organization of this Report

This report is organized into the following sections:

The *Methodology* section provides an overview of the Cadmus Team's methodology for estimating achievable technical potential, describes key components, and identifies various data sources.

The *Detailed Results* section summarizes forecasts of energy conservation potential for each sector, discusses key drivers for the potential, shows the distribution of savings by end use, and presents the highest-saving measures.

Methodology

This section describes the Cadmus Team's methodology for estimating conservation potential in BPA's service territory between 2020 and 2039, and for developing supply curves for modeling conservation in BPA's Resource Program. We describe the calculations for technical and achievable technical potential, identify the data sources for components of these calculations, and discuss key global assumptions. Estimating conservation potential involves analyzing many conservation measures across many sectors, with each measure requiring nuanced analysis. While this section does not describe the detailed approach for estimating a specific measure's unit energy savings (UES) or cost, it shows the general calculations that were used for nearly all measures.

The methods and models used in this study are based on those used by the Council to develop the *Seventh Power Plan*. For this study, the Cadmus Team developed conservation potential supply curve workbooks that replicate the calculations used for the *Seventh Power Plan*, incorporating market data (such as saturations, applicability, and sector loads) and planning assumptions (financial assumptions and ramp rates) specific to BPA's service area. To provide the Resource Program with up-to-date estimates of conservation potential, the Cadmus Team incorporated the changes that have taken place since the completion of the *Seventh Power Plan* into our approach, including updates to baselines for *Seventh Power Plan* measures, changes to RTF-approved measures, new standards, and BPA's load forecast.

Definitions of Potential

The Cadmus Team assessed two types of potential—technical and achievable technical—described below. BPA will determine the achievable economic potential (also defined below) through the Resource Program's optimization modeling.

- ***Technical potential*** assumes that all technically feasible resource opportunities may be captured, regardless of their costs or other market barriers. It represents the total conservation potential in BPA's service territory, after accounting for purely technical constraints.
- ***Achievable technical potential*** is the portion of technical potential that is assumed to be achievable during the study's 20-year forecast, regardless of the acquisition mechanism. (For example, savings may be acquired through utility programs, improved codes and standards, and market transformation).
- ***Achievable economic potential*** is the portion of achievable technical portion determined to be cost-effective by the Resource Program optimization modeling, in which either bundles or individual conservation potential measures are selected based on cost and savings. The cumulative potential for these selected bundles constitutes achievable economic potential.

The Cadmus Team provided BPA with forecasts of technical and achievable technical potential, which were then input into the Resource Program's Optimization Model to determine economic potential. **Figure 7** illustrates the three types of potential.

Figure 7. Types of Conservation Potential

The timing of resource availability is also a key consideration in determining conservation potential. There are two distinct categories of resources:

- ***Discretionary resources*** are retrofit opportunities in existing facilities that, theoretically, are available at any point over the study period. Discretionary resources are also referred to as retrofit measures. Examples include weatherization and shell upgrades, economizer optimization, and low-flow showerheads.
- ***Lost-opportunity resources*** such as conservation opportunities in new construction and replacements of equipment upon failure (natural replacement) are non-discretionary. These resources become available according to economic and technical factors beyond a program administrator's control. Examples of natural replacement measures include HVAC equipment, water heaters, appliances, and replace-on-burnout lighting fixtures.

Consistent with the Council's methodology, the Cadmus Team used a units-based approach to forecast conservation potential in the residential, commercial, and agricultural sectors. This approach involved first estimating the number of units of an energy conservation measure that are likely to be installed in each year, then multiplying unit forecasts by the measure's UES. For the industrial and distribution efficiency sectors, the Cadmus Team used a top-down method (also consistent with the Council's methodology). In the industrial sector, technical potential is calculated as a percent reduction to the baseline industrial forecast. Baseline end use loads are first estimated for each industrial segment, then potential is calculated using estimates of each measures' end use percent savings. For the distribution efficiency sector, savings were estimated as a percentage of the total utility load.

Steps for Estimating Conservation Potential

The Cadmus Team followed this series of steps, outlined in detail below the list, to estimate conservation potential:

***Market Segmentation**:* This involved identifying the regions, sectors, and segments for estimating conservation potential. Segmentation accounts for variation across different parts of BPA's service territory, and across different applications of some energy conservation measures.

Develop Efficiency Measure Data Sets: This required research into viable energy conservation measures that can be installed in each segment. The corresponding section below for this step includes the components and data sources for estimating measure savings, costs, applicability factors, lifetimes, and baseline assumptions, as well as the treatment of federal standards.

Develop Unit Forecasts: Unit forecasts vary by sector—number of homes for residential, square footage of floor space for commercial, energy for industrial, acres or cows for agriculture, poles for street lighting, and load for distribution efficiency—and reflect the number of units that could be installed for each measure. The Cadmus Team developed sector-specific methodologies to determine the number of units.

Calculate Levelized Costs: Resource Program modeling requires levelized costs for each measure, and in aggregate, to compare energy conservation to supply-side resources. The Cadmus Team used ProCost to produce TRC levelized costs. The components and assumptions for the levelized cost calculations are discussed in the Calculate Levelized Costs section.

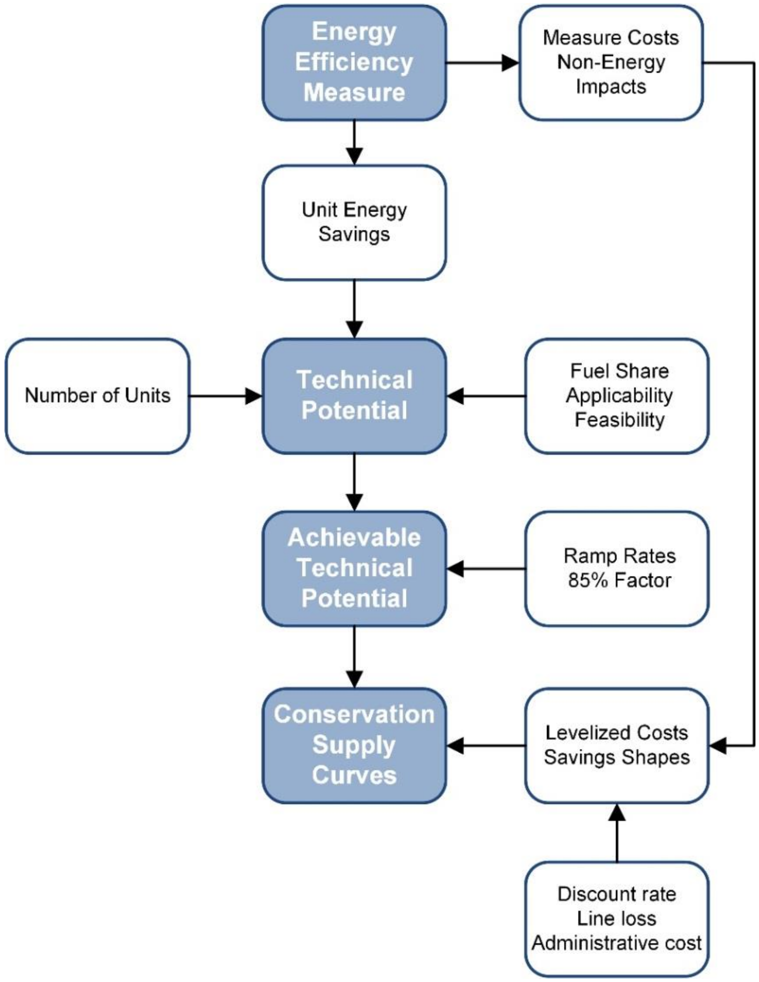
Forecast Technical Potential: Technical potential forecasts rely on the sector-specific unit forecasts and the measure data compiled from prior steps. This section presents the general equation we used for calculating technical potential.

Forecast Achievable Technical Potential: Achievable technical potential forecasts use a similar equation as we used to determine technical potential forecasts, with additional terms, described in this section, to account for market barriers and ramping.

Develop Resource Program Inputs: Forecasts of achievable technical potential were bundled by levelized costs and by other measure characteristics, so BPA's Resource Program modelers could compare conservation equally to other supply-side and demand-side resources.

Figure 8 provides a general overview of the process and inputs required to estimate potential and develop conservation supply curves.

Figure 8. Overview of Methodology



1- Market Segmentation

Market segmentation involves first dividing BPA's service territory into regions, sectors, and market segments. Careful segmentation accounts for variation in building characteristics and savings across BPA's service territory, which spans over 150 utilities and four states. To the extent possible, conservation measure inputs reflect primary data, such as the Northwest Energy Efficiency Alliance's 2014 *Commercial Building Stock Assessment* (CBSA) and 2018 RBSA. However, the analysis of these data sets showed that there was an insufficient sample to produce robust BPA-specific estimates for the commercial sector. Therefore, the regional sample from the 2014 CBSA to inform the commercial analysis. In the residential sector, sample sizes were large-enough to produce statistically representative and BPA-specific estimates for each residential segment.

Considering the benefits and drawbacks of different segmentation approaches, the Cadmus Team identified three parameters that produce meaningful and robust estimates:

Region*:* Residential versus commercial measures, urban versus rural, with a breakout by climate zone for weather-sensitive measures. The urban and rural segmentation did not apply to the industrial, agriculture, and utility (distribution efficiency) sectors.

Sector*:* Residential, commercial, industrial, agriculture, street lighting, and utility (distribution efficiency).

Industries and Building Types*:* Four residential, 18 commercial, 19 industrial, three agricultural, one utility, and one street lighting segment.

The designated sectors, segments, and climate zones are consistent with those used in the *Seventh Power Plan*. The Team only used the urban and rural parameter, which was not a part of the *Seventh Power Plan*, to produce different sector-level unit forecasts and inputs into measures' UES and applicability calculations. We did not re-estimate costs and lifetimes for different urban and rural strata. The regions, sectors, and segments are discussed in more detail below.

Regions

The breakout of BPA's service territory into regions reflected the different climate zones (by heating and cooling zones) as well as differences in urban and rural areas. For weather-sensitive measures, three cooling and three heating zones were considered, which are consistent with RTF definitions. **Table 7** lists combinations for heating and cooling zones and shows the assumed heating degree days and cooling degree days for each combination.

Table 7. Climate Zones

Climate Zone	Heating Degree Days	Cooling Degree Days
Heating 1 - Cooling 1	<6,000	<300
Heating 1 - Cooling 2	<6,000	>300-899
Heating 1 - Cooling 3	<6,000	>900
Heating 2 - Cooling 1	6,000-7,499	<300
Heating 2 - Cooling 2	6,000-7,499	>300-899
Heating 2 - Cooling 3	6,000-7,499	>900
Heating 3 - Cooling 1	>7,500	<300
Heating 3 - Cooling 2	>7,500	>300-899
Heating 3 - Cooling 3	>7,500	>900

The Cadmus Team developed separate unit forecasts for urban and rural areas in the residential and commercial sectors. Using the U.S. Department of Agriculture Economic Research Service's *Rural-Urban Continuum Codes* (USDA ERS RUCC), which classifies zip codes into one of nine rural or urban categories, we disaggregated BPA's service territory into rural and urban subgroups. The Northwest Energy Efficiency Alliance's 2014 CBSA also relied on the USDA ERS RUCC for urban and rural strata. Like with the CBSA, the Cadmus Team classified zip codes with a USDA ERS RUCC of two or less as urban and of three or greater as rural.

Sectors and Segments

Table 8 shows the segments in each sector. Sectors and segments were aligned with those in the *Seventh Power Plan*.

Table 8. Industries and Building Types by Sector

Market Sector	Building Characteristics	
Residential	Single family	Multifamily low rise
	Multifamily high rise	Manufactured
Commercial (by gross floor square footage, if applicable)	Large office (>50,000)	Warehouse
	Medium office (5,000 to 50,000)	Supermarket (>5,000)
	Small office (<5,000)	Minimart (<5,000)
	Extra-large retail (>100,000)	Restaurant
	Large retail (50,000 to 100,000)	Lodging
	Medium retail (5,000 to 50,000)	Hospital
	Small retail (<5,000)	Residential care
	School K-12	Assembly
	University	Other
Industrial	Mechanical pulp	Hi tech – chip fab
	Kraft pulp	Hi tech – silicon
	Paper	Metal fab
	Foundries	Transportation, equipment
	Frozen food	Refinery
	Other food	Cold storage
	Wood – lumber	Fruit storage
	Wood – panel	Chemical
	Wood – other	Misc. manufacturing
	Sugar	
Agricultural[a]	Irrigation	
	Area lights	
	Dairy	
Utility	Distribution efficiency	

[a] This assessment did not include conservation measures for cannabis cultivation or other indoor agriculture measures.

2- Develop Energy Efficiency Measure Data Sets

Overview and Components

The Cadmus Team compiled energy efficiency data sets that include the UES, costs, measure lives, non-energy impacts, and applicability factors for each energy conservation measure. Specifically, these data sets include several details for each measure permutation:

Unit energy savings. UES are a conservation measure's annual per-unit kilowatt-hour savings. The UES from the Council's *Seventh Power Plan* supply curve workbooks and RTF measure workbooks were used. For measures where regional values are inputs into the derivation of UES values, updated calculations with BPA-specific data were applied.

Costs and non-energy impacts. Costs include the incremental per-unit equipment (capital), labor, annual O&M, and periodic (or avoided periodic) re-installation costs associated with installing an energy efficiency measure. Non-energy impacts are the annual dollar savings per year associated with quantifiable non-energy benefits (such as water). We relied on cost data from the *Seventh Power Plan* or RTF workbooks.

Effective useful lives. EUL is the expected lifetime (in years) for an energy efficiency measure from the *Seventh Power Plan* or RTF.

Applicability factors. Applicability factors reflect the percentage of installations that are technically feasible and the current saturation of an efficiency measure. Where possible for residential measures, we calculated new BPA-specific applicability factors using the RBSA for each measure to ensure that unit forecasts reflect the characteristics of BPA's service territory.

End-use savings percentage (industrial only). The industrial sector's top-down approach to estimating potential requires assessments of the end-use percentage savings for each energy conservation measure. We relied on estimates included in the Council's *Seventh Power Plan* industrial tool for these values.

Savings shape. The Team assigned an hourly savings shape to each measure, which we then used to disaggregate annual forecasts of potential into hourly estimates.

Table 9 summarizes each component listed above and identifies the main sources.

Table 9. Conservation Measure Components and Sources

Component	Sources
Unit Energy Savings	*Seventh Power Plan* and RTF, adjusted with BPA-specific primary data
Costs and non-energy impacts	*Seventh Power Plan* and RTF
Effective useful lives	*Seventh Power Plan* and RTF
Applicability factors	2012 and 2017 RBSA; 2014 CBSA; BPA and utility program data (where available)
End-use savings percentage	*Seventh Power Plan*
Savings shape	*Seventh Power Plan*

Considerations for Compiling Measure Data

Use of Regional Stock Assessment Data

In the commercial and residential sectors, the Cadmus Team relied on the 2014 CBSA and the 2012 and 2017 RBSAs, respectively, to produce BPA-specific applicability factors and, for some measures, UES estimates. Sample sizes for a BPA-specific subset of CBSA data were relatively small, at 251 BPA-specific CBSA sites (of nearly 1,400 sites in the region). Sample sizes for individual building types ranged from 20 to 40 (depending on the building type). Given the small sample sizes, the Cadmus Team only used BPA-specific CBSA details to estimate heating and cooling end use and fuel saturations. For other inputs derived from the CBSA, we used regional estimates.

In the residential sector, the Cadmus Team used draft 2017 RBSA data for single-family homes and 2012 RBSA data for multifamily and manufactured homes. Multifamily and manufactured home data from the 2017 RBSA was not yet available for this study. For the single-family and manufactured segments, the Cadmus Team developed BPA-specific estimates for the urban and rural regional segments; however, there was an insufficient sample of rural multifamily homes to allow the Team to develop separate estimates for urban and rural regions. RBSA informed several inputs, including:

- End-use saturations (such as the average number of refrigerators, freezers, or clothes washers)
- Fuel saturations (percentage of homes or units with electric space heat, electric water heat, and electric cooking)
- Baseline insulation levels
- Heating and cooling saturations by climate zone

Changes to *Seventh Power Plan* Baselines

The Cadmus Team made several adjustments to account for this study's start year (2020), which included incorporating new RTF analysis, BPA's program accomplishments through 2019, and several new standards:

- ***RTF analysis.*** The Cadmus Team incorporated the latest RTF analysis as of September 2017. For many measures, RTF updates used new market data and equipment standards.
- ***BPA's program accomplishments.*** The Cadmus Team used measure-level data compiled from the regional conservation progress data sets to estimate annual savings for each measure from BPA utilities for 2016 and 2017. Program saving estimates from the BPA EE Action Plan were used to estimate program accomplishments for 2018 and 2019. These savings were subtracted out, at a measure category level, from an initial forecast of potential that assumed no program accomplishments between 2016 and 2020.
- ***Equipment standards.*** The Cadmus Team incorporated equipment standards either enacted or adopted after December 2014 (the cutoff for the *Seventh Power Plan*). For most affected measures, this involved either removing the measure from analysis or updating the baseline to reflect the new minimum efficiency.

Accounting Standards

The Cadmus Team accounted for building energy codes and equipment standards in a way that was generally consistent with the Council's treatment in the *Seventh Power Plan*, where for most measures the impact of codes and standards are embedded in UES estimates. However, the Cadmus Team changed either UES estimates or applicability for measures affected by standards adopted since the December 2014 cut off for the Seventh Plan. **Table 10** lists the standards the Cadmus Team considered and each standard's effective date. Most of these standards have either already been adopted or are scheduled to go into effect before this study's 2020 start date. Thus, equipment that meets the specifications of each respective standard were not included in estimates of energy conservation potential. Generally, accounting for these standards reduced the total conservation potential.

Table 10. Standards Considered

Equipment Electric Type	New Standard	Sectors Impacted	Study Effective Date
Clothes Washer (top loading)	Federal standard 2015	Residential	March 7, 2015
Clothes Washer (front loading)	Federal standard 2018	Residential	January 1, 2018
Clothes Washer (commercial sized)	1. Federal standard 2013 2. Federal standard 2018	Nonresidential	1. January 8, 2013 2. January 1, 2018
Dehumidifier	1. Federal standard 2012 2. Federal standard 2019	Residential	1. October 1, 2012 2. June 13, 2019
Dishwasher	Federal standard 2013	Residential	May 30, 2013
Dryer	Federal standard 2015	Residential	January 1, 2015
External Power Supplies	1. Federal standard 2016 2. Federal standard 2017	Nonresidential/Residential	1. February 10, 2016 2. July 1, 2017
Freezer	Federal standard 2014	Residential	September 15, 2014
Microwave	Federal standard 2016	Residential	June 17, 2016
Refrigerator	Federal standard 2014	Residential	September 15, 2014
Automatic Commercial Ice Makers	1. Federal standard 2010 2. Federal standard 2018	Nonresidential	1. January 1, 2010 2. January 28, 2018
Commercial Refrigeration Equipment (semi-vertical and vertical cases)	1. Federal standard 2010 2. Federal standard 2012 3. Federal standard 2017	Nonresidential	1. January 1, 2010 2. January 1, 2012 3. March 27, 2017
Vending Machine	1. Federal standard 2012 2. Federal standard 2019	Nonresidential	1. August 31, 2012 2. January 8, 2019
Walk-in Cooler Walk-in Freezer	1. Federal standard 2014 2. Federal standard 2017	Nonresidential	1. August 4, 2014 2. June 5, 2017
Central Air Conditioner	Federal standard 2015 (no change for Northern region)	Residential	January 1, 2015
Heat Pump (air source)	Federal standard 2015	Residential	January 1, 2015
Packaged Terminal Air Conditioner and Heat Pump	1. Federal standard 2012 2. Federal standard 2017	Nonresidential	1. October 8, 2012 2. January 1, 2017
Room Air Conditioner	Federal standard 2014	Residential	June 1, 2014
Single Package Vertical Air Conditioner and Heat Pump	1. Federal standard 2010 (phased in over six years) 2. Federal standard 2019	Nonresidential	1. January 1, 2010 2. September 23, 2019
Small, Large, and Very Large Commercial Package Air Conditioner and Heat Pump	1. Federal standard 2010 2. Federal standard 2018 3. Federal standard 2023	Nonresidential	1. January 1, 2010 2. January 1, 2018 3. January 1, 2023

Equipment Electric Type	New Standard	Sectors Impacted	Study Effective Date
Fluorescent Lamp Ballast	Federal standard 2014	Nonresidential	November 14, 2014
General Service Fluorescent Lamp	1. Federal standard 2012 2. Federal standard 2018	Nonresidential	1. July 14, 2012 2. January 26, 2018
Lighting General Service and Specialty Lamp (EISA backstop provision)	Federal standard 2020	Nonresidential/Residential	October 1, 2021[a]
Lighting General Service Lamp (EISA)	Federal standard 2014 (phased in over three years)	Nonresidential/Residential	January 1, 2014
Metal Halide Lamp Fixture	Federal standard 2017	Nonresidential	February 10, 2017
Electric Motor (small)	Federal standard 2015	Nonresidential	March 9, 2015
Electric Motor	1. Federal standard 2010 2. Federal standard 2016	Nonresidential	1. December 19, 2010 2. June 1, 2016
Furnace Fan	Federal standard 2019	Residential	July 3, 2019
Pump	Federal standard 2020	Nonresidential	January 27, 2020
Pre-Rinse Spray Valve	Federal standard 2019	Nonresidential	January 28, 2019
Water Heater > 55 Gallons	Federal standard 2015	Nonresidential/Residential	April 16, 2015
Water Heater ≤ 55 Gallons	Federal standard 2015	Nonresidential/Residential	April 16, 2015

[a] The lighting standards are currently under review, with an expected date of fall 2021.

3- Develop Unit Forecasts

General Approach

The Cadmus Team developed a 24-year forecast (2016 through 2039) of the number of units that could feasibly be installed for each permutation of each energy efficiency measure researched in the previous step.[4] Separate unit forecasts were developed for two types of lost opportunity measures (natural replacement and new construction) and one type of discretionary measures (retrofit):

- ***Natural replacement (lost opportunity) measures*** are installed when the equipment it replaces reaches the end of its EUL. Examples include appliances, such as clothes washers and refrigerators, and HVAC equipment, such as heat pumps and chillers.
- ***New construction (lost opportunity) measures*** are applied to homes and buildings that will be constructed over the study forecast. The unit forecast for new construction is driven by anticipated new home and new commercial construction, which we derived from utility customer forecasts and regional *Seventh Power Plan* forecasts.
- ***Retrofit (discretionary)*** measures encompass upgrades to existing equipment or buildings, and which can theoretically be completed any time over the study forecast. Unlike natural replacement measures, the timing of retrofit savings is not determined by turnover rates. Examples of retrofit measures include weatherization and controls.

[4] We started unit forecasts in 2016 to include 2016 data provided by BPA utilities and to apply growth rates derived from *Seventh Power Plan* forecasts (which also start in 2016).

To determine measure-specific unit forecasts, used to estimate technical potential, four factors were considered:

- ***Sector unit forecasts*** are estimates of the number of homes (residential) or square footage of floor space (commercial) derived from BPA's utility data and BPA's load forecasts.

Measure saturations (units per sector unit) are estimates of the number of units per sector unit (per home or per square foot) within BPA's service territory. Where possible, the Cadmus Team calculated these using data from the CBSA and RBSA.

- ***Applicability factors (technical feasibility percentage and measure competition share)*** are the percentage of homes or buildings that can feasibly receive the measure and the percentage of eligible installations, after accounting for competition with similar measures.
- ***Turnover rates (for natural replacement measures)*** are used to determine the percentage of units that can be installed in each year for natural replacement measures. The turnover rate equals 1 divided by the measure EUL.

Figure 9 illustrates the general equation we used to determine the number of units for each measure over the study forecast horizon. By default, the turnover rate for retrofit and new construction measures is 100% (turnover is not accounted for in these permutations).

Figure 9. Unit Forecast Equation

Sector Units × Saturation × Applicability Factor × Turnover Rate = Measure Units

To determine unit forecasts, the Cadmus Team relied on data that represents BPA's service territory, as shown in **Table 11**. The sections following the table describe the Team's approach for developing unit forecasts in each sector.

Table 11. Unit Forecast Components and Data Sources

Component	Data Source	Specific to BPA's Service Territory?
Sector Units	BPA and U.S. Energy Information Administration (EIA) 861 data; U.S. Census Bureau American Community Survey; Regional stock assessments; BPA utility customer data (when available)	Yes
Saturation	BPA load forecasts; regional stock assessments; BPA utility customer data (when available)	Yes
Applicability Factor	Regional stock assessments; BPA utility customer data (where available)	Yes
Turnover Rate	*Seventh Power Plan* supply curve workbooks	No; turnover rate is a function of measure life, which was derived from RTF workbooks or secondary sources

Unit Forecasts in Each Sector

This section outlines the Cadmus Team's method for developing unit forecasts in each sector. Generally, each approach involved first calculating the units in 2016, then applying a growth rate derived from Council forecasts to produce values through 2039. Starting unit forecasts in 2016, and not 2020 (the first year of the Resource Program), allowed us to incorporate 2016 actuals into each forecast. Many of the forecasts relied on growth rates derived from *Seventh Power Plan* forecasts, which span 2016 through 2035. For all forecasts, we determined 2036 through 2039 estimates by applying an average growth rate calculated from the 2016 through 2035 forecasts.

Residential Sector

The residential unit forecast is an estimate of the number of residential housing units within BPA service territory. To create the residential unit forecast, the Cadmus Team began with EIA Form 861 data for 2015, which contains electric load and customer counts for each utility in the Northwest (specifically the states of Oregon, Washington, Idaho, and Montana). Where available, we compared the information from the EIA Form 861 data to residential load data provided directly to us by utilities within BPA's service territory and updated the EIA data if appropriate.

Based on the EIA Form 861 data, the Cadmus Team determined which utilities are investor-owned utilities (IOUs) and whether each utility is a BPA customer. Then, zip codes were mapped to each utility. For zip codes with more than one utility, we determined the percentage of the zip code that the utility represented.

The Team next retrieved household data by number of units, zip code, and state from the U.S. Census Bureau *American Community Survey* 2015 "Units in Structure" estimates. We assigned building types to the *American Community Survey* data according to the number of units in the structure: residences with four or fewer units are classified as single family, residences with five or more units are classified as multifamily, and mobile homes are classified as manufactured residences. These household data are mapped to the EIA Form 861 data by zip code and building type. Then the Cadmus Team multiplied these household counts by the zip code percentage for each utility within BPA territory and excluded IOUs to estimate the number of customers of non-IOU utilities within BPA service territory.

The Team then mapped rural and urban designations to each of the utility and county combinations using the 2013 USDA ERS RUCC. These rural and urban designations are available at the county level and were chosen to maintain consistency with the 2013 Commercial Building Stock Assessment, which also used 2013 USDA ERS RUCC data to distinguish between urban and rural areas.

After applying rural and urban designations, the Cadmus Team aggregated the zip code–level household estimates by state and population density (urban or rural). We then disaggregated multifamily households by state into estimates for multifamily high-rise and multifamily low-rise residences by applying state-specific distributions of these household types calculated from the Council's unit forecasts for the greater Northwest region.

This provided the baseline household count by state, building type, and population density for BPA service territory for 2015. The Cadmus Team next calculated annual growth rates from 2015 to 2035 using the Council's *Seventh Power Plan* residential unit forecasts and applied these growth rates to the 2015 BPA-specific housing unit estimate to create a BPA-specific household forecast for 2015 to 2035. We extrapolated the average growth rate from these years to the 2036 through 2039 period to estimate the number of residences by sector for the final four years. Finally, the Cadmus Team aggregated the state-level forecasts into two BPA-territory-wide forecasts by residential building type, one each for urban and rural.

Residential Sector Unit Forecast Data Sources

To determine the residential unit forecast, the Cadmus Team leveraged data from the following sources:

- U.S. EIA Form 861: 2015 data
- U.S. Census Bureau *American Community Survey* Table B25024 "Units in Structure," 2015
- USDA ERS RUCC
- 2016 load and customer forecast data from BPA customer utilities
- Growth rates by state and sector derived from the Council's *Seventh Power Plan* unit forecasts

Commercial Sector

The methodology to determine the commercial unit forecast is like that of the residential unit forecast, but the commercial forecast is an estimate of commercial square footage rather than number of structures. Like the residential unit forecast, the commercial forecast is based on EIA Form 861 data for the Northwestern United States. Where available, the Cadmus Team compared the information from EIA Form 861 to commercial load data provided directly to us by utilities within BPA's service territory and updated the EIA data if appropriate.

Based on the EIA Form 861 data, the Cadmus Team determined which utilities are IOUs and whether each utility operates within BPA's service territory. We then applied the zip code mapping created for the residential unit forecasts to the commercial EIA Form 861 data. For zip codes with more than one utility, we determined the percentage of the zip code that the utility represented.

Next, the Cadmus Team calculated the percentage of BPA-specific load by state by dividing total commercial load by state within BPA's service territory by total 2015 load by state for the commercial sector in the greater Northwest. We then applied USDA ERS RUCC codes and urban/rural designations to the list of BPA utilities and calculated the percentage of rural sales by state divided by total sales by state.

The Cadmus Team applied the proportions of BPA-specific sales by state and the proportions of rural sales by state to the Council's *Seventh Power Plan* Northwest 2015 commercial square footage estimates by building type to estimate 2015 sales by state and building type for BPA service territory. We next calculated annual growth rates from 2015 to 2035 using the Council's *Seventh Power Plan* commercial unit forecasts, then applied these growth rates to the 2015 BPA commercial square footage estimate to create a BPA-specific commercial square footage forecast for 2015 to 2035. We extrapolated the average growth rate from these years to the 2036 through 2039 period to estimate the square footage by sector for the final four years. Finally, we aggregated the state-level forecasts into two BPA-territory-wide forecasts by commercial building type, one each for urban and rural.

Commercial Sector Unit Forecast Data Sources

To determine the commercial unit forecast, the Cadmus Team leveraged data from the following sources:

- U.S. EIA Form 861: 2015 data
- USDA ERS RUCC
- 2016 load and customer forecast data from BPA customer utilities
- Growth rates by state and sector derived from the Council's *Seventh Power Plan* unit forecasts

Industrial Sector

Industrial potential is based on estimates of load in each industrial segment (such as wood products, pulp and paper, and cold storage). As such, the industrial unit forecast is simply the forecasted load. This level of detail is not readily available for BPA's service territory, so the Team scaled the Council's industrial sector forecast by BPA's share of industrial load in each state.

The Cadmus Team used 2015 industrial sales by utility as reported to the EIA to identify BPA's share of industrial loads in each state. While there is some discrepancy between what is included in industrial sales reported to the EIA and the industrial sector loads considered in this analysis, this approach was found to be the best method for allocating industrial sector loads between BPA and non-BPA utilities. The Team made four adjustments to the EIA data:

- Removed direct service industrial loads from BPA's load
- Removed new large single loads from individual utility loads, if those utilities included the new large single loads in their EIA-reported industrial sales[5]
- Reduced other loads to account for the closure of several large industrial plants
- Removed a portion of Northwestern Energy's load to count only the portion in western Montana

The Team applied the shares of BPA industrial load in each state to the Council's *Seventh Power Plan* industrial forecast for each state. The Council's load forecast was similarly adjusted to account for recent plant closures. Since the Council's *Seventh Power Plan* forecasts do not cover the full 20 years of this study, the Cadmus Team performed a linear extrapolation to extend the forecast to 2039.

Finally, the Team added BPA portions of each state's industrial load to form a region-wide industrial forecast for all BPA customers' territories.

[5] New Large Single Loads are defined by the NW Power Act as "*any load associated with a new facility, an existing facility, or an expansion of an existing facility which is not contracted for, or committed to, as determined by the Administrator, by a public body, cooperative, investor-own utility, or Federal agency customer prior to September 1, 1979, and which will result in an increase in power requirements of ten average megawatts or more in any consecutive twelve-month period." (NW Power Act, 839a(13))*

New Large Single Loads are not served by BPA's Preference power, therefore any conservation implemented at these sites would not impact BPA's Preference loads. Consumer-owned utilities serving new large single loads do so via power procured outside of their Long-Term Regional Dialogue power supply contracts with BPA.

Industrial Sector Unit Forecast Data Sources

To determine the industrial unit forecast, the Cadmus Team leveraged data from the following sources:

- U.S. EIA Form 861: 2015 industrial sales
- Share of Northwestern Energy in western Montana (data provided by the Council)
- 2015 new large single loads provided by BPA
- Plant closure data provided by utility, historical load data, and various news sources
- Recent industrial energy efficiency achievements and future projections (determined through analysis of the RTF's 2016 Regional Conservation Progress data file)
- *Seventh Power Plan* industrial load forecast

Agricultural Sector

In the *Seventh Power Plan*, the unit forecasts for the agricultural sector are largely based on data from the 2013 *Farm and Ranch Irrigation Survey*. This survey contains detailed information about irrigation, but only at the state level. To quantify a BPA unit forecast for agricultural measures, the Cadmus Team scaled the *Seventh Power Plan* agricultural forecasts, like how we scaled forecast for the industrial sector.

To scale the *Seventh Power Plan* forecast, the Cadmus Team used three data sets: one was a mapping of zip codes to counties and utility service territories, and the other two came from the 2007 Census of Agriculture, which included zip code–level detail on the numbers of farms and dairy operations. Zip code–level data was not available from any subsequent Census of Agriculture products. The Cadmus Team applied this zip code data to a utility mapping file to estimate a BPA share of farms and dairy operations by county. The most recent Census of Agriculture was published in 2012 and includes county-level data on irrigated land, numbers of farms, and dairy production. The Team combined this data with the previous files to determine county- and state-level estimates of BPA shares of statewide totals.

The Team applied statewide shares of irrigated land, numbers of farms, and dairy production to *Seventh Power Plan* forecasts based on the nature of the measure.

Agricultural Sector Unit Forecast Data Sources

To determine the agricultural unit forecast, the Cadmus Team leveraged data from the following sources:

- Utility/county/zip code mapping file
- 2007 Census of Agriculture (counts of farms and dairy operations by zip code)
- 2012 Census of Agriculture (counts of farms, irrigated acreage, and dairy production by county)
- *Seventh Power Plan* agricultural forecast

Street Lighting

Street lighting potential differs from other commercial measures in that it is quantified not by square footage, as with other commercial measures, but by the number of street lights, which is estimated based on population. Accordingly, the Cadmus Team used 2015 American Community Survey data together with the utility/county/zip code mapping file to estimate the 2015 population for each state's BPA service territory. The Team estimated the population for future years by applying *Seventh Power Plan* population growth rates for each state to the respective BPA population forecast.

Street Lighting Unit Forecast Data Sources

To determine the street lighting unit forecasts, the Cadmus Team leveraged data from the following sources:

- 2015 American Community Survey (population in BPA service territory)
- *Seventh Power Plan* population forecast (state-level population growth rates)
- *Seventh Power Plan* workbook detail of completed measures

Distribution Efficiency

Savings for utility distribution system efficiency measures are quantified in terms of savings per unit of utility sales. Accordingly, the unit forecast for BPA is simply the forecast of BPA sales. The only adjustment the Cadmus Team made to the forecast was to extrapolate it an additional three years to cover the full years from 2020 through 2039.

Distribution Efficiency Unit Forecast Data Sources

To determine the distribution efficiency unit forecast, the Cadmus Team leveraged data from the following sources:

- BPA sales forecast
- *Seventh Power Plan* analysis of distribution efficiency potential (measure cost, savings, applicability)
- Recent energy efficiency achievements (determined through analysis of the RTF's 2016 Regional Conservation Progress data file)

4- Calculate Levelized Costs

For each permutation of each energy conservation measure, The Cadmus Team calculated a TRC levelized cost of energy ($/kWh). Determining the levelized cost for each measure allows for bundling conservation into supply curves for BPA's Resource Program modeling. To ensure consistency with the *Seventh Power Plan* and RTF, the Team used the same components and software (ProCost version 3.0.47) to perform levelized cost calculations. **Table 12** shows the levelized cost components.

Table 12. Levelized Cost Components

Cost or Benefit	Component	Source/Value	Incorporated in CPA[a] Analysis or Resource Program?	TRC
Cost	Capital and Labor	Varies by measure; *Seventh Power Plan* and RTF	CPA	Yes
	Annual O&M	Varies by measure; *Seventh Power Plan* and RTF	CPA	Yes
	Program Administration	20% of incremental measure costs	CPA	Yes

Cost or Benefit	Component	Source/Value	Incorporated in CPA[a] Analysis or Resource Program?	TRC
	Periodic Replacement	Varies by measure; *Seventh Power Plan* and RTF	CPA	Yes
	Other Fuel Costs	Varies by measure; *Seventh Power Plan* and RTF	CPA	Yes
	Non-Energy Impacts	Varies by measure; *Seventh Power Plan* and RTF	CPA	Yes
Benefit	Avoided Energy Costs	BPA Resource Program modeling	Resource Program	Yes
	Avoided Carbon Costs	BPA Resource Program modeling	Resource Program	Yes
	Deferred Transmission and Distribution Expansion	BPA	CPA	Yes; includes Transmission rate as proxy for T&D value
	Regional Act Credit	10%	Resource Program	Yes
	Deferred Generation Capacity Investment	BPA Resource Program modeling	Resource Program	Yes
	Avoided Periodic Replacement	Varies by measure; *Seventh Power Plan*	CPA	Yes
	Other Fuel Benefits	Varies by measure; *Seventh Power Plan*	CPA	Yes
	Non-Energy Impacts	Varies by measure; *Seventh Power Plan*	CPA	Yes
	Risk Mitigation Credit	BPA Resource Program modeling	Resource Program	Yes

The Cadmus Team developed capital, labor, O&M, periodic replacement, other fuel costs and benefits, and non-energy impacts using *Seventh Power Plan* and RTF workbooks. Program administration costs are equal 20% of incremental costs.

The Cadmus Team aligned with the Council's approach by using ProCost to calculate levelized costs, which considers the costs required to sustain savings over a 20-year study and includes reinstallation costs for measures with an EUL under 20 years, beginning in 2020. For conservation resources with an EUL that extends beyond the end of the 20-year study, ProCost incorporates an end effect, treating the resource's levelized cost over its EUL as an annual reinstallation cost for the remainder of the 20-year period.[6]

For example, **Table 13** shows the timing of initial and reinstallation costs for a resource with an EUL of eight years in the context of a 20-year study. Because this table shows that a resource's lifetime ends after the study

[6] This method applies both to measures with an EUL greater than 20 years and to those with an EUL that extends beyond the twentieth year at the time of reinstallation.

horizon, the final four years (Year 17 through Year 20) are treated differently, with resource costs levelized over the resource's eight-year life and treated as annual reinstallation costs.

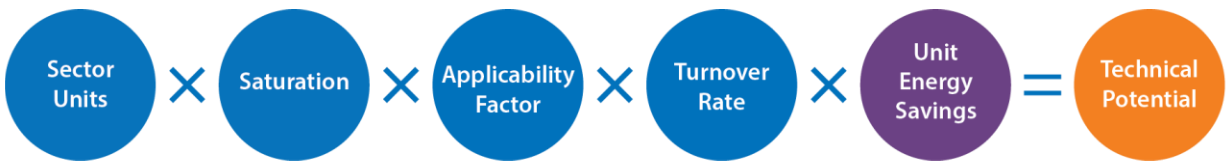
Table 13. Illustration of Capital and Reinstallation Cost Treatment

Component	Year																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Initial Capital Cost																				
Re-installation Cost																	***End Effect***			

5- Forecast Technical Potential

After compiling UES estimates and developing unit forecasts for each permutation of each energy efficiency measure, the Cadmus Team multiplied the two to create 20-year forecasts of technical potential beginning in 2020. **Figure 10** shows the equation for calculating technical potential—blue components make up the measure unit calculation (shown previously in **Figure 9**).

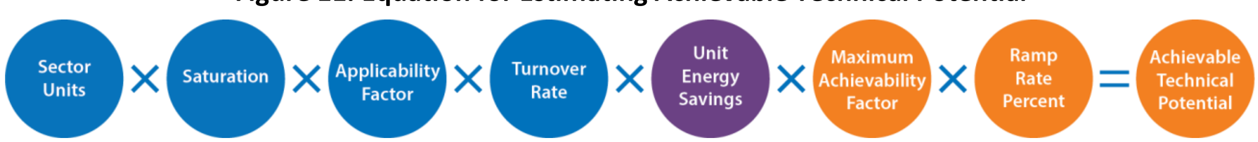
Figure 10. Technical Potential Equation



6- Forecast Achievable Technical Potential

Achievable technical potential equals the product of a unit forecast, the measure UES, the maximum achievability factor, and ramp rate factors (**Figure 11**). Blue components are a part of the measure unit calculation. The purple component is a part of the technical potential calculation. The blue, purple, and orange components make up the achievable potential calculation. See **Figure 9** and **Figure 10** for illustrations of the measure unit and technical potential calculations.

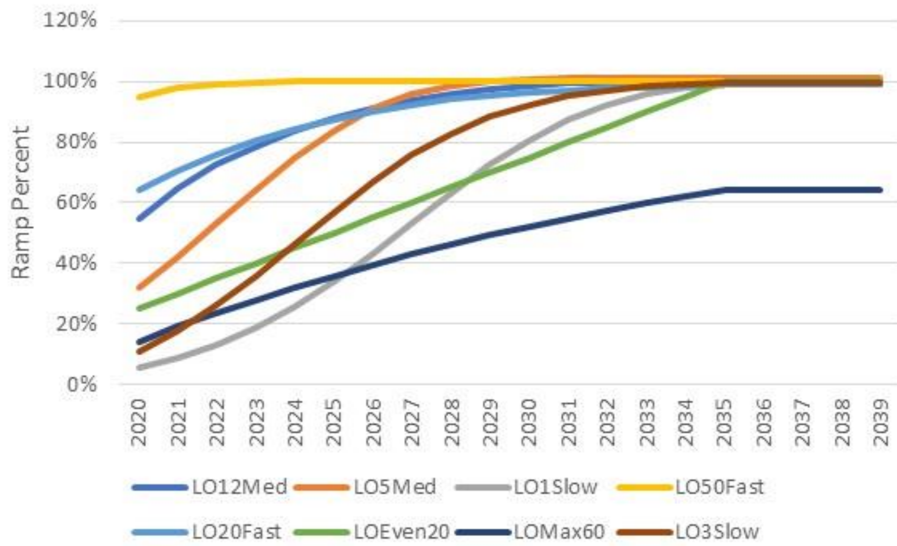
Figure 11. Equation for Estimating Achievable Technical Potential



As illustrated in Figure 11, achievable technical potential is the product of technical potential and both the maximum achievability factor and the ramp rate percentage. The Team used a maximum achievability factor of 85% for all measures. Ramp rates are measure specific, which we based on the ones developed for the *Seventh Power Plan*. However, we adjusted ramp rates to account for this study's 2020 to 2039 horizon.

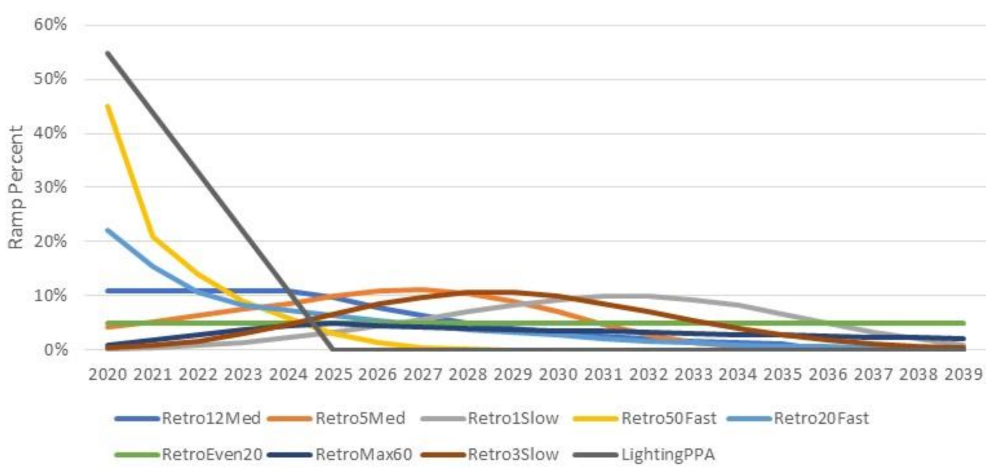
For lost opportunity measures, we used the same ramp rates as those used in the *Seventh Power Plan*. However, *Seventh Power Plan* ramp rates only cover the 2020 to 2035 period of our 2020 through 2039 study. Because nearly all lost opportunity ramp rates approach 100%, we set ramp values for 2036 to 2039 equal to the 2035 value from the *Seventh Power Plan*. Figure 12 illustrates the lost opportunity ramp rates.

Figure 12. Lost Opportunity Ramp Rates



For discretionary measures, the Cadmus Team used the same ramp rates as those used in the *Seventh Power Plan*. However, we shifted these ramp rates to start in 2020, instead of 2016, to ensure that discretionary ramp rates sum to 100% and that we excluded no feasible discretionary savings due to ramp rates. **Figure 13** shows the discretionary ramp rates.

Figure 13. Discretionary Ramp Rates



7- Develop Resource Program Inputs

The Cadmus Team developed conservation supply curves to allow BPA's resource optimization model to identify the cost-effective level of conservation. BPA's optimization model, AURORA, required weekly forecasts of conservation potential. To produce these forecasts, Cadmus first assigned hourly savings shapes to each measure. These savings shapes are the same as those used in the *Seventh Power Plan* and by the RTF (including generalized shapes that were expanded to hourly shapes).

The Cadmus Team and BPA then determined the format of the inputs into the resource optimization model, which involved bundling conservation potential forecasts by three categories:

- Levelized cost bin (such as measures that cost between $10 per MWh and $20 per MWh)
- Measure type (discretionary or lost opportunity)
- End-use group (such as HVAC, lighting, or water heating)

Once the Cadmus Team assigned savings shapes to each measure and defined Resource Program bundles, forecasts of annual achievable technical potential were disaggregated for each hour of the study horizon using each measure's respective savings shape, then were aggregated by the bundle groups described above (levelized cost, measure type, and end use group). This produced hourly forecasts of achievable potential for 2020 through 2039 for each combination of levelized cost bin, measure type, and end-use group. BPA then used these hourly results to produce the weekly conservation shapes required by the Resource Program. In total, this process produced ninety separate conservation bundles.

Detailed Results

Overview

This assessment included a comprehensive set of commercially available and vetted conservation measures characterized by the Council, Regional Technical Forum, and BPA. The Cadmus Team considered different measure applications within different sectors, market segments, and construction vintages. In total, the Cadmus Team analyzed 89 measure categories and over 2,700 measure applications. **Table 14** shows the number of measure categories and applications for each sector.

Table 14. Measure Categories and Applications by Sector

Sector	Measure Categories	Measure Applications
Residential	28	1,338
Commercial	36	1,218
Industrial	18	63
Agricultural	6	128
Utility	1	5
Total	89	2,752

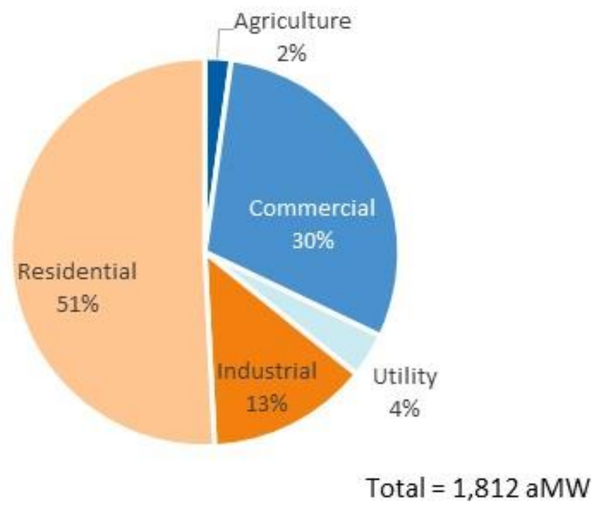
Table 15 illustrates 20-year cumulative achievable technical potential for each sector. In total, the Cadmus Team identified 1,812 aMW of cumulative achievable technical potential through 2039.

Table 15. Cumulative Achievable Technical Potential by Sector

Sector	20-Year (2020-2039) Cumulative Achievable Technical Potential - aMW
Agricultural	39
Commercial	542
Utility	67
Industrial	243
Residential	920
Total	1,812

The residential sector accounts for a little over one-half (51%) of the total achievable technical potential, followed by the commercial (30%), industrial (13%), utility (4%), and agricultural (2%) sectors. **Figure 14** illustrates the distribution of total technical achievable by sector.

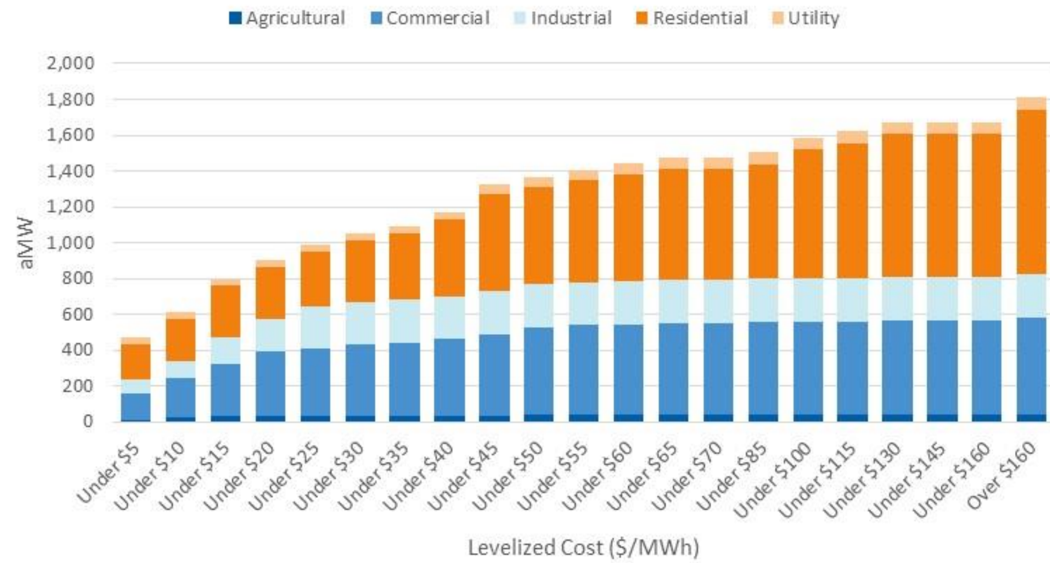
Figure 14. 20-Year Cumulative Achievable Technical Potential by Sector



The distribution of technical achievable potential by sector, however, varies at different cost-thresholds. Conservation potential in the commercial and industrial sectors is generally lower cost than in the residential sector. For instance, while the residential sector accounts for approximately one-half of the total technical achievable potential, for measures less than $50/MWh levelized, the residential sector only accounts for 41% of the total potential, while the commercial and industrial sectors account for 34% and 18%, respectively, of the total potential. For measures less than $20/MWh the residential sector only accounts for 32% of the total potential, while the commercial and industrial sectors account for 40% and 32%, respectively, of the total potential.

Generally, the residential sector has more savings from high-cost measures (examples include heat pump water heaters, weatherization, and ductless heat pumps). **Figure 15** shows 20-year cumulative achievable potential by levelized cost and sector.

Figure 15. Achievable Technical Potential Supply Curve by Sector



The Cadmus Team applied ramp rates from the 7th Power Plan, adjusted for this study's 2020 to 2039 horizon, to determine the incremental achievable technical potential in each year. For natural replacement measures, turnover rates also influence the amount of potential in each year. Incremental potential ramps from approximately 90 aMW in the first year (2020), reaching a peak of 148 aMW in 2027, and ramping down to 110 aMW by 2039. Average incremental savings over the twenty years is approximately 125 aMW per year; this estimate includes the reinstallation of energy conservation measures (which are excluded from the estimates of cumulative conservation potential discussed below). **Figure 16** shows incremental achievable technical potential by sector.

Figure 16. Incremental Achievable Technical Potential

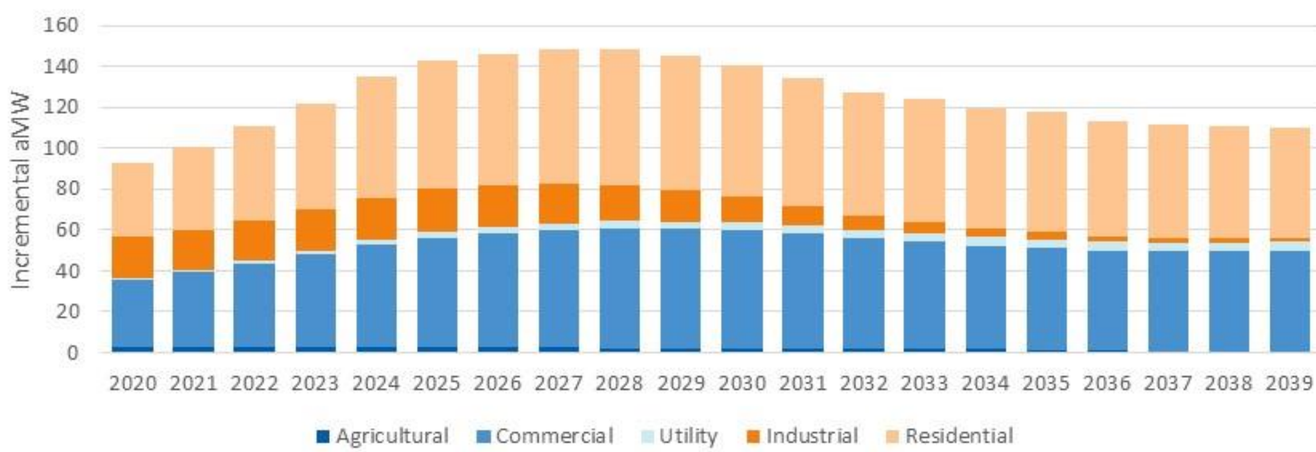


Figure 17 illustrates cumulative technical achievable potential in each year of the 2020 through 2039 study horizon. To avoid double-counting the cumulative impact on BPA's load, these estimates exclude the re-installation of energy conservation measures. In effect, once the measures are first installed, savings persist

through the remainder of the study horizon. While incremental savings are often used for program planning, because they allow planners to estimate the costs associated with energy conservation programs, cumulative savings are often used for resource planning, because it represents to the total expected reduction in load due to energy conservation. More savings occur within the first ten years of the study horizon (64% of 20-year cumulative), and savings ramp down in the last ten years.

Figure 17. Cumulative Achievable Technical Forecast Potential by Sector

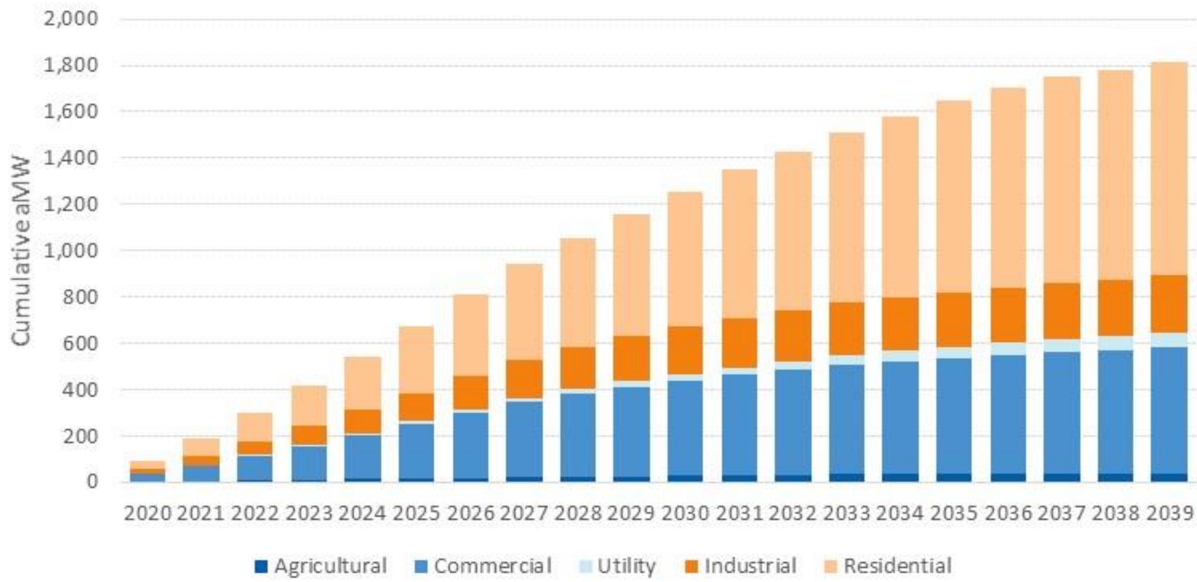
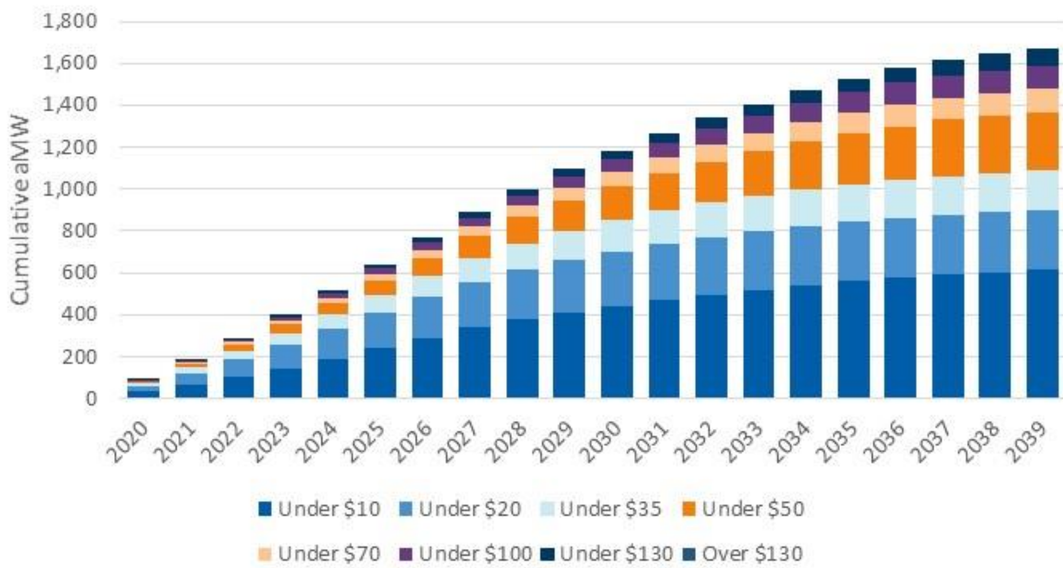


Figure 18 illustrates the distribution of cumulative potential by cost in each year of the study. Lower-cost measures account for a greater share of energy conservation potential in the early years, while higher-cost measures are ramped in the later years. For instance, in the first six years, measures under $20/MWh account for 60% of the total achievable technical potential, however, they only account for 50% by 2039. This is because lower-cost measures, such as lighting, face fewer market barriers to adoption. Many of these measures are already offered through well-established conservation programs, so savings can be acquired over a shorter period.

Figure 18. Cumulative Achievable Technical Potential by Cost Bundle



The following sections provide detailed conservation potential results for each sector. We discuss:

- The distribution of conservation potential by end use
- The total potential and cost for the highest-saving measures
- The sector-specific supply curve
- Factors the influence the potential and costs for the sector

Generally, we present 20-year cumulative achievable technical potential in each section, unless indicated otherwise. All values reflect savings at busbar.

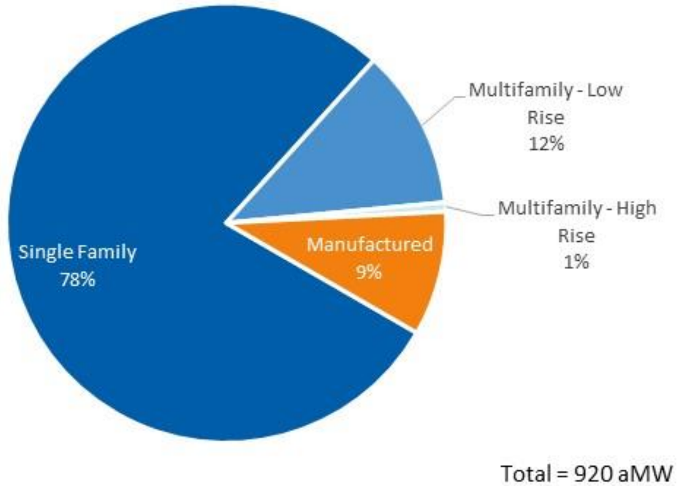
Residential

The Cadmus Team identified 920 aMW of achievable technical conservation potential in the residential sector, with most of this potential in the single-family segment (78% of total residential potential). **Table 16** and **Figure 19** illustrates the 20-year cumulative achievable technical potential for each residential segment.

Table 16. Residential Achievable Technical Potential by Segment

Segment	20-Year (2020-2039) Cumulative Achievable Technical Potential - aMW
Single Family	721
Multifamily - Low Rise	109
Manufactured	84
Multifamily - High Rise	6
Total	920

Figure 19. Residential Achievable Technical Potential by Segment



There is a strong correlation between the distribution of potential by residential segment and the distribution of households. Cadmus used U.S. Census Bureau American Community Survey data to determine the number of households for each residential segment (single family, multifamily high rise, multifamily low rise, and manufactured homes). This data indicates that single family homes account for approximately 74% of homes in BPA's service territory; single family homes account for a slightly higher share of achievable technical potential (78%). This is likely because energy consumption per home in single family homes is higher than the other building types, which produces greater potential savings.

The Cadmus Team analyzed energy conservation measures applied to nearly every end use in the residential sector. Water heating and HVAC end uses account for most of the achievable technical potential. Measures affecting water heating load include upgrades to efficient equipment (such as a heat pump water heater) and water-saving devices (such as aerators and showerheads). HVAC measures account for 39% of residential potential and water heating measures account for 37%.

Table 17 shows the 20-year cumulative achievable technical potential for each end use category in the residential sector. **Figure 20** shows the distribution by end use.

Table 17. Residential Achievable Technical Potential by End Use

End Use	20-Year (2020-2039) Cumulative Achievable Technical Potential - aMW
HVAC	359
Water Heating	342
Electronics	77
Lighting	62
Dryer	24
Refrigeration	23
Whole Building/Meter Level	21
Food Preparation	12
Total	920

Figure 20. Residential Achievable Technical Potential by End Use

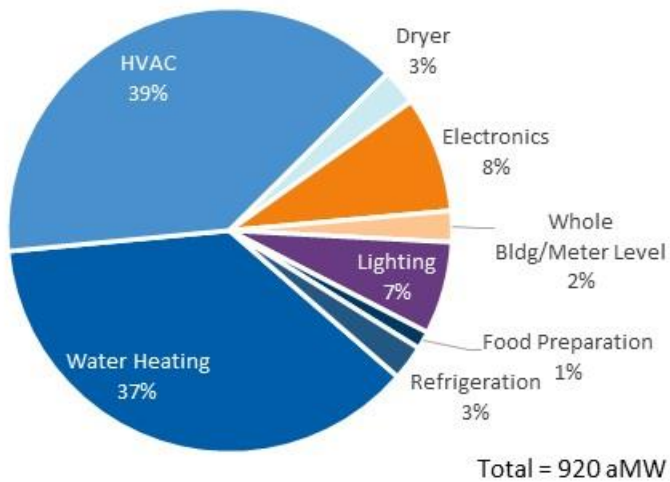
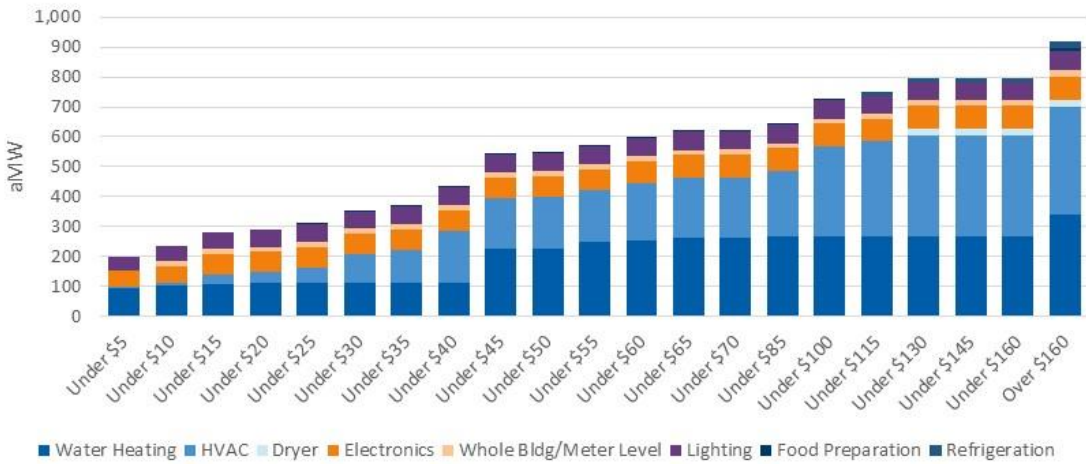


Figure 21 illustrates the residential supply curve—it shows the cumulative 20-year achievable technical potential at ascending levelized cost thresholds. Compared to the other sectors, residential potential is generally higher-cost. Approximately 59% of the residential potential comes from measures with levelized costs less than or equal to $50/MWh.

Figure 21. Residential Supply Curve



While HVAC and water heating measures account for 76% of the total residential potential, they account for a much lower share in the lower cost bundles. For instance, for measures under $25/MWh, HVAC and water heating measures only account for 53% of the residential potential; at this cost level, electronics and lighting account for a higher share of the potential.

Table 18 lists the twenty highest-saving residential measures; weighted average levelized costs, weighted by achievable technical potential, are indicated in parenthesis. Heat pump water heaters produce the highest potential in the residential sector, with 20-year cumulative savings of 255 aMW. The heat pump water heater measure category includes several applications, including Tier 1, Tier 2, Tier 3, and Tier 4 heat pump water heaters. Each of the applications have varying costs—on average heat pump water heater measures produce savings at a levelized cost of $107/MWh.

Table 18. Top-20 Residential Measures

Measure Category	Residential Cumulative 20-Year Achievable Technical Potential (aMW)
Heat Pump Water Heater ($107/MWh)	255
Weatherization ($57/MWh)	138
Ductless Heat Pump ($91/MWh)	79
Lighting (-$11/MWh)	60
Advanced Power Strips ($9/MWh)	63
ASHP ($273/MWh)	36.3
DHP Ducted ($30/MWh)	43
Showerheads (-$104/MWh)	22
Refrigerator ($136/MWh)	23
Clothes Dryer ($119/MWh)	24
Controls Commissioning and Sizing ($36/MWh)	23
Solar Water Heater ($466/MWh)	22
Clothes Washer ($18/MWh)	22

Behavior ($9/MWh)	18
Ground Source Heat Pump ($106/MWh)	14
Duct Sealing ($48/MWh)	13
Aerator (-$150/MWh)	14
Computer ($34/MWh)	12
Electric Oven ($281/MWh)	10
Heat Recovery Ventilation ($94/MWh)	10

Commercial

Table 19 and **Figure 22** illustrate commercial achievable technical potential by end use. Lighting measures, consisting of controls and equipment applied to both interior and exterior applications, account for 35% of the total identified achievable technical potential. Measures affecting HVAC end uses (primarily heating, cooling, and fans) account for 31% of the total achievable technical potential. These measures encompass both equipment replacement, equipment retrofits, and building retrofits (such as weatherization and shell upgrades). The electronics end use primarily accounts for measures installed in embedded data centers—this end use accounts for 20% of the total achievable technical potential in the commercial sector.

Table 19. Commercial Achievable Technical Potential by End Use

End Use	20-Year (2020-2039) Cumulative Achievable Technical Potential - aMW
Lighting	192
HVAC	170
Electronics	107
Refrigeration	23
Food Preparation	18
Process Loads	14
Motors/Drives	10
Compressed Air	5
Water Heating	3
Total	542

Figure 22. Commercial Achievable Technical Potential by End Use

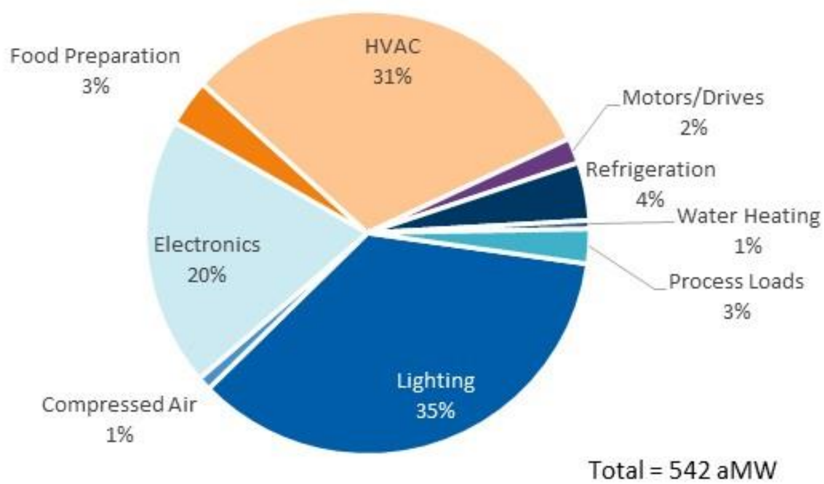


Figure 23 illustrates the commercial supply curve—it shows the cumulative 20-year achievable technical potential, by end use, at different levelized cost thresholds. Generally, commercial potential is lower cost than residential potential. Approximately 90% of the total commercial potential comes from measures with a levelized cost less than or equal to $50/MWh (compared to 53% in the residential sector). Lighting and electronics measures account for a larger share of low-cost savings, while HVAC measures account for a larger share of high-cost savings.

Figure 23. Commercial Supply Curve

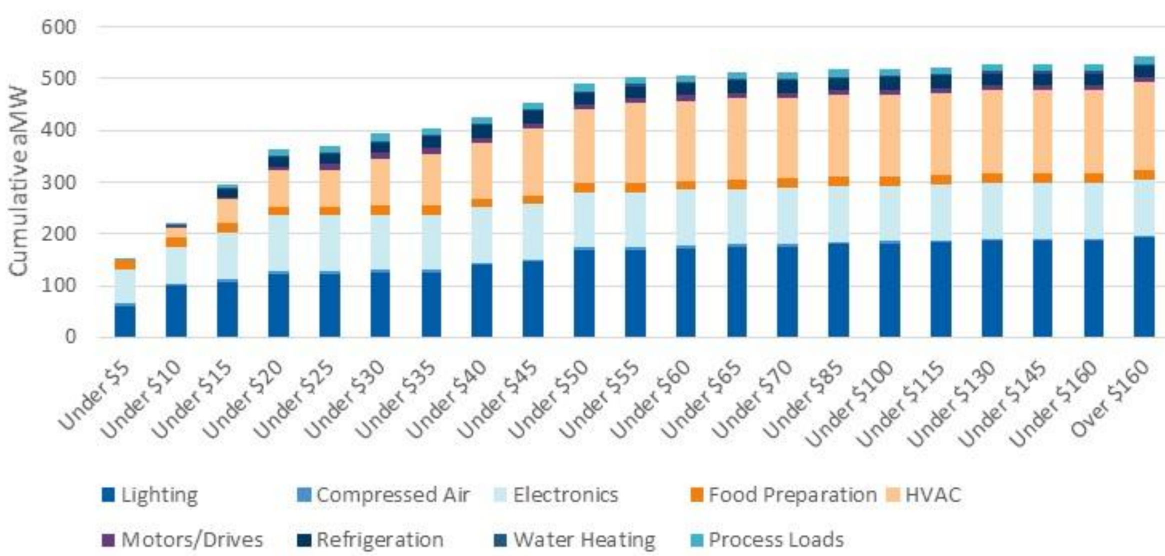


Table 20 shows twenty measure categories with the highest achievable technical potential. Weighted average levelized costs, weighted by achievable technical potential, are shown in parenthesis. The lighting interior package measure category is the highest-saving category; this category includes TLED replacements for fluorescent fixtures. Data centers measures includes upgrades to embedded data center operations, such as server virtualization, as well as upgrades in efficiency for the various HVAC equipment required to operate a data center. Data center estimates do not include enterprise data centers—they only include embedded data centers (primarily server rooms in existing commercial buildings).

Table 20. Top-20 Commercial Measures

Measure Category	Commercial Cumulative 20-Year Achievable Technical Potential (aMW)
Lighting Interior Package ($19/MWh)	99
Data Centers ($6/MWh)	65
Exterior Building Lighting ($8/MWh)	49
Advanced Rooftop Controller ($19/MWh)	48
Variable Refrigerant Flow ($41/MWh)	33
Ductless Heat Pump ($44/MWh)	24
Commercial EM ($12/MWh)	21
Grocery Refrigeration Bundle ($17/MWh)	19
Desktop (-$1/MWh)	17
Cooking Equipment (-$7/MWh)	18
Smart Plug Power Strips ($16/MWh)	16
Lighting Controls Interior ($143/MWh)	15
Secondary Glazing Systems ($141/MWh)	15
Low Power LF Lamps ($11/MWh)	10
Municipal Sewage Treatment ($16/MWh)	10
Demand Control Ventilation ($23/MWh)	10
ECM-VAV ($18/MWh)	9
Economizer ($24/MWh)	8
LEC Exit Sign (-$14/MWh)	8
Monitor (-$1/MWh)	7

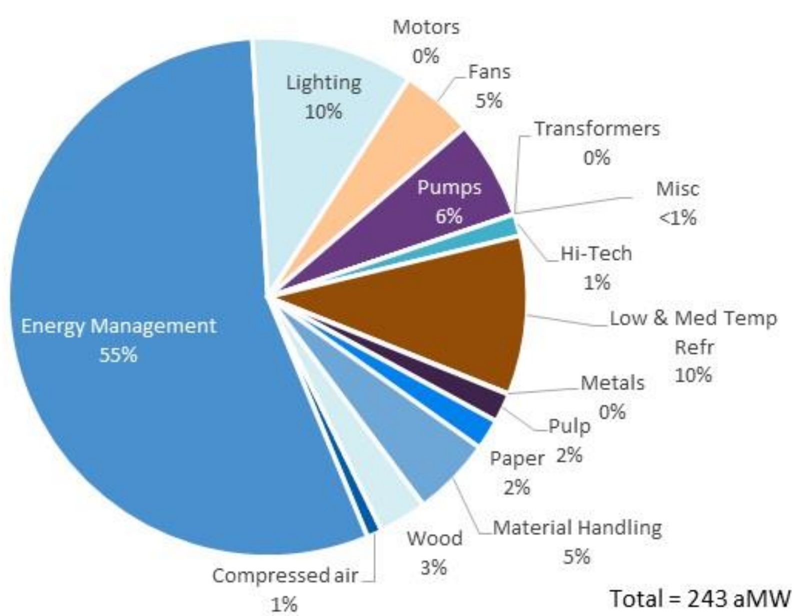
Industrial

Table 21 shows 20-year cumulative achievable technical potential for the industrial sector by end use. The energy management category, which includes whole-facility energy management as well as the management of specific end use systems, accounts for over one-half (55%) of the achievable technical potential in the industrial sector. **Figure 24** illustrates the distribution of achievable technical industrial potential by end use.

Table 21. Industrial Achievable Technical Potential by End Use

End Use	20-Year (2020-2039) Cumulative Achievable Technical Potential - aMW
Energy Management	134
Lighting	25
Low & Med Temp Refrigeration	24
Pumps	15
Material Handling	12
Fans	11
Wood	7
Paper	5
Pulp	4
Hi-Tech	3
Compressed air	2
Metals	<1
Motors	<1
Transformers	<1
Miscellaneous	<1
Total	243

Figure 24. Industrial Achievable Technical Potential by End Use



Industrial energy conservation potential is generally very low-cost. Nearly all the 20-year industrial achievable technical potential comes from measures with levelized costs below $25/MWh. **Figure 25** illustrates the industrial supply curve by end use.

Figure 25. Industrial Supply Curve

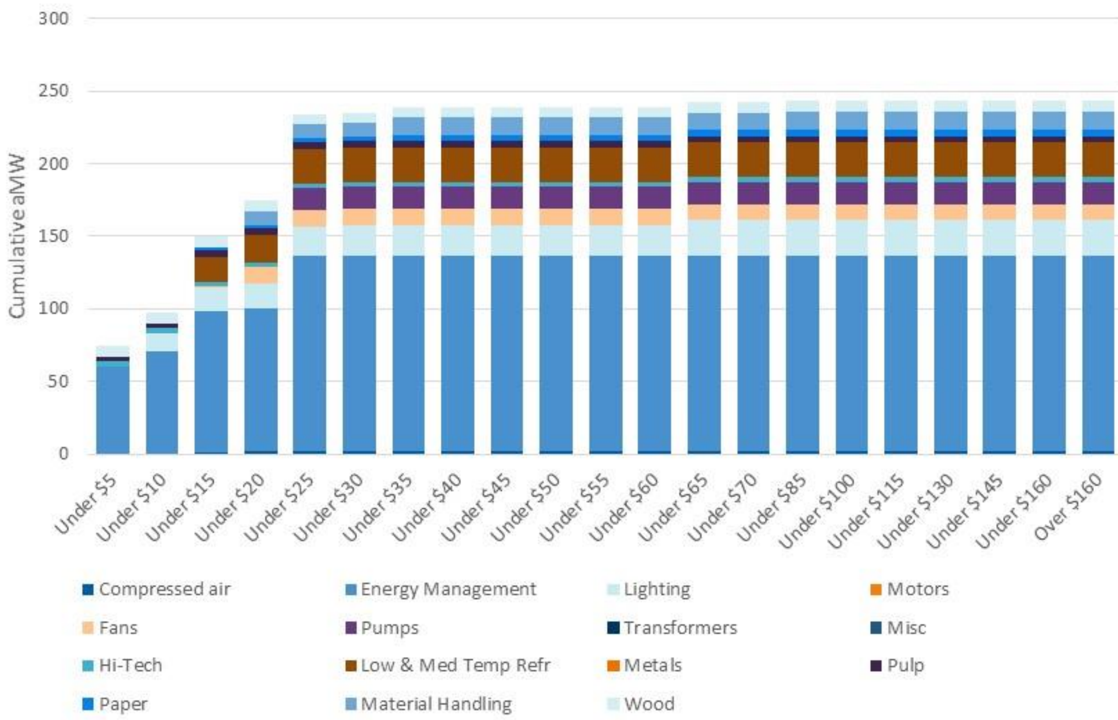


Table 22 illustrates the highest-saving industrial measures. We show the weighted average levelized cost for each measure, weighted by achievable technical potential, in parenthesis. Energy management collectively accounts for 55% of the industrial potential, and much of this savings comes from energy project management, integrated plant energy management, and plant energy management measures.

Table 22. Top Industrial Measures

Measure Category	Industrial Cumulative 20-Year Achievable Technical Potential (aMW)
Energy Project Management ($23/MWh)	37
Pumps ($8/MWh)	36
Integrated Plant Energy Management (-$1/MWh)	33
Food Storage ($12/MWh)	28
Fans ($13/MWh)	25
Lighting ($18/MWh)	25
Plant Energy Management ($14/MWh)	18
Material Handling ($22/MWh)	12
Wood (-$29/MWh)	7
Food Processing ($21/MWh)	5
Compressed Air ($9/MWh)	5
Paper ($26/MWh)	5
Pulp ($6/MWh)	4
Hi-Tech Process (-$14/MWh)	4

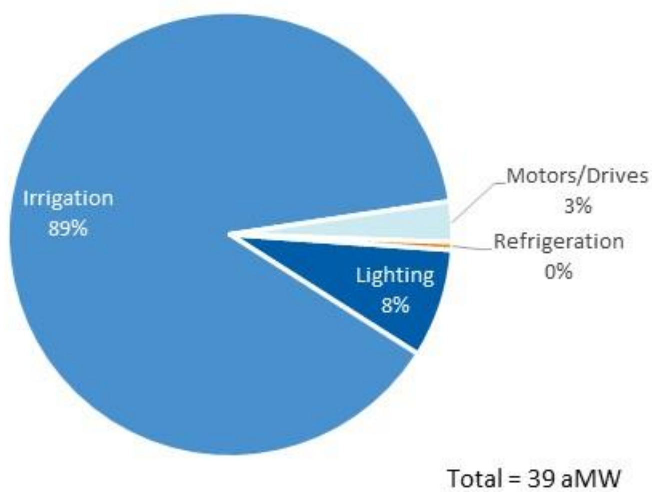
Agricultural

The Cadmus team considered energy efficiency measures in the agricultural sector, primarily for irrigation and dairy farms. Overall, we identified 39 aMW of achievable technical conservation potential through 2039. Most of these savings come from irrigation efficiency (89%). **Table 23** illustrates the 20-year cumulative achievable technical potential in the agricultural sector, by end use. **Figure 26** shows the distribution of agricultural potential by end use.

Table 23. Agricultural Achievable Technical Potential by End Use

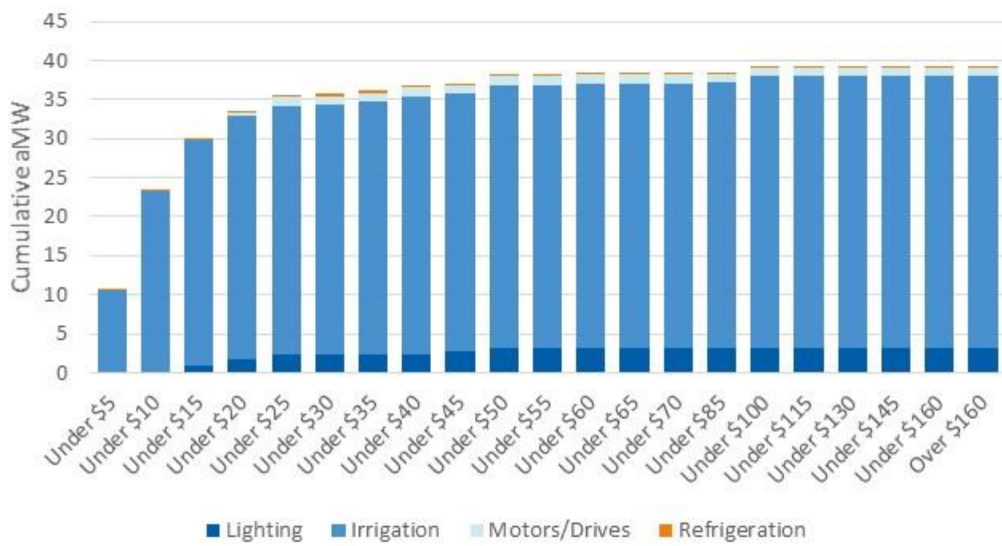
End Use	20-Year (2020-2039) Cumulative Achievable Technical Potential - aMW
Irrigation	35
Lighting	3
Motors/Drives	1
Refrigeration	0
Total	39

Figure 26. Agricultural Achievable Technical Potential by End Use



Agricultural measures are generally low-cost, with 90% of the sector's savings coming from measures with a levelized cost of $25/MWh or less. **Figure 27** illustrates the supply curve for the agricultural sector.

Figure 27. Agricultural Sector Supply Curve



Various irrigation improvements, including upgrades to hardware, reductions in system pressure, and water application efficiency, account for most of the achievable technical potential in the agricultural sector. **Table 24** shows the highest-saving agricultural measures—weighted average levelized costs, weighted by achievable technical potential, are shown in parenthesis.

Table 24. Top Agricultural Measures

Measure Category	Agricultural Cumulative 20-Year Achievable Technical Potential (aMW)
Irrigation Hardware ($11/MWh)	20
Irrigation Pressure ($17/MWh)	9
Irrigation Efficiency ($6/MWh)	7
Lighting ($23/MWh)	3
Irrigation Motor ($19/MWh)	1
Dairy ($2/MWh)	<1

Distribution Efficiency

The Cadmus Team characterized the achievable technical conservation potential for efficiency improvements to BPA's member utilities' distribution system. This includes various strategies for conservation voltage regulation (CVR) such as lowering the distribution voltage level using a line drop compensation method, phase load balancing, and lowering the distribution level using an end-of-line (EOL) voltage control method.

Overall, the Cadmus Team identified 67 aMW of cumulative achievable technical potential by 2039. **Table 25** shows the 20-year cumulative distribution efficiency potential, measure. Weighted average levelized costs, weighted by achievable technical potential are shown in parenthesis.

Table 25. Distribution Efficiency Potential

Measure Category	Cumulative 20-Year Achievable Technical Potential (aMW)
1 - LDC voltage control method ($1/MWh)	22
3 - Major system improvements ($42/MWh)	17
2 - Light system improvements ($3/MWh)	16
4 - EOL voltage control method ($84/MWh)	11

Distribution efficiency are gradually ramped over the study horizon. **Figure 28** shows the incremental 20-year distribution efficiency potential and **Figure 29** shows the cumulative distribution efficiency potential.

Figure 28. Incremental Distribution Efficiency Potential

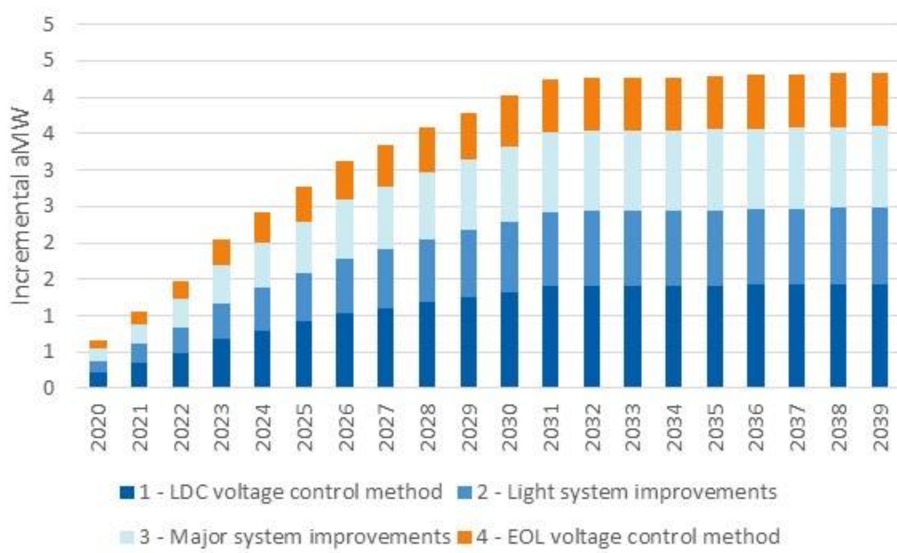


Figure 29. Cumulative Distribution Efficiency Potential