New Horizons for Energy Efficiency: Major Opportunities to Reach Higher Electricity Savings by 2030

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Executive Summary

INTRODUCTION

Improving the energy efficiency of our homes, industries, businesses, and institutions has long been recognized as a way to reduce energy costs and improve the environment. Utilities in many states have solid records of administering energy efficiency programs for their customers in order to reduce overall system costs and individual energy bills. These programs have contributed to the significantly reduced growth of electricity demand in recent years.

To date, many utilities and other program administrators have relied on a few measures, such as compact fluorescent lights (CFLs) and efficient fluorescent tubes and ballasts, for a large share of the savings from their energy efficiency programs. These measures are becoming common practice and will eventually become the market default as federal minimum efficiency standards for these products take full effect. Now program administrators are beginning to look for new, large savings opportunities to complement or replace these traditional measures in their program portfolios.

It should be noted that at the same time as programs are seeking large savings opportunities, the baseline energy efficiency against which savings are measured is increasing due to more stringent building codes and standards for lighting, appliances, and building equipment. Thus while total energy savings may continue to rise, the share of savings that utility programs can claim may be reduced. This will make large savings opportunities all the more attractive.

In meeting future energy savings targets, it is unlikely that program administrators will be able to rely on just one or two energy efficiency measures with the homerun savings potential of CFLs and other efficient fluorescent lights. Instead, analyses of energy efficiency potential suggest a future in which a larger set of measures contribute the majority of savings, not only through conventional program approaches and delivery channels, but also through new and innovative ones. In this report we examine and analyze a set of such promising measures for yielding significant energy savings.

RESEARCH OBJECTIVES

The objective of this research is to identify and profile a set of emerging but market-ready and cost-effective efficiency measures that could result in substantial future energy savings. For this project we define substantial savings as at least 1% of total annual electricity sales in 2030 from the cumulative impact of programs from 2015 to 2030. Note also that we use the term "measure" broadly—it includes individual end-use measures, system improvements (e.g., to HVAC or pump systems), and even entire buildings. Our study focuses on the measures we believe have the greatest potential to achieve substantial annual energy savings by 2030 based on our research and screening.

A secondary objective is to demonstrate the savings potential available through the combined impact of this set of selected measures. In this report we estimate savings potentials from each selected measure by the year 2030 and combine these savings to yield a rough estimate of overall savings potential.

METHODOLOGY

In the first phase of this research, we identified and screened a large set of energy efficiency measures not presently in widespread use that could each cost effectively reduce total annual electricity sales by 1% or more by 2030. We also included a few very promising measures whose savings potential, although difficult to estimate, amounted to at least 0.5%. Here is the full set of 18 measures that passed our screening and that we included in our analysis:

- High-efficiency residential appliances (refrigerators, clothes washers, and clothes dryers)
- Residential LEDs targeted at current incandescent applications
- Real-time feedback on energy use to promote customers' conservation behaviors
- Residential smart (learning) thermostats
- Advanced residential air conditioners and heat pumps
- Heat pump water heaters
- Comprehensive residential retrofits
- New construction programs targeting future model and state building codes
- Large reductions in key targeted plug loads (miscellaneous energy loads)
- Advanced commercial lighting design and controls
- Advanced commercial rooftop air-conditioning units
- Smart commercial buildings
- Comprehensive commercial retrofits
- Strategic energy management for large commercial and industrial customers
- Energy performance labels for commercial and industrial equipment
- Smart manufacturing
- Conservation voltage reduction
- Combined heat and power systems

For each of these measures this report describes the opportunity, estimates the savings available using national data, assesses cost effectiveness based on both current and estimated future costs, and describes program experience and lessons learned to date. Certain key variables, such as participation rates and measure costs, are very uncertain. In each profile we discuss key uncertainties for each measure and provide all data, assumptions, and equations used to estimate total savings to make these calculations transparent.

For each measure we calculate midrange, high, and low savings estimates, varying the participation rate and, on occasion, other variables. These are ballpark estimates and should be treated as approximate but as indicative of what we believe is possible. We assume that fairly aggressive program efforts can yield the participation rates used in our analyses.

The report focuses on electricity savings only. While many of the measures we examine would yield significant nonelectric (e.g., natural gas) energy savings, we did not estimate these saving or directly account for them in our cost-effectiveness calculations. In many cases the additional natural gas savings would increase cost effectiveness and the associated value to customers.

RESULTS

Our midrange estimated total savings for our selected set of measures is 22% of estimated electricity sales in 2030. Our low estimate is 15%, and our high estimate is 31%. As we expected from our initial screening, no single measure is capable of capturing a major share of future program savings within a full portfolio of programs, as has been the case with CFLs. Instead, the savings we estimate for each of the selected measures range from 0.5% to 3.4% of 2030 electricity sales. The median and mean are about 1%. Program portfolios will need to include a variety of program types targeting different end uses in order to reach high savings goals.

The top dozen measures in terms of 2030 energy savings in our midrange case are:

- Large reductions in key targeted plug loads (savings of 3.4% of projected 2030 US electric use)
- Conservation voltage reduction (2.1%)
- New construction programs (1.9%)
- Comprehensive commercial retrofits (1.7%)
- Smart manufacturing (1.6%)
- High-efficiency residential central air conditioners and heat pumps with quality installation (1.5%)
- Combined heat and power systems (1.3%)
- Replacing electric furnaces and strip heat with high-efficiency heat pumps (1.2%)
- Smart commercial buildings (1.2%)
- Residential LEDs targeted at current incandescent applications (1.1%)
- Advanced commercial lighting design and controls (1.3%)
- Residential retrofits (1.0%)

The measures we examined are generally very cost effective; most of them have a levelized cost-of-saved energy of 7.5 cents per kWh or less, based on a total resource cost perspective. Thus they would often be less expensive than building a new natural-gas-fired power plant. A few of the measures we examined have higher levelized costs based on current costs, which means that to begin with they may make sense only in high-cost regions and that initial efforts will need to target cost reductions.

RECOMMENDATIONS

Three overarching trends drive new and expanded opportunities for energy efficiency: technological innovation, systems solutions, and behavior change. Stakeholders should take multiple steps to realize these opportunities. For one thing, the regulatory frameworks that govern utility and related programs must change. As programs push the frontiers of new technologies and more comprehensive, systemic approaches to energy efficiency, regulators must establish frameworks and rules that support and reward these efforts. New approaches and metrics may be necessary for program evaluation. Utility business models and rate structures also may need to change to support high energy savings goals.

More particularly, we recommend the following actions and directions for utilities and energy efficiency program administrators:

- Research, catalyze, and complement markets.
- Support research, development, and demonstration of new and emerging energy-efficient technologies.
- Expand eligible options within programs to include new technologies as appropriate.
- Integrate and target behavioral change.
- Explore systems approaches.
- Launch pilot programs to test new program models and explore ways to improve measure cost effectiveness.

Finally, we recommend particular next steps for program administrators in each of the 18 areas included in the report.

Chapter 1. Overview of Methodology, Energy Savings, Costs, and Opportunities

Author: Dan York

INTRODUCTION

Improving the energy efficiency of our homes, industries, businesses, and institutions has long been recognized as a means to both reduce energy costs and improve the environment. Utilities in many states have lengthy records of administering energy efficiency programs for their customers as a way to reduce both overall system costs and individual customer energy costs (York et al. 2012). Such utility and related customer programs have grown rapidly since 2000—from $1.1 billion spent on programs in 2000 to $7.4 billion in 2013 (Gilleo et al. 2014). The impact of these programs is a significant factor in the much-reduced growth of electricity demand in recent years. Some leading states are achieving savings of 2% or more each year on total system electricity sales through energy efficiency programs. Even with these significant results already realized, a majority of states have policies in place that require such programs to continue to achieve high savings, termed energy efficiency resource standards (EERSs). Many of the state EERS policies set long-term savings goals (e.g., 10% savings or more by selected forward target years, such as 2020), while others require utilities to achieve the maximum amount of cost-effective savings available in each year (Downs and Cui 2014). Some states have aggressive energy efficiency targets. For example, Massachusetts seeks to achieve all cost-effective savings, and California seeks to double the energy efficiency of existing commercial buildings by 2030.

To date, many utilities and other energy efficiency program administrators have relied on a few measures, such as compact fluorescent lights (CFLs) and efficient fluorescent tubes and ballasts, for a large share of the savings from their energy efficiency programs. These measures are now becoming common practice and will eventually become the market default as federal minimum efficiency standards for these products take full effect. Program administrators are looking for new, large savings opportunities to complement or replace these traditional measures in their program portfolios. The search for new measures becomes particularly important for program administrators who are trying to increase the amount of savings achieved each year. For example, many programs may be working to meet 1.5% per year savings as a percentage of total sales as suggested in state-by-state targets in the US Environmental Protection Agency's (EPA's) draft rule to reduce carbon dioxide emissions from existing power plants (EPA 2014).

Rising baseline energy efficiency squeezes available additional energy savings. Programs can top federal minimum efficiency standards, which have become more stringent over time and affect a wide and expanding set of common household appliances and equipment.[1] More stringent building energy efficiency codes work the same way to increase the baseline energy efficiency of new construction (resulting in lower baseline energy use). The combined impact of higher efficiency standards and more stringent building codes is that

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[1] Standards for many such devices have been in place for many years and have increased periodically in upward steps. Other devices may have just recently become subject to standards or will be as such standards are developed and implemented by the US Department of Energy.

baseline energy efficiency has increased and will continue to increase. Utilities and related energy efficiency programs continually measure their energy savings and associated program cost effectiveness against this increasing baseline. Thus, while total energy savings continue to increase from all influences, the share of savings that utilities are able to capture through programs may be reduced.

Program administrators must identify technologies, end uses, and measures that can yield cost-effective energy savings from energy efficiency improvements above these rising baselines, while continuing to meet increasing targets. The nature of programs has always been to push the frontiers of energy efficiency upward and expand markets for energy-efficient products and services. Analyses of energy efficiency potential consistently have shown that there remain large savings opportunities through expanded application of a wide set of cost-effective energy-efficient technologies and related measures and practices that yield higher efficiency and lower energy use (Neubauer 2014). Another means to achieve higher savings is to increase program participation. Recent research by ACEEE on high participation shows that most types of programs have ample opportunities to expand and serve many more customers (York et al. 2015).

In meeting future energy savings targets, program administrators are unlikely to be able to rely on just one or two energy efficiency measures with the home run savings potential of CFLs and other efficient fluorescent lights. Instead, analyses of energy efficiency potential suggest a future in which perhaps a much larger set of measures contribute the majority of savings, not only through conventional program approaches and delivery channels, but also through new and innovative ones. Concomitant innovation in regulatory design and program evaluation will also be required, particularly to enable technologies for which conventional engineering calculations are often impractical, inaccurate, or cost ineffective except for the largest efficiency projects.

In this report we examine and analyze a set of such promising measures for yielding significant energy savings.

RESEARCH OBJECTIVES

The primary objective of this research is to identify and profile a set of emerging but market-ready and generally cost-effective efficiency measures that could result in substantial energy savings in the future. For this project we define "substantial" as estimated to save at least 1% of total annual electricity sales by 2030 from the cumulative impact of cost-effective programs from 2015–2030. Note that for simplicity we use the term "measure" broadly—it can encompass sets of individual end-use measures, system-wide improvements, and even entire buildings and retrofits that incorporate comprehensive energy efficiency improvements. The measures included in our study are those we believe have great potential based on our research and screening. We acknowledge, however, that there may be other energy efficiency measures with significant savings potential that we did not include.

We profile each selected energy efficiency measure, providing details of our analyses, data, and assumptions. The profiles also provide information to guide program administrators in developing or expanding their program portfolios to incorporate these new measures. Some of these measures are already in use by some program administrators, while others may be emerging technologies or practices that are just now being commercialized. Other measures may have been commercialized but too expensive to pass cost-effectiveness screening. The costs of many such technologies have decreased significantly recently and continue to decline. Consequently, such measures may now be—or may soon be—cost effective.

A secondary objective is to demonstrate the substantial additional savings potential available through the combined impact of this set of selected measures. In this report we estimate the savings potential from each selected measure by the year 2030 and combine these savings to yield a rough estimate of overall savings potential.

METHODOLOGY

The first phase of this research was to identify and screen a large set of energy efficiency measures not presently in widespread use that could each cost effectively reduce total electricity sales by 1% or more by 2030. We generated the initial set of measures to screen based on our previous research and experience. We also reviewed relevant literature and other published research. A research advisory committee provided additional input on this initial set of measures (advisory committee members are listed in the Acknowledgments at the beginning of this report). The resulting set includes some measures already being used in some energy efficiency programs, but generally at an early stage or on a limited scale.

Below is the set of measures that we screened and included in our analysis. We describe and discuss each of them in individual chapters following this overview. A few of these measures fell slightly below our initial screening threshold of 1%, but we included them if they offered potential energy savings of at least 0.5%. In these latter cases, the measures are very promising but are subject to greater uncertainty regarding possible future impacts. The full list of measures examined are

- High-efficiency residential appliances (refrigerators, clothes washers, and dryers)
- Residential LEDs targeted at current incandescent applications
- Real-time feedback on energy use to promote customers' conservation behaviors
- Residential smart (learning) thermostats
- Advanced residential air conditioners and heat pumps
- Heat pump water heaters
- Comprehensive residential retrofits
- New construction programs targeting future model and state building codes
- Large reductions in key targeted plug loads (miscellaneous energy loads)
- Advanced commercial lighting design and controls
- Advanced commercial rooftop air-conditioning units
- Smart commercial buildings
- Comprehensive commercial retrofits
- Strategic energy management for large commercial and industrial customers
- Energy performance labels for commercial and industrial equipment
- Smart manufacturing
- Conservation voltage reduction
- Combined heat and power systems

We screened additional measures but did not include them in this study because they did not meet our screening threshold, or because available data are too limited and uncertain at this time. These measures are

- Use of smart-meter data to estimate and reward achievement of actual savings
- Thermoelectric cooling
- Duct and air sealing
- Retrofit HVAC controls in commercial buildings for individual rooms
- 20% reduction of water use in public water supplies
- Improved data centers
- Improved set-top boxes
- Demand-controlled ventilation

The measures we identified and screened largely are defined according to end uses and broad customer classifications, such as advanced commercial building lighting design or residential appliances. Therefore, in some cases our measures may be incorporated into several different types of programs. For example, comprehensive residential retrofits may be provided by several initiatives—such as low-income weatherization, home performance, and multifamily programs—within an overall portfolio. We recognize that there is great potential for increased energy savings for certain programs that serve a particular subset of a larger customer class, such as multifamily buildings and small businesses. In these cases the program designs and approaches may need to change to reach more customers and achieve high savings. Certain types of customers face barriers that existing programs may not be addressing effectively. ACEEE's research on next-generation program designs (York et al. 2013) examines how programs are evolving to achieve high savings and serve customer segments that historically may not have been well served, such as multifamily and small business customers.

Each of the chapters in this report describes an opportunity, estimates the savings available using national data, assesses cost effectiveness based on both current and estimated future costs, and describes program experience and lessons learned to date. Projecting potential impacts 15 years ahead is inherently uncertain. Certain key variables, such as participation rates and measure costs, are particularly uncertain. In each profile we discuss key uncertainties for each measure, and to make our calculations transparent, we provide all data, assumptions, and equations used to estimate total savings.

Drawing together the chapter-by-chapter data on each measure, in this chapter we estimate total savings available in 2030 from all of the measures profiled, adjusting to eliminate estimated overlap and including estimates of achievable participation rates.

Our analysis takes a top-down approach, rather than the bottom-up approach usually performed for detailed energy efficiency potential studies. Such top-down analysis can provide a reasonable broad-brush view of what is possible, which is our objective. However there are limitations to this approach stemming from not using detailed data on specific markets and customer end uses.

Energy Savings and Cost-of-Saved-Energy Analyses

For each of the measures examined in this report, we estimated electricity savings and cost per kWh saved using a standardized approach. Some measures required slight variations or additions to this approach. In this section we discuss the methodology for these calculations.

Energy Savings

We generally used the following formula to calculate energy savings:

> Energy savings =
>
> Estimated 2030 US energy use for the covered end use(s) (from EIA 2014)
>
> X % of the end use attributable to the measure (based on specific estimates for each measure)
>
> X average % savings (also based on specific estimates for each measure)
>
> X participation rate (% of eligible customers who participate by 2030) (assumptions discussed below)
>
> X ratio of net savings to gross savings (unless otherwise noted, we assume 95%.)

We then took the resulting savings, in billion kWh, and divided by projected 2030 US electricity consumption (from EIA 2014) to estimate how much each measure could reduce total US 2030 electricity usage (end use) on a percentage basis.

Estimates from the Energy Information Administration (EIA) account for some improvements in energy efficiency in the economy. EIA's modeling uses energy intensity variables that reflect past trends and corresponding assumptions about future values, such as energy use per square foot in commercial office space. Detailed end-use data for individual technologies are generally not provided. Therefore, we could not determine the magnitude of savings possibly included in EIA projections from some of the efficiency improvements that will occur due to the measures we examine in this report. There could be some overlap between our savings estimates and what EIA has already included in its forecast. However we believe this impact is generally small because we are projecting relatively aggressive, expanded program efforts and associated customer participation rates.[2] To reach the savings we project would require greatly expanded and sustained investments in energy efficiency through utility and related programs, compared with past and current investment levels. The amount of possible overlap would be small relative to the savings we estimate could be achieved for each measure included in our analysis.

For each measure we calculated midrange, high, and low savings estimates, varying the participation rate and, on occasion, other variables. These estimates are essentially ballpark estimates and should be treated as very approximate, but indicative of what we believe is

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[2] The overlap may be significant for the residential and commercial LED lighting measures.

possible. We assume that fairly aggressive program efforts can yield the participation rates used in our analyses.

The key variable for these different scenarios—high, medium, and low—is the participation rate. We developed two standard sets of participation rates: one for measures that would ultimately be subject to building codes or equipment efficiency standards, and the other for most measures that do not lend themselves to codes or standards. Codes and standards generally lead to participation rates close to 100% in the long term, whereas without codes and standards, long-term participation is typically lower.[3] For each of these two cases, we generally estimated participation rates for medium-, high-, and low-participation scenarios as shown in table 1-1.

Table 1-1. Participation rate scenarios (%) with and without codes and standards (std)

	Medium		High		Low	
Year	w/o std	w/ std	w/o std	w/ std	w/o std	w/ std
2016	5	5	10	10	2.5	2.5
2017	10	10	20	20	5	5
2018	15	15	30	30	7.5	7.5
2019	20	20	40	40	10	10
2020	25	25	50	50	15	15
2021	30	30	60	75	20	20
2022	35	35	65	100	25	25
2023	40	40	65	100	30	30
2024	45	45	65	100	35	35
2025	50	50	65	100	40	40
2026	55	75	65	100	45	45
2027	60	100	65	100	50	50
2028	65	100	65	100	50	75
2029	65	100	65	100	50	100
2030	65	100	65	100	50	100
Average	39%	50%	53%	75%	29%	37%

The average rate for the entire period is what we use in our savings calculations. However, in a few cases, such as for whole-home and whole-building comprehensive retrofits, even the lowest of these figures is too high, and for these we developed program-specific estimates. For example, for whole-home retrofits participation ramps up to 15% by 2030 in our medium case, while for whole-building commercial retrofits we ramp up to 20% by 2030

[3] Code compliance may not reach 100% due to limitations on enforcement, but we factor this into our savings estimate for the new construction measure in our study.

(rationales for these figures are discussed in the individual measure chapters). We also used program-specific participation rates for residential LED lighting, strategic energy management, smart buildings, smart manufacturing, conservation voltage reduction, and combined heat and power systems.

More details on participation rates and other data used to estimate savings are given in the subsequent chapters. Each chapter provides detailed calculations so that readers may modify them as needed, for example by substituting local or regional data.

The focus of this report is electricity savings only. While many of the measures we examine would yield significant savings of nonelectric energy sources, such as natural gas, we did not estimate these savings or directly account for them in cost-effectiveness calculations. In many such cases the additional natural gas savings would increase the cost effectiveness and associated value to customers. Table 1-2 summarizes possible natural gas savings that would result from the set of measures we selected.

Table 1-2. Natural gas savings from selected measures

	Negligible	Modest	Significant
Residential appliances		x	
Residential LEDs	x		
Energy-use feedback and behavioral response			x
Residential smart thermostats			x
High-efficiency residential air conditioners and heat pumps		x	
Heat pump water heaters		x	
Residential retrofits			x
New construction programs			x
Large reductions in plug loads	x		
Advanced commercial lighting design and controls	x		
Advanced commercial rooftop units	x		
Smart commercial buildings			x
Comprehensive commercial retrofits			x
Commercial and industrial strategic energy management			x
Energy performance labels for commercial and industrial equipment	x		
Smart manufacturing			x
Conservation voltage reduction	x		
Combined heat and power			x

Cost of Saved Energy

The cost of saved energy (CSE) is the average cost per kWh saved over the lifetime of a measure. We calculated the CSE, in cents per kWh saved, by looking at the typical cost and kWh savings for each measure. For many measures the costs and savings vary based on the application. Our estimates are based on a common, typical application.

For costs we estimated current costs and what costs are likely to be in the longer term (e.g., in about the 2020–2025 period). Many measures save only electricity, but some measures save both electricity and other fuels. For the latter type of measure, we took a fraction of the total costs, where the fraction is the portion of source energy savings that are electric savings.

We calculated the CSE by taking the levelized annual cost of a measure over the estimated measure life and dividing by the annual kWh savings. We calculated the levelized annual cost using the PMT function in a spreadsheet to figure out the annual loan payment needed to fully amortize the investment with a loan term equal to the measure life and an interest rate equal to the discount rate (we used a 5% real discount rate). Since we had two cost estimates (current and long term), we also calculated two different costs of saved energy (current and long term).

As with the energy savings estimates, the cost of saved energy estimates are highly approximate. Our primary estimates are based on a total-resource cost (TRC) perspective because we include the total measure cost. Utility and related programs generally do not pay full measure costs as incentives for customers. Rather, they offer an increment of the cost, typically paid as a rebate. Using this incremental cost along with other program costs yields a cost of saved energy based on a utility cost perspective, which generally will be lower than if estimated from the total-resource cost perspective.[4] For example, if a program pays an incentive of half of the incremental cost of a measure and program administrative costs are 20% of incentive costs (illustrative numbers), then the cost of saved energy from the program administrator perspective is 60% of the cost of saved energy from the TRC perspective.

Quite a few states and utilities use the program administrator cost test (PACT). Therefore, we also calculated a set of very approximate costs for this test, again based on both current and long-term costs. To do this we added 10% to the total measure costs to reflect program marketing and various administrative costs, then applied ratios for the PACT to the TRC developed by Lawrence Berkeley National Laboratory from a review of the costs of hundreds of programs (Hoffman et al. 2015).

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[4] For more on cost-effectiveness tests, see NESP 2014. ACEEE supports the use of the utility cost test for screening and evaluating energy efficiency measures and programs, particularly in conjunction with utility resource planning. For this reason, ACEEE's research on cost of saved energy, such as Molina 2014, is based on a utility cost perspective. These results cannot be compared directly with results in this study, which are based on the TRC perspective.

RESULTS

Our research shows that indeed there are numerous measures available to energy efficiency program administrators that can yield significant energy savings. Table 1-3 summarizes our results for our midrange estimate, table 1-4 presents our high estimate, and table 1-5 presents our low estimate.

Our midrange estimated total savings for our selected set of measures is 22% of estimated total electricity sales in 2030. Our low estimate is 15% and our high estimate is 31%. These figures include an adjustment for overlap of savings among measures to avoid double counting. The adjustment value we used was a 2.3% decrease in total estimated savings in the medium case. See Appendix A for the details of our calculations.

As expected from our initial screening, there is no single measure capable of capturing a major share of future program savings within a full portfolio of programs, as has been the case with CFLs. Instead, the range of savings we estimate for each of the selected measures is from 0.5% to 3.4%. The median and mean are about 1%. Program portfolios will have to include a wide variety of program types targeting different end uses in order to reach aggregate savings to meet EERS or other high savings goals.

Table 1-3. Electricity savings in 2030, all measures, medium case

	Measure	End-use TWh	% covered	% savings	Participation rate	Net-to-gross ratio	Other adjustment	Total (TWh)	As % of 2030 TWh
2	Residential appliances, leverage standards							29	0.7%
	Refrigerator	113	100%	22%	50%	95%		12	
	Clothes washer	61	100%	25%	50%	95%		7	
	Clothes dryer	67	100%	30%	50%	95%		10	
3	Residential LEDs in current incandescent applications	144	62%	80%	85%	75%		46	1.1%
4	Real-time energy use feedback and behavioral response	1,526	100%	5%	50%	95%		36	0.8%
5	Residential smart thermostats	413	90%	12%	50%	95%		21	0.5%
6	Very high effic'y unitary air conditioners and heat pumps (HP)								
	(a) High effic'y AC with Quality Installation (QI)	313	87%	32%	50%	95%	110%	46	1.1%
	(b) High effic'y HP replacements for HP, with QI	341	28%	32%	50%	95%	110%	16	0.4%
	(c) High effic'y HP replacements for electric furnaces and strip heat, with QI	341	71%	70%	30%	95%	110%	53	1.2%
7	Heat pump water heaters and other advanced systems	147	80%	50%	50%	95%		28	0.6%
8	Residential retrofits	1,526	100%	20%	15%	95%		43	1.0%
9	New construction programs								
	Residential	1,526	11%	37%	38%	95%		21	0.5%
	Commercial	1,517	28%	40%	38%	95%		60	1.4%
10	Large reductions in key targeted plug loads	2,285	29%	47%	50%	95%		148	3.4%
11	Advanced commercial lighting design and controls	268	68%	65%	50%	95%		56	1.3%
12	Advanced commercial rooftop units	336	57%	58%	37%	95%		39	0.9%
13	Smart commercial buildings	1,517	50%	20%	35%	95%		50	1.2%
14	Comprehensive commercial retrofits	1,517	100%	25%	20%	95%		72	1.7%

	Measure	End-use TWh	% covered	% savings	Participation rate	Net-to-gross ratio	Other adjustment	Total (TWh)	As % of 2030 TWh
15	Strategic energy management for large facilities								
	Commercial	1,517	20%	8%	30%	95%		7	0.2%
	Industrial	1,270	50%	8%	50%	95%		24	0.6%
16	Energy performance labels for commercial and industrial equipment	1,451	50%	7.5%	39%	95%		20	0.5%
17	Smart manufacturing	1,270	80%	20%	35%	95%		68	1.6%
18	Conservation voltage reduction	4,526	100%	2.3%	90%	95%		89	2.1%
19	Combined heat and power systems	68	100%	included	90%	95%		58	1.3%
	Sum (includes overlap)								23.8%
								Max	3.4%
								Median	1.0%
								Mean	1.1%
								Min	0.5%
								Overlap adjustment	2.3%
								Adjusted total	21.5%

Table 1-4. Electricity savings in 2030, all measures, high case

	Measure	End-use TWh	% covered	% savings	Participation rate	Net-to-gross ratio	Other adjustment	Total (TWh)	As % of 2030 TWh
2	Residential appliances, leverage standards (RF, CW, CD)							49	1.1%
	Refrigerator	113	100%	22%	85%	95%		20	
	Clothes washer	61	100%	25%	85%	95%		12	
	Clothes dryer	67	100%	30%	85%	95%		16	
3	Residential LEDs in current incandescent applications	144	84%	80%	85%	75%		62	1.4%
4	Real-time energy use feedback and behavioral response	1,526	100%	8%	50%	95%		58	1.3%
5	Residential smart thermostats	413	90%	15%	50%	95%		26	0.6%
6	Very high effic'y unitary air conditioners and heat pumps								
	(a) High effic'y AC with QI	313	87%	32%	70%	95%	110%	64	1.5%
	(b) High effic'y HP replacements for HP, with QI	341	28%	32%	70%	95%	110%	22	0.5%
	(c) High effic'y HP replacements for electric furnaces and strip heat, with QI	341	71%	70%	40%	95%	110%	71	1.6%
7	Heat pump water heaters and other advanced systems	147	80%	50%	75%	95%		42	1.0%
8	Residential retrofits	1,526	100%	20%	20%	95%		58	1.3%
9	New construction programs								
	Residential	1,526	11%	37%	50%	95%		28	0.7%
	Commercial	1,517	27%	40%	50%	95%		80	1.9%
10	Large reductions in key targeted plug loads	2,285	29%	47%	75%	95%		222	5.1%
11	Advanced commercial lighting design and controls	268	68%	65%	75%	95%		84	2.0%
12	Advanced commercial rooftop units	336	57%	58%	50%	95%		53	1.2%
13	Smart commercial buildings	1,517	50%	30%	50%	95%		108	2.5%
14	Comprehensive commercial retrofits	1,517	100%	25%	30%	95%		108	2.5%

	Measure	End-use TWh	% covered	% savings	Participation rate	Net-to-gross ratio	Other adjustment	Total (TWh)	As % of 2030 TWh
15	Strategic energy management for large facilities								
	Commercial	1,517	20%	10%	50%	95%		14	0.3%
	Industrial	1,270	50%	10%	75%	95%		45	1.0%
16	Energy performance labels for commercial and industrial equipment	1,451	50%	7.5%	53%	95%		27	0.6%
17	Smart manufacturing	1,270	80%	20%	50%	95%		97	2.2%
18	Conservation voltage reduction	4,526	100%	2.9%	90%	95%		112	2.5%
19	Combined heat and power systems	68	100%	included	100%	95%		58	1. 5%
	Sum (includes overlap)								34.6%
								Max	5.1%
								Median	1.4%
								Mean	1.6%
								Min	0.5%
								Overlap adjustment	3.2%
								Adjusted total	31.4%

Table 1-5. Electricity savings in 2030, all measures, low case

	Measure	End-use TWh	% covered	% savings	Participation rate	Net-to-gross ratio	Other adjustment	Total (TWh)	As % of 2030 TWh
2	Residential appliances, leverage standards (RF, CW, CD)							29	0.7%
	Refrigerator	113	100%	22%	50%	95%		12	
	Clothes washer	61	100%	25%	50%	95%		7	
	Clothes dryer	67	100%	30%	50%	95%		10	
3	Residential LEDs in current incandescent applications	144	62%	80%	50%	75%		27	0.6%
4	Real-time energy use feedback and behavioral response	1,526	100%	3%	50%	95%		22	0.5%
5	Residential smart thermostats	413	90%	8%	50%	95%		14	0.3%
6	Very high effic'y unitary air conditioners and heat pumps								
	(a) High effic'y AC with QI	313	87%	32%	38%	95%	110%	35	0.8%
	(b) High effic'y HP replacements for HP, with QI	341	28%	32%	38%	95%	110%	12	0.3%
	(c) High effic'y HP replacements for electric furnaces and strip heat, with QI	341	71%	70%	23%	95%	110%	40	0.9%
7	Heat pump water heaters and other advanced systems	147	80%	50%	37%	95%		21	0.5%
8	Residential retrofits	1,526	100%	20%	10%	95%		29	0.7%
9	New construction programs								
	Residential	1,526	11%	37%	22%	95%		12	0.3%
	Commercial	1,517	27%	40%	22%	95%		35	0.8%
10	Large reductions in key targeted plug loads	2,285	29%	47%	37%	95%		110	2.6%
11	Advanced commercial lighting design and controls	268	68%	65%	38%	95%		42	1.0%
12	Advanced commercial rooftop units	336	57%	58%	25%	95%		26	0.6%
13	Smart commercial buildings	1,517	50%	15%	25%	95%		27	0.6%
14	Comprehensive commercial retrofits	1,517	100%	25%	10%	95%		36	0.8%

	Measure	End-use TWh	% covered	% savings	Participation rate	Net-to-gross ratio	Other adjustment	Total (TWh)	As % of 2030 TWh
15	Strategic energy management for large facilities								
	Commercial	1,517	20%	5%	23%	95%		3	0.1%
	Industrial	1,270	50%	5%	38%	95%		11	0.3%
16	Energy performance labels for commercial and industrial equipment	1,451	50%	7.5%	29%	95%		15	0.3%
17	Smart manufacturing	1,270	80%	20%	25%	95%		48	1.1%
18	Conservation voltage reduction	4,526	100%	1.8%	90%	95%		70	1.6%
19	Combined heat and power systems	68	100%	included	75%	95%		49	1.1%
	Sum (includes overlap)								16.5%
								Max	2.6%
								Median	0.6%
								Mean	0.7%
								Min	0.5%
								Overlap adjustment	1.2%
								Adjusted total	15.3%

Our estimates of the average cost of saved energy for the different measures we examined are summarized in table 1-6. Most of the measures examined have a TRC cost of 7.5 cents per kWh or less, and thus should often be less expensive than building a new natural-gas–fired power plant.[5] However a few of the energy efficiency measures we examined have higher TRC levelized costs based on current costs, which means that these measures may make sense at first only in high-cost regions and/or that initial efforts need to target cost reductions. Another option is to initially target some measures to high-use customers. For example, as is discussed in the heat pump water heater chapter, heat pump water heaters are more cost effective in households with three or more people. From the PACT perspective, most measures have levelized costs below 7.5 cents based on current costs and all are below 7.5 cents based on long-term costs.

[5] EIA estimates that a standard combined cycle power plant has a levelized cost of 7.5 cents per kWh (www.eia.gov/forecasts/aeo/electricity_generation.cfm). This does not include any avoided transmission and distribution costs.

Table 1-6. Cost of energy saved, all measures

			Incremental cost				Cost of saved energy: total resource cost			Cost of saved energy: program administrator cost	
	Measure	Energy savings (kWh)	Current	Long term	% of costs assigned to other benefits	Average measure life (years)	Current	Long term	Program administrator % of total costs	Current	Long term
2	Residential appliances										
	Refrigerators	82	$150	$75	0	15.4	$0.16	$0.09	58%	$0.10	$0.06
	Clothes washers	63	$100	$50	0.5	14.2	$0.08	$0.04	58%	$0.05	$0.03
	Clothes dryers	255	$450	$200	0	16	$0.16	$0.07	58%	$0.10	$0.04
3	Residential LED replacements for incandescents	23	$8	$3	0	25	$0.04	$0.01	58%	$0.03	$0.01
4	Real-time feedback and behavioral change	58	$250	$75	0	10	$0.11	$0.07	58%	$0.07	$0.04
5	Smart thermostats	485	$250	$150	0	10	$0.07	$0.04	58%	$0.04	$0.03
6	Advanced residential air conditioning										
	Residential AC, equipment + quality installation, hot climates	1,100	$958	$719	0	18	$0.07	$0.06	58%	$0.05	$0.04
	Residential AC, equipment + quality installation, rest of nation	474	$727	$545	0	18	$0.13	$0.10	58%	$0.08	$0.06
	High-efficiency HP replacements for HP, with QI	3,600	$997	$748	0	18	$0.02	$0.02	58%	$0.02	$0.01
	High-efficiency HP replacements for electric furnaces, with QI	3,600	$997	$748	0	18	$0.02	$0.02	58%	$0.02	$0.01

			Incremental cost				Cost of saved energy: total resource cost			Cost of saved energy: program administrator cost	
	Measure	Energy savings (kWh)	Current	Long term	% of costs assigned to other benefits	Average measure life (years)	Current	Long term	Program administrator % of total costs	Current	Long term
	Ductless minisplit replacements for electric strip heat in living space	3,629	$3,874	$2,906	0	18	$0.09	$0.07	58%	$0.06	$0.04
7	Heat pump water heaters	1,438	1,500	1,100	0	13	$0.11	$0.08	58%	$0.07	$0.05
8	Residential retrofits	2,627	7,000	6,000	0	15	$0.08	$0.07	58%	$0.05	$0.04
9	New construction										
	Residential	3,813	$6,000	$4,000	0	45	$0.07	$0.04	58%	$0.04	$0.03
	Commercial	6,084	$3.00	$2.00	0	45	$0.02	$0.02	58%	$0.02	$0.01
10	Large reductions from miscellaneous end loads										
	Computers	92	30	2	0	5	$0.08	$0.01	58%	$0.05	$0.00
	Televisions	114	81	41	0	10	$0.09	$0.05	58%	$0.06	$0.03
	Ceiling fans	128	700	140	80%	14	$0.11	$0.02	58%	$0.07	$0.01
	Average						$0.09	$0.02	58%	$0.06	$0.02
11	Commercial lighting	1.9	$2.00	$1.00	0	15	$0.10	$0.05	45%	$0.05	$0.03
12	Commercial rooftop air conditioners	6,357	$5,408	$4,101	0	15	$0.08	$0.06	45%	$0.04	$0.03
13	Smart buildings	656,000	$500,000	$375,000	50%	15	$0.04	$0.03	45%	$0.02	$0.01
14	Comprehensive commercial retrofits	NA	NA	NA	0	NA	$0.02–0.04		45%	$0.01–0.02	
15	Strategic energy management										
	Commercial	500,000	$80,000	$60,000	0	3	$0.06	$0.04	45%	$0.03	$0.02
	Industrial	1,600,000	$80,000	$60,000	0	3	$0.02	$0.01	45%	$0.01	$0.01

			Incremental cost				Cost of saved energy: total resource cost			Cost of saved energy: program administrator cost	
	Measure	Energy savings (kWh)	Current	Long term	% of costs assigned to other benefits	Average measure life (years)	Current	Long term	Program administrator % of total costs	Current	Long term
16	Energy performance labels for commercial and industrial equipment	30,000	$6,200	$5,000	0	13	$0.02	$0.02	45%	$0.01	$0.01
17	Smart manufacturing	2,000,000	$1,000,000	$750,000	60%	10	$0.03	$0.02	45%	$0.01	$0.01
18	Conservation voltage reduction					15	$0.02		100%	$0.02	
19	Combined heat and power systems	81,468	$19,760	$19,760	0	20	$0.05	$0.07	45%	$0.03	$0.03

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Chapter 2. Residential Appliances: Refrigerators, Clothes Washers, and Dryers

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MEASURE DESCRIPTION

Federal standards regulating the energy used by refrigerators, clothes washers, and dryers have increased in stringency in recent years, resulting in appliances that offer consumers substantial savings over products that were produced 10 or more years ago. Based on these standards, EPA has also racheted up ENERGY STAR® specifications for these three product classes. As appliances meeting the new specifications become available, energy efficiency programs can continue to offer incentives to consumers to replace their old models. Program administrators can reap greater savings from efficiency programs by leveraging improved technology and innovative program approaches.

Refrigerators, clothes washers, and clothes dryers account for approximately 16% of household electricity use (EIA 2009). Nearly all homes in the US have a refrigerator, and 23% of homes have two or more (EIA 2009). About 30% of households have a refrigerator that is 10 years or older, and more than 50% of second refrigerators are 10 years or older (EIA 2009; EPA 2015a).

More than 80% of homes have a clothes washer; the remainder use clothes washers at laundromat or multifamily laundry facilities. About 30% of clothes washers in homes are at least 10 years old (EIA 2009; EPA 2015b). Just under 80% of households have a clothes dryer. Of these households, 82% use the dryer every time a load of clothing is washed. About 30% of dryers are at least 10 years old (EIA 2009).

Among households that do not wash clothes at home, many wash in multifamily laundry rooms. The appliances in these common areas offer a largely untapped potential for energy and water savings, since the majority of these washers are less-efficient, top-loading models (Cluett et al. 2013).

EXPERIENCE TO DATE

Standards and ENERGY STAR

The energy use of refrigerators, clothes washers, and dryers has been regulated under federal energy efficiency standards that have contributed to considerable energy savings since 1987, when the National Appliance Energy Conservation Act (NAECA) was passed. In addition, EPA's ENERGY STAR certification for each of these appliance categories recognizes high-efficiency products on the market whose performance surpasses the federal standards. EPA also recognizes refrigerators and clothes washers that are the highest-performing units on the market, through the ENERGY STAR Most Efficient product designation.[6] For dryers, EPA recognizes very high-efficiency emerging technology through the ENERGY STAR Emerging Technology Award.

[6] The ENERGY STAR Most Efficient designation is an extension of the ENERGY STAR brand designed to identify and advance highly efficient products in the marketplace.

Refrigerators

Refrigerator efficiency has increased considerably over the past decade. The updated energy efficiency standard for refrigerators was finalized by the US Department of Energy (DOE) in 2011 and took effect in fall 2014. Four federal standards for refrigerators since 1987 have helped to drive the energy use of a typical new refrigerator from about 1,000 kWh/year to less than 500 kWh/year today, as shown in figure 2-1.

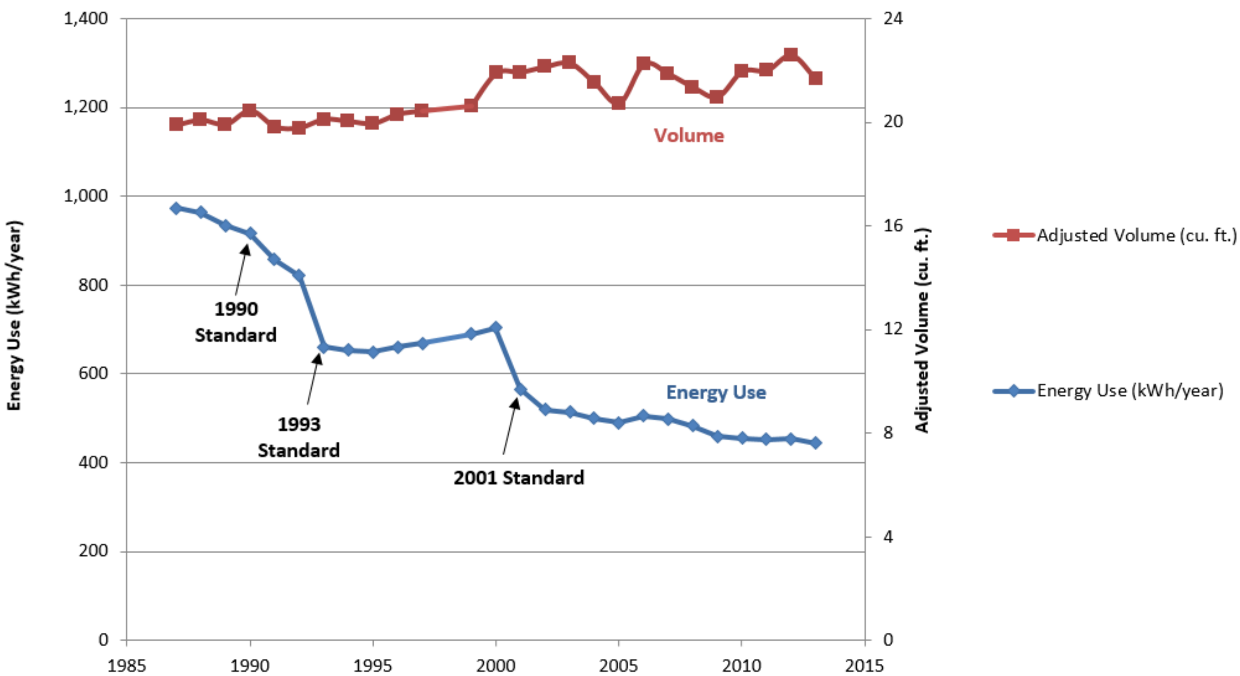

Figure 2-1. Refrigerator volume and energy price, 1987–2013. *Sources:* Mauer et al. 2013; AHAM 2013.

The new standards will save an average of 25% for the major refrigerator categories from the current standard, as follows:

- 25% for top-mount and side-by-side refrigerator-freezers
- 20% for bottom-mount refrigerator-freezers
- 30% for automatic-defrost freezers (ASAP 2011)

ENERGY STAR requirements for refrigerators were changed in September 2014 to reflect the new standard. For certification, all categories of refrigeration (refrigerators, freezers, and compact refrigerators) must use at least 10% less energy than the minimum federal efficiency standard (EPA 2014b). On average, products on this list use 17% less energy than the federal standard; the most efficient products use 22% less. Programs targeting the adoption of the highest-efficiency refrigerators available can therefore aim to achieve savings of about 17% over the current federal standard by using the ENERGY STAR Most Efficient refrigerator product list.

Clothes Washers

A new energy efficiency standard for clothes washers was adopted in 2012, setting more stringent requirements for top-loading and front-loading washers, as shown in table 2-1 below. The new standard also uses a new metric, the integrated modified energy factor (IMEF), to add stand-by and off-mode energy consumption. Top-loading washers have a two-phase standard that represents about 33% energy savings over the prior standard. Current front-loading washer standards represent 15% savings over the previous standard (ASAP 2012).

Many clothes washers in the existing stock go beyond the federal standards for energy efficiency. The new ENERGY STAR specification, which took effect in March 2015, requires the minimum efficiencies represented in table 2-1. The most efficient clothes washers on the market today, as represented on the ENERGY STAR Most Efficient product list, have even higher efficiency levels. Available products range from efficiency levels of 2.74 to 3.1 IMEF, representing energy savings over the 2018 standard of about 28% (EPA 2014b). About 17% of the products on the DOE certification database meet the 2015 ENERGY STAR Most Efficient criteria, including 6 top-loading models and 34-front loading models from 7 brands (M. Fiffer, ENERGY STAR appliances program manager, EPA, pers. comm., July 8, 2015).

Table 2-1. Clothes washer efficiency levels

	Federal standard	ENERGY STAR	2015 ENERGY STAR Most Efficient
Top loading	1.29 IMEF (effective March 2015) 1.57 IMEF (effective Jan 2018)	2.06 IMEF	2.74 IMEF
Front loading	1.84 IMEF (effective March 2015)	2.38 IMEF	2.76 IMEF

Sources: ASAP 2012; EPA 2014b

Clothes Dryers

High-efficiency clothes dryers can provide considerable energy savings for energy efficiency programs. Standards set in 2011 took effect January 1, 2015, reducing energy use by 5% over the prior standard. On the same day, the first ENERGY STAR specification for dryers also took effect; it certifies dryers using 20% less energy than conventional models (EPA 2014a). For a long time, the way dryers were tested to determine energy use was flawed because it did not capture the automatic shutoff capability of dryers provided by sensors that assess the moisture content of the load. The test required that the dryer be stopped before it automatically shut off, the assumption being that all dryers have equally effective controls for determining when a cycle is complete (ASAP 2015). More realistic testing showed that there is variation in the effectiveness of automatic termination controls, and this variation impacts energy use. Today a test procedure that better measures the automatic shutoff capibility of dryers allows the identification of models that have better controls. Dryers with the most effective control systems are qualifying for the ENERGY STAR specification.

An additional opportunity for savings rests with advanced clothes dryers, which use heat pump technology to provide savings of about 40% over standard models. Heat pump dryers are a mature technology globally and have made significant gains in market share in Australia and Europe (Denkenberger et al. 2013). Yet market penetration in the US is still very low (Denkenberger et al. 2013). Until recently, there were no heat pump dryer models available in the US market, so Americans are generally not familiar with the technology. Additionally, American customers are less accustomed to the longer drying times that are characteristic of many European heat pump dryer models. Manufacturers are now targeting the US market with hybrid heat pump clothes dryers that give customers the option of using heat pump technology to signficantly improve efficiency. Because these products are very new to the market, there is some uncertainty around how they will be used and how much energy will be saved.

EPA recognized three models available in the US market from Whirlpool, LG, and Kenmore with an ENERGY STAR Emerging Technology Award in 2014; it has since added one more model, from Blomberg, to the list of dryers that meet the 2014 Award performance criteria (EPA 2014a). These models come at a cost premium but are expected to go down in price as the technology becomes more widespread. Pacific Northwest National Laboratory (PNNL) and Bonneville Power Administration (BPA) are working with a clothes dryer manufacturer to further improve heat pump efficiency and lower costs (E3T 2015).

Heat pump technology is just one opportunity for advancing energy efficiency in the clothes dryer market. A number of other technical pathways are being explored, including ultrasonic drying and infrared heating technology (Goetzler et al. 2014). For example, Oak Ridge National Laboratory (ORNL) and GE Appliances are developing an ultrasonic clothes dryer that could increase energy efficiency and reduce drying time considerably by relying on high-frequency vibration to extract water from fabric (Shoemaker 2015).

PROGRAM ACTIVITY

Refrigerators and Clothes Washers

Residential appliance programs have targeted refrigerator and clothes washer replacements through incentives, marketing, and consumer education to increase the saturation of energy-efficient appliances in retail stores and, ultimately, in homes. Most refrigerator and clothes washer appliance programs offer rebates directly to the consumer, usually ranging from $25 to $50 (York et al. 2015). Most programs offer rebates for ENERGY STAR–qualified appliances, while others are beginning to offer rebates only for products with an ENERGY STAR Most Efficient designation. Some programs offer tiered rebates that vary according to efficiency levels. Some programs also focus on retailers and manufacturers through training and education in order to increase the supply and sale of efficient appliances. As traditional appliance rebate programs that incentivize ENERGY STAR–qualified products have successfully increased saturation of energy-efficient appliances in the market, particularly refrigerators and clothes washers, new program designs will be necessary to reap savings (York et al. 2013).

Dryers

Until recently, few energy efficiency programs offered rebates for dryers. With the new ENERGY STAR specification that took effect on January 1, 2015, a number of utilities now offer rebates to consumers who purchase ENERGY STAR dryers, with rebates ranging from $25 to $50 for qualified models (EPA 2015d). While ENERGY STAR Most Efficient designation does not yet exist for dryers, some utilities are offering a significantly higher rebate ($300–400) for the dryers that received the ENERGY STAR Emerging Technology

Award.[7] As mentioned above, these save about 40% of dryer energy versus the 20% that ENERGY STAR–qualified models save.

Program Approaches

While the majority of appliance rebate programs for refrigerators, clothes washers, and dryers currently provide incentives to customers via mail-in rebate after a qualifying unit is purchased, there are alternative approaches. Some programs, for instance, offer point-of-sale rebates at certain retailer locations, giving customers an instant rebate for purchasing a qualifying product. For example, the Sacramento Municipal Utility District (SMUD) offers point-of-sale rebates at certain retailers in addition to a mail-in rebate option for qualifying dryers and refrigerators (CEE 2014).

While most programs leverage the ENERGY STAR specifications to determine qualified products, other tools are becoming available for identifying highly efficient products. For example, the online marketplace Enervee provides ranking systems that identify the most efficient products on the market (Enervee 2015).

Some programs also offer a midstream incentive to retailers for stocking and selling more efficient appliances. For example, New Jersey's Clean Energy Program offers a $50 incentive to the retailer in addition to a $50 rebate to the consumer for refrigerators and clothes washers (CEE 2014).

The ENERGY STAR Retail Products Platform is an innovative approach designed to engage program sponsors in coordinated efforts to work with retailers. It is currently being piloted through a number of utilities including Pacific Gas and Electric (PG&E), SMUD, Southern California Edison (SCE), Efficiency Vermont, and DC Sustainable Energy Utility (EPA 2014c). The platform provides program sponsors with a framework for motivating retailers to change business practices to offer more energy-efficient appliances. Program sponsors adopt common strategies and practices to reduce program administration costs for themselves and for retailers while still allowing differentiation in local markets (EPA 2014c).

Energy utilities can partner with water utilities to offer joint rebates for clothes washer programs. A joint program with PG&E and a number of local water utilities offers a $50 rebate from PG&E and a $100 rebate from the water utility, resulting in a more robust rebate for consumers than either party could offer on its own (PG&E 2015).

Additionally, administrators sometimes pair rebate programs with appliance recycling programs. A number of utilities offer incentives to consumers to eliminate second refrigerators, through refrigerator recycling programs that offer a rebate and/or free pick up of old units. Often these programs are marketed in tandem with new refrigerator rebate programs, to discourage consumers from continuing to use their old refrigerator as a backup unit after they purchase a new one (Cluett et al. 2013). In spring 2015, many

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[7] These utilities include the Burlington (Vermont) Electric Department, Efficiency Vermont, DC Sustainable Energy Utility, PSEG Long Island, New Jersey's Clean Energy Program, and Sacramento Municipal Utility District (EPA 2015d).

ENERGY STAR utility, retail, and manufacturer partners participated in an early-replacement and recycling promotion, *Flip Your Fridge*. EPA will continue with a similar campaign in which utilities can participate, in 2016 (EPA 2015c).

Fewer clothes washer recycling programs exist, but the idea is currently being pursued in California through the California Technical Forum by the Natural Resources Defense Council (Chou 2015).

The New York State Research and Development Authority (NYSERDA) has taken an upstream program approach to advancing more efficient products. The New York Energy $mart Products (NYE$P) program works to promote ENERGY STAR appliances (and other energy-efficient products) by increasing public awareness and by increasing the supply of qualifying products through partnerships with retailers, manufacturers, and distributors (York et al. 2015). Retailers become partners in the program by offering at least four models of ENERGY STAR products and reporting monthly sales data to NYSERDA. In exchange, retailers receive assistance with advertising, sales staff training, and free promotional materials. Manufacturers become partners by producing at least one ENERGY STAR product (or qualified energy-efficient product) and reporting quarterly shipping data (Cluett et al. 2013).The program provides incentives to retailers and manufacturers for cooperative advertising and special promotions, as well as marketing campaigns. In New York the market share of ENERGY STAR refrigerators has increased from approximately 20% to 72% between 2001 and 2014; for clothes washers, market share has grown from approximately 20% to 75% during the same period (York et al. 2015).

PROGRAM OPPORTUNITIES

Due to the wide variety in refrigerator types, sizes, configurations, and features, there can be considerable variation in energy use among models. Programs can offer incentives for refrigerators that do not exceed a certain energy-use limit (kWh/year).

Programs also can address how clothes washers and dryers are used in the home through programs targeting consumer behavior. Utilities can provide consumer education on ways to adjust washer and dryer settings to increase drying efficiency, such as setting clothes washers to the highest-speed spin cycle and setting dryers to a lower drying temperature. Dryer efficiency can be increased up to 30% by lowering the temperature clothes are dried at (Denkenberger et al. 2014). Programs can address clothes washer energy use by encouraging cold water washing. ENERGY STAR estimates that with an older washer, switching to cold water, as opposed to using an average mix of water temperatures, saves about 584 kWh annually with an electric water heater and 27 therms annually with a gas water heater. In multifamily or laundromat settings, incremental pricing for washer loads based on water temperature can offer consumers more choice and yield substantial energy savings. For example, a multifamily property manager in Washington, DC, set up incremental pricing so that the washing machines charge more for warm and hot water than they do for cold water. Residents switched from almost exclusively using hot water to very often using cold, resulting in 25–30% energy savings (ASE 2011). Utilities could work with multifamily building owners/property managers to implement similar controls to achieve considerable savings.

ENERGY SAVINGS

Table 2-2 shows estimated 2030 energy savings for refrigerators, washers, and dryers. We determined the baseline energy use for each product according to the appliance standard that applied in 2015. The energy use of the best available products is representative of the most efficient products on the ENERGY STAR Most Efficient product list for refrigerators and clothes washers today. For dryers, we set the estimated energy savings of the best available products (30%) midway between the ENERGY STAR specification (20% savings) and the savings achieved by recipients of the ENERGY STAR Emerging Technology Award (40%).

Table 2-2. Electricity savings in 2030 from refrigerators, washers, and dryers

	Current energy use (kWh/year)	Best available (kWh/year)	Savings from best available (%)	Covered energy use in 2030 (TWh)	Participation rate (%)	Total savings (TWh)[1]	Total savings (%)[2]
Refrigerators	438[3]	356	22%	113	50%	12	
Clothes washers[4]	461[5]	353	25%	61	50%	7	
Clothes dryers	855	600	30%[6]	67	50%	10	
			Total			29	0.7%

Current energy use (kWh/year) is a rough estimate based on the current standard level. While there are many older installed units that likely consume more energy, this is counterbalanced to some extent by above-standard products that have been sold for years. Baseline studies focused on a specific region are more useful for program administrators determining energy savings. [1] Total savings are calculated by multiplying % savings x % penetration rate x covered energy use in 2030. [2] Total savings are expressed as a percentage of total electricity sales in 2030 (EIA 2014). [3] Weighted average across product classes, based on 2015 standard levels. [4] Includes energy associated with water heating. [5] Based on standard in effect in 2015. Standards will become more stringent for top-loading washers in 2018. [6] Midpoint savings estimate between ENERGY STAR spec 20% and ENERGY STAR Emerging Tech Award 40% since little information is available on how units are performing in the field.

Based on the energy savings estimates for each appliance in the table above, we estimate the cumulative savings possible from refrigerators, clothes washers, and clothes dryers in table 2-3. In our medium-case estimate, we assume a participation rate of 50%. We find total savings of 0.7% in the medium case. In the high-case estimate, we assume a participation rate of 75%. We estimate savings for this case to be 1.0% of US 2030 electricity consumption. In the low-case estimate, we assume a participation rate of 37%. We estimate savings for this case to be 0.5% of US 2030 electricity consumption.

Table 2-3. Cumulative electricity savings in 2030 from refrigerators, washers, and dryers

	Value	Unit	Comments
	1,526	TWh	2030 residential electricity consumption from EIA 2014.
x	16%	energy use covered	See table 2-2 for details. Electricity use by refrigerators (7%), clothes washers (4%), and dryers (4%).
x	26%	average savings	See table 2-2 for details. Average savings from refrigerators (22%), clothes washers (25%), and dryers (30%).

	Value	Unit	Comments
x	50%	participation rate	Percentage of the market reached
x	95%	net-to-gross	Standard assumption for this report
=	29	TWh	Total savings
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.70%	of US electricity use	

COSTS AND COST EFFECTIVENESS

Table 2-4 estimates the cost of saved energy for refrigerators, washers, and dryers based on current and long-term projections of energy use and appliance costs. Current energy use is based on a model that meets the current appliance standard. Long-term energy use estimates are based on the best units in the market, as shown in table 2-2. Incremental cost estimates are based on current costs of the best available products on the market and our projections of long-term costs based on historical price evaluations (Mauer et al. 2013).

Table 2-4. Cost of energy saved through refrigerators, washers, and dryers

	Unit energy use (kWh)			Incremental cost of high-efficiency measure				Cost of saved energy per kWh	
	Federal standard level	High efficiency	Energy savings (kWh)	Current	Long-term	% of costs assigned to other benefits	Average measure life (years)	Current	Long-term
Refrigerators	438	356	82	$150	$75	0%	15.4	$0.17	$0.09
Clothes washers	461	353	108	$100	$50	50%*	14.2	$0.08	$0.04
Clothes dryers	855	600	255	$450	$200	0%	16	$0.16	$0.07

CSE is calculated by taking the levelized annual cost of a measure and dividing by the annual energy savings. The levelized annual cost is calculated using the PMT function in Excel to figure out the annual payment needed to fully amortize the investment with a loan term equal to the measure life and an interest rate equal to the discount rate (we use a 5% real discount rate). *Half of costs are assigned to water and sewer savings (DOE 2012).

UNCERTAINTIES

The long-term savings estimates we present are based on the best available appliances on the market in each product category today. As products continue to evolve in the next 15 years, it is likely that we will see continued increases in efficiency from each product category. This means our long-term savings estimates are likely conservative. Long-term incremental costs are also uncertain. Over time, as efficiency has increased, prices have continued to decrease for both clothes washers and refrigerators (Mauer et al. 2013). Between 1987 and 2010, real prices for refrigerators decreased by about 35% while average energy use decreased by more than 50%. Real prices for clothes washers decreased by about 40% while average energy use decreased by 75% (Mauer et al. 2013). While the efficiency of clothes washers and refrigerators may not continue to increase as significantly as in the past, there are still efficiency gains to be realized from advances in technology. For clothes dryers, units with heat pump technology that make drying about 40% more efficient are just beginning to reach the US market. As this technology gains footing here, costs could come down considerably. Clothes dryers offer a large potential savings in the US because more efficient technology is already available but has yet to gain significant market share.

RECOMMENDATIONS AND NEXT STEPS

Utilities can gain energy savings from appliance programs by promoting the most energy-efficient products on the market, as identified by the ENERGY STAR Most Efficient designation. Utilities can also encourage and assist in the development of more stringent standards for these appliances through participation in DOE's appliance standards rulemaking process. In addition, utilities can advocate for the continued ratcheting up of EPA's ENERGY STAR requirements. If efficiency standards continue to improve from the levels they are at today, utility programs will continue to have savings opportunities in these program categories.

Utilities can expand efforts to reduce energy use from these appliances through more targeted approaches to markets that have been largely untapped by efficiency programs, such as the common washer and dryer areas in multifamily buildings, where the existing stock of clothes washers is made up largely of less efficient, top-loading units.

In addition, utilities should develop program approaches that streamline program participation for customers. The process for redeeming rebates should be as simple as possible, and rebates should be substantial enough that consumers can justify making the more efficient purchase (York et al. 2015). Point-of-sale rebates can expedite the process of rebate redemption by offering the consumer an instant discount.

Midstream incentives to retailers to encourage sale of more efficient appliances can be a critical way to increase future program participation. EPA's ENERGY STAR Retail Products Platform presents a promising framework by which to streamline relationships with retailers and program sponsors (EPA 2014c). Focusing on midstream and upstream program designs (at the manufacturer level) saves customers the effort of participating and leverages the marketing and sales expertise of retailers and manufacturers, resulting in a larger potential for sustained participation and market transformation (York et al. 2015).

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Chapter 3. Residential LED Lamp Replacement for Incandescent Lamps

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MEASURE DESCRIPTION

Light-emitting diode (LED) technology has advanced rapidly in recent years and is revolutionizing a wide variety of both residential and commercial lighting applications. The creation of LED screw-in lamps (bulbs) capable of replacing either conventional incandescent or compact fluorescent lamps marks a turning point in lighting technology. LED lighting offers numerous benefits over incandescent and compact fluorescent lighting (CFL) technologies.[8] Quality LED lamps are more durable and offer light that is comparable to or better than other types of lighting. High-quality LED lamps, such as those meeting ENERGY STAR specifications, have a rated life of 25,000 hours or more, which is 25 times the rated lifetimes of typical incandescent lamps. While there are lower-quality LEDs with shorter rated life spans (10,000–15,000 hours), in many applications LED lamps are essentially lifetime technologies—needing replacement only after many years of operation. Additionally, LED lamps contain no hazardous mercury, and many of them offer dimming capabilities that can provide additional energy savings throughout their lives.

LED lamps are highly energy efficient compared with incandescent equivalents, both traditional incandescent lamps and more efficient halogen lamps. Table 3-1 shows the energy performance of different lighting technologies that would all provide equivalent lumens (amount of light). As shown in this table, a 12-watt LED replacement for a conventional 60-watt incandescent lamp uses just 20–25% of the electricity required to yield equivalent lumens. With federal lighting standards (EISA) in place, traditional inefficient incandescent lamps are no longer readily available; the replacement products, such as halogen lamps, use energy-saving incandescent technologies.[9] LED lamps are still far more energy efficient—using 28% of the electricity of these types of halogen lamps.

[8] NEEP 2014 (page 2) offers a comprehensive summary table comparing qualities of LED, CFL, halogen, and incandescent lighting technologies.

[9] The Energy Independence and Security Act of 2007 (Pub. L. 110-140) established efficiency standards for appliances and lighting among its many provisions. Conventional incandescent lamps (bulbs) do not meet the lighting standard. To meet the new standard requires new, higher-efficiency halogen incandescent technology or such alternatives as compact fluorescent and LED lamps.

Table 3-1. Traditional incandescents, halogen incandescents, CFLs, and LEDs

	60W traditional incandescent	43W energy-saving incandescent	15W CFL		12W LED	
			60W traditional	43W halogen	60W traditional	43W halogen
Energy $ saved (approx.)	—	25%	75%	65%	75–80%	72%
Annual energy cost*	$4.80	$3.50	$1.20		$1.00	
Bulb life	1,000 hours	1,000–3,000 hours	10,000 hours		25,000 hours	

*Annual energy costs are based on two hours per day of usage and an electricity rate of 11 cents/kWh. *Source:* DOE 2014.

While there are many benefits to LED lighting, there have also been barriers to widespread adoption of this technology, the biggest being cost and customer acceptance (Goebes et al. 2014). There also initially was a challenge presented by adapting LED technology, which emits light in a single direction, into consumer products—like screw-in bulbs—capable of providing diffuse (omnidirectional) light as required for general-purpose ambient lighting. Manufacturers have met the technological challenges, and there is now a large and growing selection of LED lamps available to residential customers. As with other solid-state electronic technologies, product costs have decreased rapidly. While some of the initial LED screw-in lamps cost $40 or more, in June 2015 Philips introduced an LED lamp equivalent to a 60-watt incandescent for $5, and General Electric similarly introduced low-cost LEDs, pricing a three-pack of 60-watt-equivalent lamps for $10 (Business Wire 2015). Costs are expected to continue to decrease as the LED lighting market grows and matures, although future decreases will be less than these initial large decreases.

The market for residential LED lamps is very dynamic, as evidenced by the rapid price decreases and rapid expansion of available products and manufacturers. There also is and will continue to be a range of prices for LED products due to differences in key attributes of the products. These attributes are cost, efficiency, lighting quality and rated lifetimes. Generally low-cost units will have lower quality performance and shorter lifetimes than those conforming to higher performance and lifetime standards, such as lamps meeting ENERGY STAR specifications. Some manufacturers and other key stakeholders associated with this market, such as US EPA ENERGY STAR, have focused on high quality as LED technology has been developed and introduced. This is a lesson learned from the introduction of CFLs, which suffered from poor product quality and performance for many years. LEDs can be adapted to most applications—including dimming, three-way, rough-and-vibration service, and decorative lamps such as candelabras—replacing many lamps that CFLs could not.

LED lamps require consumers to change traditional perspectives on lighting products for the home. LEDs are markedly different than traditional incandescent products, which were cheap to purchase and had relatively short lives, requiring frequent replacement. As noted earlier, LED technology also offers many benefits over CFL technology and customer response to LED has generally been very positive. Consequently, LEDs are well poised for rapid market growth, likely to become a dominant technology among residential lighting technologies.

EXPERIENCE TO DATE

Residential lighting programs promoting and offering incentives for energy-efficient lighting, primarily CFLs, have been a backbone of most utility and related energy efficiency programs—some dating back 10 to 20 years or more in various forms. Such programs have typically yielded the largest single share (up to 50% or more) of energy savings within a given portfolio of all customer energy efficiency programs offered by a utility or related organization. The primary program approach has been to reduce the purchase cost of qualified products, whether in the form of consumer rebates or midstream retail buy-downs. The latter is generally the preferred approach taken by programs today as it is easiest for consumers; they simply pay a discounted price on products at the point of purchase. Residential lighting programs have achieved high participation and associated market impact (York et al. 2015). Successful programs serving large customer populations have promoted sales of millions of CFLs. The success of such programs is evident by the now ubiquitous nature of CFLs in residential lighting markets and their relatively low cost.

There are a growing number of residential lighting programs now promoting LED lamps through similar approaches—education, marketing, and rebates for qualified products. States where such programs are in place include California, Colorado, Connecticut, the District of Columbia, Illinois, Maryland, Massachusetts, New York, Rhode Island, Vermont, Washington, and Wisconsin, among others (DOE 2015; NEEP 2014). Household "socket saturation" surveys (counts of the number of different types of lighting technologies in place in homes) show that the shares of efficient lighting technologies (primarily CFLs) are generally in the range of 25–40% in states and regions with long histories of promoting such products (NEEP 2013; Baylon et al. 2012). This suggests a significant remaining potential for replacement of inefficient and less efficient lighting technologies with highly efficient LED technologies. Customers also are likely to replace existing CFL lamps with LED lamps over the long term–a market shift expected as any purchase price advantage of CFLs is eventually eliminated.

Data on results for residential LED lighting programs are limited due to the newness of such programs. Many of these have been providing incentives for qualified LED products for just a year or less. Available market research suggests that both residential and non-residential customers are receptive to this new technology and the performance it offers compared with other lighting options (Goebes et al. 2014). Customer responses to LEDs suggest rapid market growth. According to a program manager for Puget Sound Energy's residential lighting program, customer adoption of LEDs is occurring far faster than it did for CFLs. The program had to double its initial forecasts for adoption of LEDs, and this forecast still underestimated actual adoption by 50%. This early rapid growth could just be attributable to early adopters. It still is too early to know how well the general public will accept LEDs and how large the LED share of the market will be over the long term.

Purchase price has been the biggest barrier for more widespread adoption of LED technologies, but as discussed above, rapid price decreases are quickly lowering this barrier. A survey of PG&E's residential customers found that they are unwilling to spend more than $20 on any type of LED and would prefer a purchase price of $5.99 or less (Goebes et al. 2014). Such a market price has been reached, suggesting a rapid expansion of this market in the near term.

Replacing incandescent lamps—even halogen incandescent lamps that meet new standards—with LED lamps is cost effective from a customer perspective, as shown below. With federal lighting standards in place, the baseline against which efficiency is measured has been raised, which reduces the energy savings that can be attributed to adoption of LEDs. At the same time, however, the drop in the price of LEDs has helped improve their cost effectiveness. Utilities face different avoided costs when screening energy efficiency programs for cost effectiveness. There may be a need for additional decreases in prices and improvements in product efficiencies to meet cost-effectiveness thresholds for some programs.

Data from the Northeast illustrate the rapid growth of LEDs. According to the National Electrical Manufacturers Association (NEMA), shipping trends for LEDs show an increase of 42.3% from 2012 to 2013 (NEMA 2014a) and an increase of 35.8% from the first quarter of 2014 to the second quarter of 2014 (NEMA 2014b).[10] At the same time, CFL shipments decreased slightly. Despite the rapid increase in LED shipments, the market share of LEDs is still small: 1.1% of all shipments in 2013 and 2.9% in the second quarter of 2014. The CFL market share was 33.8% in 2013 and 36.4% in the second quarter of 2014 (NEMA 2014a and 2014b).

Programs promoting LEDs show rapid transformation as well. Data available through or into the third quarter of 2014 for lighting programs in the Northeast demonstrate this rapid growth, as shown below in table 3-2. The percentages are for the share of LED products receiving incentives from programs compared with all energy-efficient lighting products receiving incentives.

[10] Shipping of units is a readily available metric; actual sales data are not readily available. While shipping is a proxy for sales, they are not necessarily equivalent.

Table 3-2. LED retail lighting program market share, 2013 and 2014 YTD

State	2013	2014	2014 YTD through
Connecticut	15%	39%	Sept. 30
District of Columbia	4%	23%	Sept. 30
Massachusetts	15%	20%	Aug. 31
Rhode Island	9%	20%	Aug. 31
Vermont	20%	31%	Sept. 30
PSEG-LI	26%	38%	Oct. 31
NYSERDA	47%	44%	Sept. 12

Source: NEEP 2014

Programs in other regions show similar rapid growth. For example, the share of lighting incentivized in Pacific Gas & Electric's Residential Segment (portfolio of relevant residential programs) increased from 5% in the 2010–2012 program cycle to 70% in the 2013–2015 program cycle (Chansanchai 2015).[11]

These examples demonstrate phenomenal growth by any measure. Clearly programs are quickly moving to the promotion of LED lamps and decreasing efforts for CFLs, although a significant share of residential lighting programs continue to target CFLs.

ENERGY SAVINGS

The data in table 3-3 are estimates for our midrange scenario. For the high case we assume a higher share of residential lighting targeted (84% as used by DOE) with a participation rate of 85%. For the low case we assume a 50% participation rate and a lower value of residential lighting targeted (62%; also used for midrange scenario). As the table shows, our midrange estimate is 1.1% savings. Our high estimate is 1.4% and the low estimate is 0.6%.

[11]These values are initial estimates, subject to revisions as full evaluations are completed and data are verified.

Table 3-3. Electricity savings in 2030 from LED lamp replacements

	Value	Unit	Comments
	144	TWh	2019 residential lighting electricity consumption from EIA 2014. Beginning in 2020, new standards take effect; they are factored into 2020–2030 projections.
x	62%	share of residential lighting targeted	Assume LEDs are targeted only to home lighting applications now using incandescent bulbs (Gifford et al. 2012).
x	80%	average savings	Energy savings for LED replacement of incandescent lamps
x	85%	participation rate	We expect most incandescent lamps to be replaced by 2030.
x	75%	net-to-gross ratio	Evaluations of residential lighting programs suggest a relatively large number of free riders; thus we use a relatively low value of net-to-gross energy savings.
=	45.5	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	1.1%	of US electricity use	Midrange estimate

For comparison with this estimate, DOE projects that total savings from LED residential use by 2030 will be 61 TWh (Navigant 2014). The biggest difference lies in the assumption about future market share; DOE projects a total market share for LED lamps of 84% by 2030. Our estimate is only for the share of lighting that is currently incandescent and does not include higher-efficiency lighting such as CFLs. There would be some additional gains in efficiency and resulting savings as customers switch current CFLs to LEDs, but the incremental savings are much smaller than switching from incandescents to LEDs. While our midrange estimate is more conservative, we view DOE's estimate as very possible, given the long time frame and the nature of LED technology, as we have discussed earlier. Our savings estimates also use baseline electricity consumption for residential lighting for the year 2019, as Phase II standards under the Energy Independence and Security Act of 2007 (EISA) are scheduled to become effective in 2020. Projected residential lighting electricity use for 2020 onward thus includes these standards—accounting for additional energy savings from improved lamp efficiencies. Finally, we did not estimate energy savings possible from CFL to LED replacements. This would increase possible LED energy savings by a small amount.

COSTS AND COST EFFECTIVENESS

At current and projected prices, LED lamps are cost effective. Their energy efficiency and long lifetimes yield significant savings compared with incandescent lamps, even halogen incandescent technologies that meet EISA standards. To illustrate the cost effectiveness, we use an example of a 12-watt LED replacement of a halogen incandescent lamp (43 watts), both of which provide the lumen equivalent of a conventional 60-watt incandescent lamp. We estimate cost effectiveness based on two different assumptions about LED lamp costs: $8 and $3. The higher value represents the current average LED lamp cost, and the lower value reflects long-term lamp cost. As noted earlier, this market is very dynamic; in June 2015 two major manufacturers introduced lamps at about $5 each. Also, there are differences in quality that may be reflected in purchase costs. Over the duration of this study, we assume that quality products (such as those meeting ENERGY STAR specifications) will be available at the prices we use. Table 3-4 shows the results.

Table 3-4. Cost of energy saved (CSE) through LED lamp replacement

	Value	Unit	Comments
	$8	per lamp	Current LED lamp cost
	$3	per lamp	Long-term LED lamp cost
	730	hours	Total time in use (assumes 2 hours/day)
x	31	watts	Difference between power of LED and lamp it replaces (halogen)
=	22.6	KWh savings	Annual energy savings per lamp replaced
	$0.04	per kWh	CSE based on current cost
	$0.01	per kWh	CSE based on long-term cost ($3/lamp)

This analysis does not include the cost of replacement incandescent bulbs. When these costs are included, the cost of saved energy is negative since a single LED bulb is cheaper than the 10 to 25 incandescent bulbs it would replace over its lifetime (assuming 10,000- to 25,000-hour lifetime; varies by quality of LED lamp), ignoring the energy savings.

UNCERTAINTIES

The biggest uncertainty in projecting possible energy savings from LED lamps replacing incandescent lamps is the number of such replacements that would occur from both programs and markets. In short, how large will the market grow? While there are some lessons that can be drawn from experience with CFLs as a new, innovative, and energy-efficient lighting technology, LEDs are likely to achieve a much higher market share of residential lighting products more quickly than did CFLs. This is due to the generally superior nature of LED technology compared with CFL technology and the more rapid cost decreases that are occurring with LED lamps.

While LED technology holds great promise, there remain some technological and performance-related challenges that will need to be overcome to gain widespread customer acceptance. These include lack of standards for lifetime ratings, ranges of color quality, flickering in some products, and achieving high-quality dimming performance (Sandahl et al. 2013). Customers also must become educated about this new technology so that they make the right purchase decisions for their needs and preferences. Customers face a much more complex set of choices for home lighting products than ever before. For LED markets to grow, customers will have to customers to understand LED lamps and be satisfied with them as the primary choice for their home lighting. ENERGY STAR specifications and ratings will play an important role in ensuring that high-quality LED products are readily distinguishable in this rapidly expanding market. Higher purchase costs will remain a barrier for certain customers, such as those of low income.

Another source of uncertainty for savings from LEDs is the schedule and implementation of revised federal standards (Phase II) for lighting products as established by EISA. Higher standards are to become effective in 2020, which would eliminate halogen lamps from the market. This would effectively require customers to shift to LED or CFL products, which would significantly limit the amount of energy savings to be gained from utility programs. While slated to occur, there are uncertainties surrounding the development and implementation of Phase II standards as scheduled, due to the political and administrative processes involved.

Experience with LED programs is growing rapidly. A number of utility and related programs have begun to offer financial incentives for purchasing LED lamps, usually in conjunction with existing residential lighting programs that have been offering such incentives for CFL lamp purchases.

RECOMMENDATIONS AND NEXT STEPS

LED lighting holds great promise to revolutionize residential lighting. It is a technology that not only is very energy-efficient but also offers a number of advantages over other residential lighting technologies. Further gains in efficiency with LED technology itself are possible and likely will be achieved. Utility and related programs can be important catalysts of this transformation. Goebes et al. (2014) reviewed recent research on LED lighting technologies and programs for both residential and commercial applications. Their recommendations mirror our own. To increase sales and use of residential LED lamps, we offer the following recommendations:

- Use product quality and performance specifications such as ENERGY STAR or the DesignLights Consortium (for commercial products) to encourage the adoption of high-quality LEDs, and provide incentives only to products meeting such specifications.
- Provide incentives initially for selected types of LEDs, and add additional types as suitable products are available.
- Provide incentives for LED lamps to bring price points down to acceptable levels for consumers.
- Provide customer education on LED technology, products, and applications.
- Use demonstrations of LED products to overcome customer skepticism and improve acceptance.
- Support development of higher-efficiency LED products.
- Track market baseline sales of LEDs closely to assess both the performance of programs and the development of the entire market. At some point, perhaps as soon as 2020, the market will be sufficiently developed so that further promotion will not be needed.

Evaluations of these programs and related market research will be vital to inform and guide program administrators on how best to structure these programs and on the need for such programs to move a clearly dynamic and rapidly changing market.

Supporting the development of this market by assuring quality and performance of LED products through ENERGY STAR and related labeling programs is a top priority. Expansion of CFL markets suffered setbacks due to poor quality and performance of many products. To realize the full potential of LEDs, they must become well accepted by consumers.

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Chapter 4. Real-Time Energy Use Feedback and Behavioral Response

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MEASURE DESCRIPTION

Metering of customer electricity use is undergoing rapid, fundamental change. Advanced metering infrastructure (AMI) is a blanket term used to describe a variety of technologies that are being deployed to provide customers and utilities real-time data on electricity use. More colloquially, these technologies are often referred to as smart meters. Historically, metering and corresponding feedback to customers and utilities were subject to lengthy lags, typically at least one to two months. Meters were read manually by utility staff going from customer to customer; the data were then reported and used for customer bills sent out monthly. Such lengthy delays between use and feedback greatly obscured the cause-and-effect dynamic that customers could use to modify their behavior in order to change their energy use.

AMI completely changes how utilities gather and utilize customer data. It provides both real-time metering of energy use and automation of services such as meter reading. It provides much more detailed data for customers and utilities alike. Such data can be used to optimize customer energy use, improve system reliability, and create new pricing and service options for customers. AMI enables a variety of technologies and services that customers can use to change their energy use in response to real-time data; for maximum impact, it needs to be coupled with communications, pricing, and controls. AMI also is a cornerstone for emerging new utility business models that are based on customer services and a wider set of options, such as distributed resources, renewable energy, and energy efficiency (Glick, Lehrman, and Smith 2014; Nadel and Herndon 2014).

The growth of AMI has been rapid in part because of DOE's Smart Grid Investment Grants, which were part of the American Recovery and Reinvestment Act stimulus funding. As this funding has wound down, growth has slowed over the past few years. North American shipments of AMI peaked in 2011 and have waned since then (Klemun 2013). Many states, such as Texas and California, already have AMI in place for the majority of electric customers. The Institute for Electric Innovation reports that utilities nationwide have installed 50 million AMI meters, which represents 43% of all homes (Mooney 2015).

AMI by itself is not an energy efficiency measure. Real-time metering alone does nothing to save energy. What can yield energy savings are the actions that customers take in response to these data. There are two principal approaches to using AMI data in order to get customers to respond: enhanced feedback and time-varying pricing. These approaches are not mutually exclusive. In fact, combining these approaches in comprehensive services for customers will have the greatest impact.

Enhanced feedback refers to improved communications to customers about their energy use. To make AMI data meaningful to customers requires some kind of interface, such as in-home displays (IHDs) or displays on smartphones or tablets, along with information on what the data mean and what actions may be taken in response. AMI combined with IHDs or other feedback devices enable customers to become active managers of their energy use. Customers can see directly how their choices of using various appliances and household technologies can affect energy use. Over time they can become much more energy aware and learn which behaviors and choices can yield desired levels of household energy use.

Time-varying, or dynamic, pricing is a system under which customer rates differ according to the time of use. Historically, electricity rates for residential customers have been fixed, flat, and independent of time of use. Such pricing bears no resemblance to the reality of electricity markets, where real-time pricing can readily vary tenfold and occasionally even nearly a hundredfold. High market prices typically occur during high-demand periods when supplies may be constrained, such as on hot summer days. At such times more costly supply sources, such as combustion turbines, may be loaded into the system. Also, high demand translates to high prices per basic economic theory. Dynamic pricing of electricity depends on time-of-use metering, and conventional meters cannot provide such data. Because AMI technology can provide these data, it enables the introduction and application of dynamic pricing.

There are a variety of options for time-varying and dynamic pricing structures (see Faruqui, Hledik, and Palmer 2012). A common approach is to create differentiated prices according to prescribed time blocks, which yield time-of-use (TOU) rates. It may be as simple as an on-peak rate and an off-peak rate. More advanced variations might offer several different rates for finer distinctions among times of use. TOU rates typically are static in that the pricing periods are defined and fixed in advance. For example, a summertime peak rate may be in effect across a broad period (e.g., from 10 a.m. to 8 p.m.) or a narrower period (e.g., from 4 p.m. to 8 p.m.). Another approach, which has been used by some utilities in California and other states, is called critical peak pricing. In this approach the pricing periods are not fixed but react to real market conditions. Customers are sent advance notice of times when a critical peak period will occur and associated critical peak pricing will be in effect. Customers then may choose to reduce demand through such actions as raising air-conditioning thermostat set points (such as from 76° to 78°F) or turning off air-conditioning units entirely during these times. The messages may be sent to customers via in-home displays, email, or mobile phones. Some critical peak pricing may include rate tiers that mirror typical electricity market price fluctuations, offering some intermediate prices between the lowest off-peak rates and the highest critical peak rates. The most time-dependent pricing approach is real-time pricing, which involves rates varying in real time according to market rates for electricity (Faruqui 2012).

AMI technology, coupled with improved feedback and time-varying rates, can give customers greater understanding of and control over their energy use and associated costs. Figure 4-1 shows a device that changes colors according to grid demand conditions to help residential customers make smarter energy consumption choices.

Figure 4-1. Ambient Devices' Energy Orb

A closely related development is the rise of the smart thermostat, which is another rapidly emerging means of providing much greater control and optimization of household energy use. Smart thermostats control heating and air-conditioning systems, which are the greatest users of energy in the typical household. We discuss and analyze smart thermostats in Chapter 5 of this report. In some sense AMI, under utility control, competes with smart thermostats and other non-utility controls over home energy use. There may well be a convergence as smart thermostats become part of utility programs and are linked to utilities' metering, pricing, and communications.

EXPERIENCE TO DATE

Much research has been performed over the past 10–20 years on customer response to real-time data on energy use. ACEEE completed a meta-review of advanced metering initiatives and residential feedback programs from a set of 57 studies spanning three decades from North America and Europe (Ehrhardt-Martinez et al. 2010). This meta-review found that household electricity savings were reduced an average of 4–12% across an international sample of projects as the result of some type of feedback; for US projects the range was 2–11%. For a subset of 36 studies implemented between 1995 and 2010, these researchers found that the highest savings occurred with real-time, direct feedback—either at the whole-house level, saving an average of about 9%, or at the appliance level, saving an average of 12%. The studies typically involved small subsets of customer populations. This meta-review clearly shows the potential of these mechanisms, although the upper values are unlikely to be achieved by wide populations of all residential customers.

A follow-up study by ACEEE focused on nine large-scale, real-time feedback pilots and experiments conducted more recently (2009–2011) in the US, UK, and Ireland (Foster and Mazur-Stommen 2012). Its purpose was to verify the savings found in these studies, which ranged from 0–19.5%. The average across the pilots was 3.8%, not counting the one with the highest savings (19.5%), which was excluded due to important differences in study design. A key finding was that several of the pilots found incremental savings of approximately two to four percentage points from real-time feedback devices, over and above savings from other interventions, such as energy-saving advice and more frequent, enhanced bills. This suggests that real-time pricing information, when combined with other programs and information, can lead to higher savings.

A sampling of similar reviews by others supports these earlier ACEEE studies. A review by Karlin, Zinger, and Ford (2015) of 42 studies published between 1976 and 2010 found average savings of 9%. There was wide variability, however, among the studies, with some showing little savings. The range reported in this meta-analysis was from negative effects to savings greater than 20%. The variability stems from the complex nature of these studies and the associated behavioral responses. Many variables affected the results, according to Karlin, Zinger, and Ford (2015), including:

- Study population (What were the size and characteristics of the population?)
- Study duration (How long was the study?)
- Frequency of feedback (How often did customers receive feedback?)
- Feedback medium (How were data and information provided?)
- Disaggregation (What level of energy-use data was provided? Total household energy only, or disaggregated by major uses?)
- Comparison (Were messages put in a context to allow comparisons with both household usage history and similar households?)

One key observation from reviews such as those by Karlin, Zinger, and Ford and Erhardt-Martinez is the apparent correlation between savings and the intensity of feedback (as indicated by frequency, medium, and message content). Generally higher savings are found with more intensive feedback and the associated message content. Customer engagement appears to be a key to performance. For example, a recent Pacific Gas & Electric pilot program of 400 in-home displays coupled with home area networks (HANs) that provided real-time information directly from smart meters yielded average savings of 5.6% (Conley 2014). A pilot program offered by Cape Light Compact also clearly demonstrated the importance of customer engagement. This pilot offered online tools that provided real-time feedback to customers and achieved average verified annual savings greater than 9% (MacLaury et al. 2012). Other important lessons from this three-year-pilot program include the importance of goal setting and gaining widespread participation and communication among households.

Other pilot programs have achieved relatively high savings. One example is a critical peak pricing pilot program of the Marblehead (Massachusetts) Municipal Lighting Department, which yielded 12.1% energy savings in the first program year and 3.9% in the second (GDS Associates 2013).

Some studies show little or no impact. For example, an enhanced consumer-feedback pilot implemented by Minnesota Power found no statistically significant electricity savings for either of the study's two treatment groups (Bensch, Keene, and Pigg 2014). Similarly, a pilot of smart metering by Oklahoma Gas & Electric found savings of 0–5% in energy use among the many customer segments examined for numerous periods defined by the study (Global Energy Partners 2011).

As mentioned above, dynamic pricing with associated time-of-use metering is another means to affect customer behavior and energy use. While time varying and dynamic pricing come in many forms, they are often used as a means to target peak demand (power). In numerous studies and programs over many years, time-differentiated rates have been shown to be an effective means of reducing peak demand, which can yield significant cost savings for both utilities and customers. Faruqui and Palmer (2015) reviewed 74 such experiments with dynamic pricing. They found customer response to some type of peak pricing yielded peak demand reductions of as much as 50%. Overall they also found a strong relationship between the peak/off-peak price ratio and the amount of peak reduction (the amount of response correlates with the size of the rate premium during peak periods). Effective communications to customers are critical for dynamic pricing. Customers need to understand the rate structures and how they can take advantage of them to lower energy costs, improve energy efficiency, and save energy.

While dynamic pricing has been found to be effective for peak demand management, its impact on overall energy use has been less clear. Since reducing total energy consumption typically has not been the objective of such pricing, there has not been as much research on the subject. King and Delurey (2005) examined the question of the conservation (energy-saving) effect of a broad set of demand response programs, including dynamic pricing. They reviewed 24 programs that included analyses of dynamic pricing on total energy consumption and found an average reduction in total energy use of 4% across these studies (1 commercial program and 23 residential programs). More recent time-varying rate pilots have found that energy savings impacts are typically less than 1%; however, it is possible that savings impacts increase over time as customers become more aware of pricing (Faruqui, Hledik, and Palmer 2012).

Relative to earlier efforts, the types of behavioral change programs that have emerged and been implemented over the past several years represent new approaches combined with new tools. Consequently, there remain questions on the persistence of savings that result from home energy reports and similar feedback programs. More and more experience is being gained as these programs have matured and grown. It is important for program administrators and evaluators to examine persistence of savings by gathering and analyzing longitudinal program data.

ENERGY SAVINGS

For this study we define the measure as AMI with enhanced feedback. We include time-varying rates as an addition to enhanced feedback only for the high-savings scenario. This reflects an assumption (for our midrange and low scenarios) that there may be programs that offer only enhanced feedback, without time-varying rates. Such programs will have an impact on energy use. However we do expect growth in the number of utilities offering time-varying rates, which would increase savings above the amounts achieved by enhanced feedback alone.

Overall we estimate savings of about 0.8% of US 2030 electricity use in our midrange case and 0.5% and 1.3% in our low and high cases, respectively. The three differ on the average savings per participant. In the midrange case we estimate 5% savings per participant. At the low end of the range we estimate 3%, and in the high end we estimate 8%. All of these values are supported by the research discussed above, both meta-analyses and a selection of recent individual studies. These values reflect our judgment that widespread deployment of smart thermostats will capture a significant share of the savings attributed to behavior change, because adjusting thermostats accounts for much of the savings that have been observed. We believe that as much as 50% of observed savings from behavior change could be attributed to adjusting thermostat set points in response to various types of feedback. The savings values we use in our analysis are reduced by 2% in each case (low, medium, and high) from unadjusted values (i.e., 5%, 7%, and 10% total savings). The high-end estimate includes additional savings of 3% from time-varying rates. Table 4-1 provides the details of the midrange case calculations.

Table 4-1. Electricity savings in 2030 from AMI

	Value	Unit	Comments
	1,526	TWh	2030 residential electricity consumption from EIA 2014
x	5%	average savings	A midpoint average of existing studies; also indicated by more recent studies such as Conley 2014
x	50%	participation rate	We assume that half of residential households will make use of AMI and related interface and information technologies to manage household energy use. Those not responsive to AMI include customers who may opt out of AMI.
x	95%	net-to-gross ratio	Free ridership is negligible; when utilities implement AMI, it essentially reaches all customers.
=	36	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.80%	of US electricity use	

DOE co-funded 10 research studies with utilities as part of its Smart Grid Investment Program to examine the impacts and benefits of time-based rate programs and enabling control and information technologies (Cappers, Todd, and Goldman 2013). Studies such as these should help to firm up expected load impacts to be achieved from time-based rates along with expected customer responses to AMI deployment.

COSTS AND COST EFFECTIVENESS

AMI technologies are being deployed at a large scale for a host of reasons. The primary drivers are improved system reliability and control. There also are large cost savings from automation of metering. These technologies also can enable a wide variety of customer demand–response measures; that is, short-term customer responses to reduce system demand (power as measured by kilowatts) at times when peak demand is being experienced such that system reliability may be threatened. Customer demand response is, in fact, one of the primary drivers for AMI technology. Reducing demand during high-cost peak-demand periods can yield substantial cost savings both for utility systems and for individual customers. As noted earlier, there is a convergence of AMI with smart thermostats, providing customers even more options for monitoring and managing their home energy use.

The multiple benefits of AMI technology make it difficult to isolate the benefits of energy savings relative to the costs of such technologies. The cost justification used to get such investments approved by regulators is typically a combination of system reliability benefits, reduced meter-reading costs (automated, not manual), and the need for ongoing general system infrastructure upgrades.

ACEEE's most recent work in this area (Foster and Mazur-Stommen 2012) reported average program costs for in-home displays and associated services at $500/year. For purposes of this analysis, we use a near-term cost of $250/device cost (installed) plus $25/year for administration and services for 10 years, yielding a total of $500. These assumptions lead to an estimated average cost of saved energy of $0.11/kWh with current costs and $0.077/kWh with estimated future costs. For comparison, research by Lawrence Berkeley National Laboratory (Billingsley et al. 2014) reports behavioral feedback programs as achieving a program administrator cost of $0.062/kWh (median value). Table 4-2 shows our calculations.

Table 4-2. Cost of energy saved through AMI

	Value	Unit	Comments
	11.6	MWh/home	Average household electricity use projected for 2030 from EIA 2014
x	5%	average savings	Discussed in text
=	0.58	annual MWh savings	
	$250	near-term cost of in-home displays/monitors	
	$75	long-term cost of in-home displays/monitors	
	$25	annual reporting and service costs	
	$0.11	per kWh	Cost of saved energy based on near-term cost
	$0.08	per kWh	Cost of saved energy based on long-term cost

UNCERTAINTIES

Customer response is a key variable in estimating potential impacts from implementation of real-time energy feedback programs and/or pricing. A large body of experience gained from existing studies and programs suggests a range of responses. Our base assumption of average customer savings is 5%, which reflects recent findings such as Conley (2014) and represents an approximate midpoint from many studies—some that found negligible savings and others that found 10% or slightly higher savings. Based on existing research, we believe the low end of the range of average savings to be 2% and the high end to be 9%.

Average savings of 5% is a conservative assumption that would capture likely long-term savings for large customer populations. It also reflects the strong likelihood of more effective information campaigns, customer interfaces, and control technologies that would combine to yield higher savings on average.

The other key variable is the number of households that would be responsive to dynamic pricing and enhanced feedback made possible by AMI. More research is needed in this area as large utility roll-outs occur. We assume that half of households will actively respond to improved feedback based on real-time metering over the long period of this study (to 2030). This is probably an aggressive estimate, but possible, in our opinion. It will require a major transformation in how customers receive and respond to energy use data and new pricing options and structures. Other ACEEE research (Foster and Mazur-Stommen 2012) suggests that about 10% of customers are "cyber-sensitive"—that is, engaged in and responsive to feedback data. These would likely be the early adopters. A variety of smart technologies are emerging that should enable interested customers to readily act on real-time data with dynamic pricing in place and reduce their energy use and associated costs. Such user-friendly technologies also should increase the numbers of participating households.

Persistence of savings is a major uncertainty regarding behavior change and feedback programs. The technologies and program approaches being applied are relatively recent phenomena. There has not been sufficient time yet to gather long-term data and determine persistence and possible erosion of savings over time. Customers may be engaged and actively respond to feedback in the initial year or more of programs, but over time they may become less engaged and reduce their active responsiveness to available feedback data. On the other hand, some customers may ramp up their engagement over time as they learn more about pricing signals.

Recommendations and Next Steps

AMI and associated customer interface technologies are rapidly being deployed for the many benefits such systems provide. Improved customer end-use efficiency and resulting lower energy use and costs are touted among the many benefits of AMI technology. Existing studies of real-time customer feedback show clearly that a variety of program elements need to accompany deployment of these technologies in order for customers to modify their energy use. AMI and associated dynamic rate structures are tools that can aid customers in reducing their energy costs. We offer the following recommendations to realize the energy savings potential of AMI and improved customer feedback:

- As AMI is introduced, ensure that effective information campaigns accompany such roll-outs to educate customers on the technology and how they can use it to manage and reduce energy costs.
- Provide technologies to customers that allow them to easily monitor their energy use, such as in-home displays and application software for smartphones, tablets, and other personal data devices.
- Provide easy tools for customers to visualize and understand their energy use, especially tools that will allow disaggregation of energy use to identify and quantify major types of energy use (e.g., lighting, air-conditioning, refrigeration).
- Provide normative data (comparison with comparable households), and readily track and report home energy use so consumers can examine trends and see their energy savings from specific actions in the household.
- Introduce time-of-use and other dynamic prices.

- Provide direct linkages and information on the full array of energy efficiency programs available to customers interested in taking action based on feedback information.
- Evaluate customer responses to AMI, dynamic pricing, and feedback. The results of such evaluations are important for determining the effectiveness of such measures and improving their performance over time. Since persistence of savings remains a major question for many regulators and stakeholders, conduct long-term studies of customer responses.

Ultimately for AMI and associated technologies to succeed in helping customers control and manage their household energy use, customers need to understand and value the changes possible with these technologies. Effective communication and support services will be critical. We recommend that program administrators continue to experiment with innovative programs and technologies that improve feedback to customers in conjunction with time-varying rates in order to gain more experience and information on customer responses and impacts. In this way customers can improve management of their household energy use and costs.

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Chapter 5. Smart Residential Thermostats

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MEASURE DESCRIPTION

Smart thermostats are the next generation of controls for residential heating, ventilating, and air-conditioning (HVAC) systems.[12] The ability of these devices to sense, communicate, and respond automatically are the primary technological advancements from earlier-generation programmable thermostats. These advancements enable residential HVAC equipment to be controlled intelligently—meaning these devices can react to selected real-time, complex inputs and adjust operation accordingly. For example, smart thermostats could be programmed to react to price or other signals sent by utilities to change temperature set points, or to cycle HVAC equipment off to reduce peak demand and associated energy use during times when electricity market prices are high or system reliability is threatened. They can also communicate with homeowners through mobile devices such as smartphones or tablets, enabling consumers to monitor and adjust operations of HVAC equipment and systems remotely. These devices incorporate different types of sensors and programming algorithms that essentially learn household occupancy, behavior, and comfort preferences and respond accordingly.

Connectivity and communication are key characteristics of smart thermostats. Connectivity externally to the cloud to access services associated with the hardware in a home is a key feature of connected thermostats. EPA's Connected Thermostats initiative is developing performance specifications for ENERGY STAR labeling of these devices. Smart thermostats also have the capability to be part of home area networks (HANs) composed of various smart devices, appliances, and in-home displays of energy use and associated data. Such capabilities can increase home performance, generally helping to eliminate wasteful energy use and enabling customers to closely match operation of home technologies and systems to their individual preferences and behaviors. While promising, more research and experience are needed to understand and assess performance of these systems. Connectivity is possible even with more traditional thermostats without the more advanced features that distinguish smart thermostats.

Programmable thermostats (without advanced communicating functions) have long been recognized for their potential to reduce home energy use and costs by better matching household needs for heating and cooling to occupancy schedules and varying comfort demands. In heating modes the programming typically involves reducing temperature settings from a daytime mode (e.g., 68°F) to a nighttime (sleep) mode (e.g., 60°F). There are day-away settings as well. Over the course of the last several years a few utility energy

[12] These devices have a variety of common names, including learning thermostats, programmable communicating thermostats, and connected thermostats. The names generally reflect distinguishing functionalities of the devices. Connected thermostats, for example, are those that blend climate controls with cloud services. Learning thermostats incorporate learning algorithms that sense household patterns and adjust HVAC controls in response. The terms are not entirely interchangeable. For example, not all smart thermostats are learning thermostats. "Smart thermostat" is really an umbrella term for the category, and there really is no universally accepted definition. EPA's Connected Thermostats initiative (EPA 2015) is working to develop performance specifications to go with ENERGY STAR labeling of these devices. This effort, along with other market developments, should help develop consistent terminology for these devices and technologies.

efficiency programs have offered rebates to consumers for the purchase and installation of programmable thermostats because of their ability to reduce household heating and cooling energy use. However, while the principle of programmable control is simple enough, many residential customers fail to achieve the potential savings possible due a variety of complexities with these devices and the complexities of household schedules and behaviors. As a result, some customers never properly program their thermostats or modify the program as their household conditions change. Customers also often override or turn off programmed settings, negating intended energy-saving operation.

Smart thermostats attempt to address many of the problems associated with conventional, non-communicating thermostats and have rapidly entered home-product markets. A variety of manufacturers offer smart thermostats, both long-established HVAC control companies such as Honeywell, Emerson, and Schneider Electric and newer companies such as Nest (now part of Google) and Ecobee. The Nest thermostat and others similar to it are markedly different from conventional home thermostats. In addition to their abilities to fine-tune household HVAC system performance, many feature monitoring, diagnostic, and automatic programming capabilities. These enable residential customers to engage with and track their home energy use—possibly receiving notices about performance benchmarks and unusual patterns of use that could signal equipment malfunctions or something being operated when it is not needed.

This product class is really composed of both products and the services they provide—typically data reporting and communications associated with the device in the home. While a couple of products, like the Nest thermostat, are exclusively bundled with the same company's service, the majority are designed to integrate with multiple services like EcoFactor or Energy Hub. In some cases, consumers will not be aware of this distinction, as one company will offer them a bundled product and service. Smart thermostats vary in the specific technologies used for sensing indoor conditions, such as occupancy, and in the algorithms and software used for responding to data and controlling indoor environments.

EXPERIENCE TO DATE

Assessing energy savings from use of smart thermostats faces fundamental challenges stemming from the complex nature of household energy use. A primary challenge is determining an accurate baseline of energy use. Another challenge is isolating the impacts of operational changes in household HVAC equipment resulting from smart thermostat control. There are many interactions between occupant behavior, such as engagement with control devices, and building elements and systems. These problems are not unique to smart thermostats but apply as well to traditional programmable models.

Because smart thermostats are new, there is limited—but promising—experience with their performance in reducing home energy use. A white paper released by Nest presents findings of three recent studies of energy savings resulting from Nest Learning Thermostats (Nest Labs 2015). All three of these studies were based on pre/post billing data, meaning that actual energy-use data were used, not engineering modeling as is sometimes done for estimating energy savings. Two of the studies were independently funded and conducted. One of these was a study conducted by Apex Analytics (2014) for the Energy Trust of

Oregon for a set of 185 homes heated by heat pumps.[13] The second of these independent studies was a pilot project conducted by Vectren Energy, a gas and electric utility in Indiana. This pilot consisted of Nest Learning Thermostats installed in 300 homes and standard programmable thermostats installed in 300 homes. Vectren Energy hired the Cadmus Group to evaluate the pilot program. The third study included in this white paper was performed by Nest and used a national sample of Nest customers from 41 states who had also enrolled in Nest's MyEnergy service, which provides data analysis and feedback to customers. Despite clear differences in key elements of the studies, the results were similar. The average savings were about 10-12% of total space-heating energy use and about 15% of total space cooling energy use. However savings values represent a broad distribution.

The white paper authors offer the following comment on variations among households:

> Although the average savings were similar across the three studies, it's important to note that thermostat savings in any given home can vary significantly from these averages due to differences in how people used their prior thermostat and how they use their Nest Learning Thermostat, as well as due to occupancy patterns, housing characteristics, heating and cooling equipment, and climate. Savings for any given customer may be much higher or lower than the average values. (Nest Labs 2015, 2)

A pilot thermostat program offered by the Northern Indiana Public Service Company (NIPSCO), a natural gas and electric provider, yielded similar findings (Aarish et al. 2015). In this program, 400 Nest thermostats and 400 programmable thermostats were installed in randomly selected NIPSCO natural gas and electric (dual-fuel) customers who had previously undergone a home energy assessment. Customers also received training in operation of their new thermostats. Participants in the Nest group reduced cooling electric use by 16%, and those in the programmable group reduced their electric use by 15%.

A national study that modeled energy and cost savings from the use of Honeywell's Total Connect Comfort (TCC) thermostats found that they would save about 6.6% of space conditioning energy use, which is about 2–3% of home energy use (Stewart 2014). These estimates are based on modeling results using user-interface data along with data on climate, household demographics, housing stock, and residential energy use. The energy and cost savings varied by region. Homes with TCC thermostats had lower average temperature set points during winter and higher average set points during summer. The seasonal energy savings were more pronounced: 4.5% average savings for heating and 19.4% savings for cooling. The approximate payback period, based on cost savings, varied by the type of climate zone, but was less than two years in all zones. Those regions with high air-conditioning demand showed paybacks of less than one year. The study concludes

[13] This study's primary objective was locking out auxiliary electric heat, which is provided by electric resistance heating elements. Reducing use of this auxiliary heat made up a significant part of the savings found. These savings result from the ability to properly control switchover to resistance based on outdoor temperature for heat pumps and to use anticipatory control to minimize the resistance hours.

that connected thermostats will be cost effective for many utility customers. However the authors also note the need for impact studies that employ energy-use meter data.

A recent study of 89 California households found a 6.1% reduction in whole-home electricity use (an average savings of $15.60/month) for customers who installed smart thermostats connected to web and mobile device software (Ho 2014). Savings were highest in August—an average of 17%. A key finding of this study was that after an initial adjustment period, households that adapted the thermostat's programming to their particular needs saw lasting and substantial savings. A primary determinant of savings was how much a household worked with the device to find temperature settings and associated programming that best suited their preferences. There was a learning curve that led to savings; those households that made the most of automated set points realized the greatest savings. Another finding of this study is that the bulk of program savings came from high-energy-use households.

The market for smart thermostats is growing rapidly. A recent study estimates that smart thermostats are on target to account for over 40% of the nearly 10 million thermostats sold in the US in 2015, and this trend suggests a market share of over 50% by 2017 (Hill 2015).

The technology is attractive to customers for the many features and functions offered by these devices. Because of the consumer appeal and the prospect of energy savings, many utilities and other program administrators are very interested in promoting smart thermostats through their residential energy efficiency programs. A number of utilities are conducting pilot studies or implementing full-scale programs, including National Grid Rhode Island, Efficiency Vermont, Baltimore Gas & Electric, Duke Energy, Sacramento Municipal Utility District, and Southern California Edison (Foster et al. 2015). EPA's Connected Thermostats initiative supports development of this market through performance specifications, ENERGY STAR labeling, and program partnerships. All these activities will help us understand the impacts of these devices on household energy use.

ENERGY SAVINGS

Our midrange estimate of electricity savings from smart thermostats assumes 12% average savings; for our high estimate we use 15% and for our low estimate we use 8%. These values represent likely potential savings based on early experiences with smart thermostats. They are averages across large populations; clearly there will be variations, with some customers achieving higher savings and some achieving lower savings. As shown in table 5-1, our midrange estimate is 0.5% of US electricity use. Our low estimate is 0.3% and our high estimate is 0.6%.

Table 5-1. Electricity savings in 2030 from smart thermostats

	Value	Unit	Comments
	413	TWh	2030 residential energy use for space conditioning (heating and cooling) from EIA 2014
x	90%		Estimated percentage of home heating and cooling systems controlled by central thermostats; excludes space heaters and room air conditioners. From RECS 2009 (EIA 2011): 92% of homes with heating systems have one or more thermostats; 83% of homes have AC (either central or window); of these 74% are central units, and virtually all central units are controlled by thermostats.
x	12%	average savings	Value chosen based on studies performed for Energy Trust of Oregon, Vectren, Pacific Gas & Electric, and Nest (see discussion above)
x	50%	participation rate	Average participation rate, 2016–2030, assuming a moderate ramp-up rate of adoption for new technologies. A large share of households are likely to install smart thermostats as a single-measure improvement. For the remainder of the market, over this period a majority of households will require some type of major upgrade, replacement, or servicing of household HVAC equipment. At such times we would expect that smart thermostats would be installed, capturing an additional part of the total market.
x	95%	net-to-gross ratio	Accounts for small percentage of free riders
=	21	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.50%	of US electricity use	

The energy savings from smart thermostats overlap with energy savings from customer feedback programs, which we discuss and estimate in Chapter 4. The savings estimates are for electricity only, since that is the focus of our research. It should be noted, however, that in northern climate zones with high heating loads, smart thermostats can yield significant natural gas savings as well. These would provide additional benefits to customers.

Costs and Cost Effectiveness

The price range of smart thermostats currently is $100–250 or more. As with many household appliances and devices, this wide variation reflects differences in technologies, functions, and features. Over time we expect to see some reduction in cost of the more full-featured devices as well as the introduction of more devices with fewer features to capture more of the lower end of this market.

For purposes of estimating cost effectiveness, we use a value of aggregate heating and cooling savings. More granular data are not yet readily available to support a disaggregated estimate. Table 5-2 shows our calculations.

Table 5-2. Cost of energy saved through smart thermostats

	Value	Unit	Comments
	4,072	kWh	Average home electricity use for heating and cooling. RECS 2009 (EIA 2011) gives the national average as 7.0 million Btu for heating, 6.9 million Btu for cooling, and 13.9 million Btu for total heating and cooling.
x	12%	average savings	Heating and cooling (see text)
	489	kWh	Total heating and cooling savings (annual)
	$250	device purchase price, near-term	Purchase and installation cost for smart thermostat, current
	$150	device purchase price, long-term	Purchase and installation for smart thermostat, projected
	48%	share of device cost allocated to electricity savings	Estimated percentage of total energy savings that are electricity savings; remainder are heating fuel, primarily natural gas
	10	year measure life	Assumed thermostat life cycle
	$0.03	per kWh	Cost of saved energy, current price
	$0.02	long-term cost	Long-term cost, projected

The estimated cost effectiveness in table 5-2 is for electricity savings only. As noted earlier, smart thermostats can yield significant natural gas heating savings in colder climates. Accounting for natural gas savings affects the cost effectiveness of these devices.

UNCERTAINTIES

As noted above, despite smart thermostats' rapid emergence in home-product markets and utility programs, experience is still somewhat limited as to their performance and impacts on household energy use. While most initial studies and early program results are promising, more experience and analysis are needed to reduce the uncertainty surrounding estimates of energy savings. Some studies suggest minimal savings, but this may be due to the nature of certain products and their functions. Challenges for evaluation of savings include: (1) variation among baseline practices in households and (2) variations among devices in their capabilities for sensing, learning, and communicating.

A major uncertainty is baseline practice for controlling home heating and cooling systems and resulting energy use. The largest savings for smart thermostats (and conventional programmable thermostats) result when there has previously been little or no programming or use of temperature setbacks when usage patterns have savings potential.

One problem with earlier-generation programmable thermostats was that they required customers to program them initially and then ensure that established programs were maintained and not overridden. The new generation of smart thermostats can greatly reduce this problem as many of them are capable of learning occupant use patterns and preferences. The user interface is much simpler and more intuitive. These devices also can alert household occupants of apparent problems with energy use. Because of these capabilities, there is generally high confidence that customers installing these technologies will effectively use them.

Another uncertainty is customer acceptance and resulting market share to be achieved by smart thermostats. Historically most households are slow to adopt new residential HVAC technologies, including controls. However the additional functions that can be performed via smart thermostats beyond simple control of HVAC systems, such as fire safety, combined with their ease of operation, may greatly increase the appeal of these technologies, especially compared with older-generation programmable thermostats, so that the market grows rapidly.

A final uncertainty is the persistence of savings. We are not aware of relevant studies that extend beyond one year.

Recommendations and Next Steps

Smart thermostats are revolutionary technologies that have sparked customer interest in a household device that long has been taken mostly for granted. They offer consumers a wide range of new capabilities and performance. For customers most interested in reducing and managing their energy use, smart thermostats are a positive, economical choice. The fact that one of the world's leading high-technology companies, Google, acquired Nest in a company purchase is a clear and strong indication of the promise of this household technology. The market is growing rapidly. Customers are gaining a wide spectrum of choices for smart thermostats from a growing number of suppliers---from less expensive, simpler devices to higher priced models with more functions and features.

Interest in, and markets for, smart thermostats are evolving and rapidly growing on their own, apart from any utility or related energy efficiency or demand response programs. Still, utilities and other program administrators have valuable roles they can play to foster and help grow the markets for, and increase the benefits of, smart thermostats. The information streams and communicating capabilities of these devices yield a number of benefits for utilities, including home energy use diagnostics, support for evaluation of related home energy efficiency programs, and customer engagement.

As discussed above, there still is a need for research on the performance of these devices in terms of their energy savings. There also is a need for research on the nonenergy benefits of these devices. Such data are important both to understand the value of these devices to households and to determine the cost effectiveness of providing incentives to utility customers for purchasing and installing them. Programs can accelerate adoption of new technologies like smart thermostats by providing information and possibly incentives for purchasing and installing these technologies.

The newness of the technology also means that there is a need for multiyear savings and persistence studies. Utilities and related organizations can play a critical role in conducting and evaluating long-term studies on the performance of smart thermostats. The data capabilities of smart thermostats themselves can be used to evaluate savings and persistence. The connectivity of the devices also may open up and create demand for new approaches to customer energy savings programs through such features as over-the-air software updates.

Smart thermostats will be important components in networked utility systems, providing benefits to utilities for demand response and other load management and control efforts. Utilities should factor widespread deployment of smart thermostats into their system planning and investment decisions. These devices can be integral to achieving lower system costs at the same time as they help customers save energy and money.

Our primary recommendation for program administrators is to initiate and complete pilot programs—expanding them to full programs as appropriate based on evaluation of pilots. National initiatives, such as EPA's Connected Thermostats, can support development of this market.

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Chapter 6. Advanced Residential Air Conditioners and Heat Pumps

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MEASURE DESCRIPTION

High-efficiency central air-conditioning equipment and systems, properly installed and commissioned, can greatly reduce household energy use, especially in climates with high cooling loads. Similarly, high-efficiency electric heat pump equipment and systems can yield reduced energy use for both space heating and cooling. "High efficiency" implies better components (including improved compressors, larger heat exchangers, and improved controls). To achieve optimal savings requires installation of high-efficiency central air-conditioning (AC) or heat pump (HP) units along with Quality Installation of the equipment and associated ductwork or system components necessary to distribute conditioned or heated air. We examine several baseline cases for high-efficiency replacements and new construction, assessing energy-saving potential for residential central air-conditioning and heat pumps. Residential equipment is characterized by capacity (under 65,000 Btu per hour in cooling) and power type (single phase). Anything larger is commercial, treated in Chapter 11.

Split-system heat pumps are very similar to the corresponding central air conditioners, except that the refrigeration cycle can be reversed: during winter, heat pumps capture heat from the cold outdoor air and move it indoors; for cooling this is reversed, with indoor heat moved outdoors. Internally, these systems have additional refrigerant circuitry and controls, and the design is altered to optimize as much as possible for both cooling and heating.

In North America, *ducted central systems* predominate. These exchange heat between refrigerant and air and distribute the conditioned air through ductwork to most of the rooms of the house or commercial building. AC *split systems* put the compressor and condensing heat exchanger outdoors, connected to the evaporator, ductwork, and air handler fan indoors. Alternatively, *packaged* AC, typically roof-mounted, put the two halves in a single cabinet. Where there are basements, the furnace, indoor AC coil, and most ductwork are located there. For slab-built houses, typically newer and typically in milder climates, equipment and ductwork are generally located in the attic, or possibly in a garage (which makes air distribution throughout the house more challenging).

In contrast, *ductless split systems* predominate globally, with North American types of ducted central air-conditioning systems relatively rare outside the US and Canada (CLASP et al. 2011). Ductless systems typically have variable-speed, variable-capacity, *inverter-driven* compressors. By running their compressors at very high speeds, and with adaptive controls, these units can maintain substantial capacity and efficiency down to temperatures below 0°F.

Like US split systems, ductless units employ an outdoor condensing unit. Indoors, they generally employ wall-mounted fan-coil units. The basic system has a single indoor evaporator and is functionally analogous to a room air conditioner. Modulating single-head ductless systems are beginning to gain traction in the US. They are most commonly referred to as variable refrigerant flow (VRF) or inverter systems because their modulating compressors are driven by variable-frequency inverters. They can have very high efficiency ratings with the test procedure used for multihead systems. By definition, ductless systems do not have duct air leaks or insulation issues. Their sophisticated control logic removes some of the Quality Installation issues discussed later in this chapter.[14]

Inverter-driven compressor technology is gaining traction in the US for premium ducted as well as ductless systems and will eventually be applied to all but base-level commodity products. When combined with modulating air handler fans, real "air-conditioning" with fine control of both temperature and humidity can be routine. There are advantages and disadvantages for both ductless and ducted systems. One principal challenge for ductless systems is premium pricing.[15] The principal challenge for the incumbent ducted systems is demonstrating cost-effective savings as minimum efficiency standards rise. Comprehensive Quality Installation/verification programs can be important.

The most recent public sales data indicate that annual residential sales of AC and HP systems averaged 4.4 million and 1.9 million, respectively, between 2004 and 2013 (AHRI 2015). This interval coincided with the housing bubble, collapse, and recovery. Although these central air-conditioning systems are used predominantly in single-family and low-rise multifamily applications, a small percentage of the approximately 6 million total units sold each year are installed in small commercial buildings, typically less than 5,000 square feet in size, and with construction technology similar to that for single-family houses. Their small number leads us to include them as residential installations. Sales of ductless units remain low, but manufacturers maintain that they are growing very quickly.

Residential systems are rated by seasonal energy efficiency ratio (SEER) for cooling and heating season performance factor (HSPF) for heating (heat pumps only). As the terms indicate, both are seasonal estimators. Steady-state performance metrics at 95°F for AC and heating at various ambient temperatures are called EER and COP, respectively.[16] EER is used in computing SEER and also is important to utilities concerned with peak demand.

On January 1, 2015, updated federal standards took effect. For the first time, these AC standards vary by region, as shown in table 6-1.

[14] Quality installation (i.e., the ACCA 5 QI standard) includes elements that are important to efficiency, comfort, and economics of ductless units: ventilation, proper sizing (even for modulating units), and proper installation.

[15] In this study, we use cost data from DOE's Technical Support Document (DOE 2011), which does not differentiate costs or standards levels between ducted and ductless/inverter systems. We have not found this cost approach to be optimal, but more relevant data are not available.

[16] Energy efficiency ratio (EER) measures peak capacity at high temperatures. It is the ratio of the cooling output (Btu) to the electric input (kW) under standard conditions, including 95°F outdoor temperature. Coefficient of performance (COP) measures peak heating capacity under standard conditions. Definitions and test conditions vary among equipment classes.

Table 6-1. 2015 federal minimum efficiency standards for central AC and HP

	SEER	HSPF split/packaged	EER
North	13	8.2/8.0	
South	14	8.2/8.0	
Southwest: small	14	8.2/8.0	12.2
Southwest: large	14	8.2/8.0	11.7
Southwest: packaged	14	8.2/8.0	11

We omit ratings for specialty products and the limits for stand-by and off-mode power consumption. *Source:* DOE 2015.

Pushing the Envelope on SEER and HSPF

As part of the standard-setting process, the Department of Energy attempts to determine the efficiency level associated with "Max Tech"—that is, the most efficient product (in terms of the current SEER test procedure) that can be offered with technologies available in the market. The most recent determination, in Chapter 5 of the Technical Support Document (DOE 2011), indicate max-tech SEER levels for split-system air conditioners and heat pump systems of 21–24.5 for smaller systems and 18 for large residential systems (cooling capacity of 60,000 Btu/hr). For HSPF, DOE max-tech efficiency levels are 10.3, 10.7, and 9.8 for 2-, 3-, and 5-ton capacities, respectively (Table 5.4.11). DOE did not set separate max-tech levels for ductless mini split systems (Section 5.8.2.1, p. 5-35).

Today, SEER, supplemented by EER, is the basis for residential air-conditioning incentive programs. Some voluntary programs also add various requirements, such as prescriptive installation features and tests. Several approaches offer different SEER, EER, and HSPF levels that public benefits programs could offer.

In its voluntary program approach, the Consortium for Energy Efficiency (CEE) develops standard incentive tiers at increasing performance levels (CEE 2015a). These tiers are developed as guidance for coordinated utility and other public benefits incentive programs, with the goal of establishing national consistency. This would simplify industry efforts to respond to the opportunity these rebates offer to increase sales of more efficient products. Table 6-2 shows the CEE tiers effective in January 2015.

Table 6-2. CEE incentive tiers for split central air conditioners and heat pumps

Level	SEER	EER	HSPF
CEE Tier 0	14.5	12	8.5
CEE Tier 1	15	12.5	8.5
CEE Tier 2	16	13	9
CEE Tier 3	18	13	10

CEE tier levels are based largely on the efficiency distribution of models on the market and on estimates of energy savings. "These tiers are based on considerations outlined in the initiative that may include, for example, energy savings potential, market readiness or penetration, or technical feasibility"(CEE 2015b). Feedback from manufacturers is utilized in the development process.

Another voluntary recognition program is the ENERGY STAR Most Efficient specification, which recognizes the most efficient products among those that qualify for the ENERGY STAR program. For conventional ducted equipment, tens of models, including some heat pumps, are recognized. Some of these models are Johnson Controls brands with minimum EER 13.5, SEER 18, and 10.1 HSPF for four heat pump models. All of them are small, with 2- or 3-ton capacity (24,000 or 36,000 Btu/hr).

Much higher SEER levels are attainable by small, single-head, ductless heat pumps, as recognized in the ENERGY STAR Most Efficient 2015 criteria for these products. These require minimum ratings of 20 SEER, 12.5 EER, and (for heat pumps) 9.6 HSPF. Eighteen models from three brands are recognized (ENERGY STAR 2015). The largest unit listed has 57,000 Btu/hr capacity.

In both cases, the limited number of models available and manufacturers represented and the small capacity of ducted units suggest that these levels will not be ready for mass market program adoption soon.

Thus, there is still headroom for improved efficiency, although the price per SEER unit will rise and the relative savings decline.[17] At current system and energy costs, CEE Tier 3 (SEER 18, EER 13, HSPF 10) is probably close to an upper limit for split-system programs in relatively high-cost electricity regions with relatively long, hot summer seasons.

Electricity is the primary heating source for one-third of all US houses. US houses can be divided into three roughly equal-size groups by climate: very cold/cold (roughly the northern third of the country by area); mixed-humid (roughly Texas and east, Maryland and south); and the combination of mixed-dry, hot-dry, and hot-humid/marine (mostly Southwest and Pacific Coast portions of the country) (Baechler et al. 2010; EIA 2011). The fraction of electric-heated houses varies from 14% (5.6 million) of the 39 million houses in the very cold/cold climates to 65% (12.4 million) of the 19 million hot-humid subclimate zone houses. Table 6-3 shows the distribution of electric heating by climate.

[17] The price per SEER unit increase is likely to rise as additional materials are often required (e.g., larger heat exchangers), leading to larger sizes and disproportionately greater weight increases. The percentage savings increase expected is greater from SEER 13 to 14 (almost 8%), while SEER 17 to 18 yields not quite 6%.

Table 6-3. Residential electric heating distribution by climate type (million houses and systems)

	All	Very cold or cold	Mixed-humid	Other*
Total houses	113.6	38.8	35.4	39.5
% total by climate region	100%	34%	31%	35%
Electric heated houses	38.1	5.6	13.6	19
% electric heated houses	34%	14%	38%	48%
HP houses	9.8	0.8	4.7	4.3
Electric furnaces	19.1	1.8	6.5	10.8
Built-in electric	5.7	2.4	1.6	1.7

*Mixed-dry/hot-dry, hot-humid, and marine. Population weighting by state populations in 2015 regional standards. Data calculated from EIA 2011.

Ducted central air conditioners, heat pumps, and electric furnaces all use similar types of ductwork. The most common ducted electric system is the electric furnace. Nationally, there are almost twice as many (resistance) electric furnaces installed in US houses as heat pumps (19.1 million versus 9.8 million). This is despite the fact that the heat pump will use less than half as much energy as the resistance-based electric furnace on an annual basis. The ratio of warm air electric furnaces to heat pumps ranges from 1.4:1 in the mixed-humid climate region to 2.7:1 in the hot-humid subregion.

From EIA (2011), electricity is the principal heating source for 38 million of the 113.6 million heated houses in the US (34%). About one-quarter of electric-heated houses use heat pumps, typically as part of a central air-conditioning system. Most of the remaining houses have electric furnaces (central forced-air resistance heat), baseboard resistance, ceiling-mounted radiant, or other systems. Of the 19.1 million ducted electric heating systems, only 1.8 million are in very cold or cold climates (EIA 2011). However about 5.7 million homes rely on "built-in [resistance] electric units." These are often replaceable by small ductless heat pumps, which operate successfully (high capacity and high efficiency) at temperatures below 0°F. (Hales, Lubliner, and Howard 2012). Energy savings in the Pacific Northwest are large where there is no supplemental fuel use (e.g., wood), averaging 2,700 kWh/yr for a sample of more than 3,000 houses with billing analysis. Supplemental heating use can cut electric savings in half, or even increase electricity use (Baylon, Storm, and Robison 2013).

For ducted systems, both heat pumps and electric furnaces, we evaluate savings for conversion to advanced heat pumps at HSPF 9.6, with equipment change-out and Quality

Installation (see the following section for a description of this practice). Changeover would generally be done at the time a central air conditioner is replaced.[18]

Non-ducted electric resistance systems are dominated by baseboard radiators plus wall- or ceiling-mounted radiant heating. These systems typically have room-by-room thermostats, to allow turning off or setting back rooms not in use, thereby reducing energy use. We assume these systems are replaced with ductless mini splits with HSPF 9.6, which is the 2015 ENERGY STAR Most Efficient level. Converting these resistance-heated houses to ductless heat pumps provides amenity comparable to their current systems, and allows abandoning any existing duct system installed for air-conditioning (typically attic-based) instead of attempting to make the ductwork leak free and well insulated through Quality Installation.

A Key Supplement: Quality Installation, Low-Loss Distribution

Saving energy with central air-conditioning and heat pump programs requires understanding that the split (or packaged) product is part of a system that also includes controls (thermostat, humidistat, etc.). More critical is the quality of the air distribution system that carries chilled or heated air from the air conditioner or heat pump to individual rooms through ductwork, and back as return air. Duct system performance is critically dependent on design (e.g., duct sizing, fitting selection, and use of adjustable branch dampers) and installation (insulation and sealing).

No matter how carefully equipment components are matched and installed, or how high the efficiency of the air conditioner, bad distribution systems can nullify incremental equipment investment. These issues have been intensively studied in tens of thousands of houses during the past decades, as summarized in the literature review section of Domanski, Henderson, and Payne (2014).

Significant equipment installation issues include oversizing of single-stage units, mismatched indoor and outdoor sections, wrong thermostat and/or incorrect control wiring, air handler fan undersized for ductwork, sub-optimal air filters, wrong fan speed selection, and incorrect refrigerant charge.[19] Duct issues include substantial duct leakage, substantially deficient duct installation, and equipment in uninsulated spaces such as attics; duct runs with excess pressure drops and air flow restrictions due to long, circuitous, pinched, or constricted ducts or poor fitting selection; and undersize return ducts and grilles. To summarize:

> The study found duct leakage, refrigerant undercharge, oversized heat pump with non-oversized ductwork, low indoor airflow due to undersized ductwork, and

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[18] Since these homes have air conditioning, we assume that very few of them are in very cold regions where heat pumps provide only modest energy-saving benefits.

[19] Systems installed after January 1, 2006, generally use thermostatic expansion valve (TXV) refrigerant metering, which is less sensitive to refrigerant charging by the installer than the older fixed orifice and capillary tube controls.

> refrigerant overcharge to have the most potential for causing significant performance degradation and increased annual energy consumption. Increases of energy use by 30% due to improper installation practices seem to be plausible (Domanski, Henderson, and Payne 2014, 83).

The Air Conditioning Contractors of America (ACCA), a contractors' trade association, responded to these challenges in 2007. Working with EPA, efficiency advocates, and industry, it developed HVAC Quality Installation (QI) standards (ACCA 2007, 2010, 2015), a suite of supporting documents on Quality Installation verification (ACCA 2011, for programs), and a Quality Maintenance Standard (ACCA 2007, 2013).

Regional AC Opportunities

We mention but do not analyze several specialized areas that may be of interest for advanced and/or regional programs. These include the following:

- *Low sensible heat ratio (SHR) for the Southeast.* Lower SHR values mean more humidity is removed, avoiding cold, clammy air. This may allow raising the temperature and may save energy. Although relatively little field research has been done to date, we recommend that program operators whose service areas are predominantly in warm-humid climates consider stipulating maximum SHR levels for high-SEER products and/or require systems with automatic humidity control.
- *Alternative opportunities for arid regions.* As part of ACCA QI, it may be possible to specify minimum airflow rates, such as 400 cfm/ton, although these may vary by equipment type. QI could also require setting fan controls for a longer run time after compressor cutoff, maximizing evaporation. Significant savings may be attained with evaporatively cooled condensers (Faramarzi, Lutton, and Gouw 2010; German, Dakin, and Hoeschele 2012).

EXPERIENCE TO DATE

This section is largely based on a review of the CEE 2014 Residential HVAC Program Summary (CEE 2014), which provides information on 27 utility programs. Programs vary significantly in their requirements for receiving incentives. One utility offers incentives at all CEE tiers, up to $1,100–2,000 for certain very advanced equipment. Another covers SEER 17 (between CEE Tiers 2 and 3), with payments to the distributor of $238/ton. A larger incentive, $387/ton, is offered for 18 SEER (CEE Tier 3) equipment. However, in total only about 5% of reporting CEE members offer incentives at levels comparable to CEE Tier 3 (SEER 18; EER 13). In contrast, about one-third of programs offer incentives at CEE Tier 2 (SEER 16, EER 13).

In addition to equipment specifications, over 60% of programs in CEE's set also have some Quality Installation metrics, although slightly less than half are based on ANSI/ACCA 5-2010. Savings from these programs are plausibly 20%, a more conservative estimate than that of Domanski, Henderson, and Payne (2014). Other programs include a variety of approaches, either developed locally or based on California-originated charge and airflow requirements, often with duct integrity tests also.

Zooming in, the New Jersey Clean Energy Program offers basic, statewide $500 incentives for purchase and installation of central air conditioners or ductless mini-split AC systems that meet or exceed SEER 17 and EER 13 (New Jersey Office of Clean Energy 2015). This New Jersey COOLAdvantage program also requires ACCA Manual J (load calculations) and Manual S (equipment selection) outputs from the contractor to demonstrate an appropriate equipment choice. No further Quality Installation requirements are listed.

In Massachusetts, the Mass Save Cool Smart rebates address both better equipment and Quality Installation, using both customer and contractor incentives. A $250 rebate is available for SEER 16, and $500 is offered for SEER 18, with EER 13 required for all equipment. This is coupled with ENERGY STAR Quality Installation incentives covering matched equipment, Quality Installation Verification (QIV), measured duct leakage reduction, and duct repairs.[20] This part of the program offers $100 to the consumer and up to $1,300 to the contractor (Mass Save Cool Smart 2013). For ductless mini splits, the minimum requirements are SEER 18 ($250) and SEER 20 ($500), with no QIV requirements (Mass Save Cool Smart 2015).

Puget Sound Energy in Washington offers a $1,500 rebate to residential customers who convert from an electric furnace to a new air source heat pump with minimum requirements of 8.5 HSPF/14 SEER (Puget Sound Energy 2015). Additional incentives are available for lock-out controls that limit use of backup electric resistance heating. Numerous electric cooperatives also offer incentives for these conversions.

Programs can also be used to promote installation of ductless heat pumps to replace or reduce the use of electric baseboard heat. A website called Going Ductless lists many programs that provide rebates in the Northwest (NW Ductless Heat Pump Project 2015).

ENERGY SAVINGS

Cooling Savings

Residential energy savings are projected based on continued adoption of regional standards for residential central air conditioners. As summarized in table 6–1 above, the 2015 standards require SEER 14 in southern and southwestern states and SEER 13 in the rest of the country. CEE only sets national program tiers, currently SEER 16 (Tier 2) and 18 (Tier 3). From our analysis of the DOE Technical Support Document (DOE 2011), we model regional programs at SEER 17 in southern and southwestern states and at SEER 15 for the rest of the country. This is lower than DOE's capacity-dependent max-tech levels, which range from SEER 22 for 2-ton units down to SEER 18 for 5-ton units (DOE 2011, Table 5.4.11). We believe that the levels chosen approach the levels that are cost effective regionally and generally incorporate modulating compressors and better-efficiency fan motors.

Unit AC energy consumption in the North is half that of the national average, while southern and southwestern average use is 50% higher than the national average, so the stringency difference is justified, except where energy prices are unusually low (in the

[20] ENERGY STAR Quality Installation specifications are based on the ACCA specifications. See https://www.energystar.gov/index.cfm?c=hvac_install.hvac_install_index.

South) or high (in the North). These levels balance between more energy savings versus more consumers who would face higher life cycle costs. Total savings were estimated by multiplying the SEER-based savings with the relative amounts of AC energy used in the North (18%) versus the South plus West (82%). These percentages are based on all residential AC use, not just central AC, reflecting EIA 2009 data tables (EIA 2011). Average savings are 17%, based on 18% savings in the South plus West (going from SEER 14 to 17) and 13% savings in the North (going from SEER 13 to 15).

For heat pumps, we analyzed upgrading from the current federal standard of 8.2 HSPF to a new HSPF at 9.6 and calculated a 15% energy saving.

We also considered the role of Quality Installation, which, as mentioned above, addresses duct problems, sizing, refrigerant charge, airflow, and related issues (ACCA 2007, 2010, 2015). We estimate potential QI national savings of 20%, reducing the 30% losses shown by Domanski, Henderson, and Payne (2014) because the extreme losses to the outside for attic installations should be reduced for the fraction of houses with basement or crawl space ducts, where duct losses are at least partially recovered by air and heat exchange with the living areas of the house above. Thus, Quality Installation could save even more energy than our proposed standards, if QI is required.

The implementation challenge is that equipment efficiency standards are a federal responsibility, but mandatory Quality Installation is part of state jurisdiction through building codes. Even if required by an authority having jurisdiction (AHJ), enforcement may be spotty. Consistent with other measures in this report, we estimate 50% of consumers will get QI with new installations, either because the AHJ will both adopt and enforce Quality Installation or because the serving utility will have very effective programs.

Electric Heating Savings

Electricity used for heating is remarkably constant across US Census regions: 1,986 kWh/yr, +/– 12%. Savings opportunities accrue from three large improvements:

- Improve the present stock of heat pump houses by adding QI and upgrading from today’s minimum HSPF 8.2 to HSPF 9.6. Savings are 15% from HSPF alone, and 20% (net) for QI, or 32% with HSPF plus QI. This affects about 9.8 million housing units.
- Convert 19.1 million resistance electric furnaces from HSPF 3.4 to heat pumps at HSPF 9.6 (65% savings), and include the same 20% net Quality Installation savings for total savings of 72%.[21]
- Replace or augment built-in electric units with ductless mini split equipment in the 5.7 million houses that use built-in resistance heat, as has started in the Pacific Northwest. Mini splits are suitable for all but the very coldest climates, so we deduct half of the 2.4 million (cold climate installations) from the total, for 4.5

[21] HSPF is a seasonal coefficient of heating performance, analogous to SEER. The units are thermal Btus (delivered) per site watt of electricity used. Since resistance heating has COP ~1 (watt/watt) and there are 3.412 Btu/watt, the HSPF of a resistance unit, accounting for seasonal factors, is in the range of 3.4.

million houses. This moves HSPF from 3.4 to 9.6 for each unit of resistance heat replaced. Savings are the same as calculated above for conversion of built-in electrics to mini splits.

Weighting each of these savings by the number of homes that could be affected, average savings are 50% without QI and 60% with QI.

Pulling all these assumptions together, table 6-4 estimates the energy savings that could be achieved under our medium-case participation rates. Total savings could be as much as 2.7% of projected 2030 US electricity use, considering cooling savings, heating savings from more efficient heat pumps, and heating savings from conversions of electric resistance heat to heat pumps. Without conversions of electric resistance heat, the savings are 1.5% of 2030 electricity use, including 0.8% savings from more efficient equipment and 0.7% savings from quality installation.

Table 6-4. Electricity savings in 2030 from advanced residential heating and cooling

							2030 savings	
Measure	End-use TWh	% covered	Avg. % savings	Particpn rate	Net to gross	Comm'l adder	TWh	As % of US TWh
High-efficiency AC, equip. only, no QI	313	87%	17%	50%	95%	110%	24	0.6%
High-efficiency AC with QI	313	87%	32%	50%	95%	110%	46	1.1%
High-efficiency HP replacements for HP, no QI	341	28%	15%	50%	95%	110%	7	0.2%
High-efficiency HP replacements for HP with QI	341	28%	32%	50%	95%	110%	16	0.4%
High-efficiency HP replacements for electric furnaces, no QI	341	55%	65%	30%	95%	110%	38	0.9%
High-efficiency HP replacements for electric furnaces with QI	341	55%	72%	30%	95%	110%	42	1.0%
Ductless mini split replacements for electric strip heat in living space	341	16%	65%	30%	95%	110%	11	0.3%
Total without QI							81	1.9%
Total with QI							115	2.7%

Percentage covered excludes room AC for cooling. Percentage covered for heat pumps based on different baseline units as discussed in the text. Average savings assumptions discussed in text. Participation rate 50% for equipment subject to standards (discussed in Chapter 1) and 30% for heating system changes (discussed in this chapter). Net-to-gross ratio is the standard assumption for this report as discussed in Chapter 1. Commercial adder allows for the fact that some residential-size equipment is used in the commercial sector. Totals may not quite sum due to rounding of individual values.

Examining the table, we see the following:

- The largest opportunity is converting resistance heating, whether electric furnaces or built-ins, to heat pump technology. For the former, we urge moving from electric furnaces to very efficient heat pumps, with Quality Installation. For the latter, mini splits, which require no ducting, may be preferable. Heating conversions from resistance to heat pumps could save about 1.3% of projected 2030 electricity use.
- The potential electricity savings on the heating side (1.7%) are greater than the cooling savings (1.1%). Of course, the relative savings are larger because base resistance heating is so inefficient (HSPF of resistance is about 3.1), while the base air conditioner is relatively efficient.
- The context is that projected 2030 electric heating uses only about 0.34 quad site (~1 quad source), versus 2.7 Q for natural gas heating.
- Quality Installation matters. Total savings with QI are about 40% higher overall than equipment-only.

Tables in Chapter 1 also provide low-case and high-case savings with different participation rates—25% lower and 33% higher, respectively. These cases result in maximum total savings of 2.0% and 3.6% of projected 2030 electricity consumption, respectively.

COSTS AND COST EFFECTIVENESS

In table 6–5 we tabulate results for four central air conditioner categories: equipment only versus equipment plus QI, and hot-dry/hot-humid climates in the US versus all other US climates.[22] For electric heating, we separately treat three program opportunities: forced air (FA) systems with present heat pumps replaced with advanced heat pumps (HSPF 9.6) at time of failure; FA systems with present electric furnaces replaced with advanced heat pumps, at any time; and built-in electric resistance systems (baseboard or radiant) replaced by ductless mini splits. Costs and sources are annotated below the table. For all except the built-in to ductless case, we assume 2,000 kWh/yr for electric heating in houses for which electricity is the principal heating source, from RECS 2009 Table CE 4.6 (EIA 2011). It is undoubtedly unrealistically low for electric furnaces, which have resistance technology compounded by duct inefficiencies. The reader may want to use our consumption for built-in to ductless instead. Those data were calculated from energy savings and coefficients of performance (COPs) in Ecotope 2014, table 12, net metered savings, Willamette Valley. This study is much more detailed, accounting for both take-back and auxiliary heating (primarily wood).

[22] States are classified as per the 2015 federal regional standards.

Table 6-5. Cost of energy saved through advanced residential heating and cooling

Measure	Unit energy use (kWh)		Incremental cost (dollars)		% of costs assigned to other benefits	Avg, measure life (years)	Cost of saved energy (dollars)	
	Current	With measure	Current	Long term			Current	Long term
Residential AC, equipment only, hot climates	2,896	2,375	458	344	0	18	0.08	0.06
Residential AC, equipment only, rest of nation	1,436	1,249	277	208	0	18	0.13	0.10
Residential AC, equipment plus QI, hot climates	2,896	1,796	958	719	0	18	0.07	0.06
Residential AC, equipment plus QI, rest of nation	1,436	962	727	545	0	18	0.13	0.10
High-efficiency HP replacements for HP, no QI	6,000	3,000	597	448	0	18	0.02	0.01
High-efficiency HP replacements for HP, with QI	6,000	2,400	997	748	0	18	0.02	0.02
High-efficiency HP replacements for electric furnaces, no QI	6,000	3,000	597	448	0	18	0.02	0.01
High-efficiency HP replacements for electric furnaces, with QI	6,000	2,400	997	748	0	18	0.02	0.02
Ductless mini split replacements for electric strip heat in living space	6,048	2,419	3,874	2,906	0	18	0.09	0.07

Energy use derived from DOE 2011 and RECS 2009 (EIA 2011). Present installed costs from DOE 2011, Table 8.2.25 (SEER 16.5 versus 13.5, except ductless). Ductless installed costs from Ecotope 2014, Figure 10, Willamette Valley (~2,000 installs). Current QI=$900, split between HP and AC, not used for ductless. 25% decline in equipment and QI cost over the long term. Measure life from DOE 2011.

For air-conditioning, at current DOE-estimated equipment and installation costs, the proposed SEER 17 (hot) and SEER 15 (rest of nation) levels are generally cost effective in the hot region and borderline in the rest of the nation (depending on the price of power during summer afternoons and evenings). Quality Installation looks cost effective for heat pumps and for cooling in hot regions, and borderline for cooling in other regions. Efforts to reduce the cost of Quality Installation will be useful. Switching from electric furnaces to heat pumps is generally cost effective as costs of saved energy range from 1-2 cents. Use of ductless units will often be cost effective, particularly in the long term (average cost of saved energy of 7 cents/kWh).

UNCERTAINTIES

Our estimates are subject to significant uncertainties. First, as the electric heat discussion shows, CSE is highly sensitive to the number of hours of use assumed for each year. Second, the cost of very high-efficiency equipment are uncertain—current costs are fairly high as these are niche products, but these costs will come down. How much they come down is unknown. In the cost section above we extrapolate long-term costs from the most recent DOE analysis (DOE 2011). Techniques to bring QI costs down need to be explored. However, to get QI to scale, it is at least as important to convince program administrators and code officials of the value of Quality Installation.

An upcoming challenge is the EPA-mandated transition from the current low-ozone-depletion refrigerants, predominantly hydrofluorocarbons (HFCs) like R-410A, to alternatives that also have low global warming impact.[23] Some alternatives will have flammability challenges; others will have efficiency concerns. Some high-cost synthetics have emerged, but it is likely that different applications will utilize different refrigerants, increasing engineering challenges and costs. In some cases, manufacturers will even offer *indirect* or *secondary refrigerant* systems, which keep flammable or mildly flammable refrigerants outside the building and transport energy with water or other fluids. This is an engineering challenge.

Another challenge—for the analyst as well as industry—is forecasting the penetration rate of ductless systems. These are widely used globally, and they can offer high part-load efficiency and easy zoning to *not* condition unoccupied spaces. The basic configuration includes a modulating compressor serving multiple head units with refrigerant lines instead of ductwork. This eliminates duct leakage, and the eventual incremental cost may be competitive with proper ducts, particularly in retrofits.

With these challenges and opportunities, projecting the efficiency levels that can be justified for 2030 is challenging. We have chosen to rely on DOE costs at different efficiency levels, with input from the performance levels that CEE has chosen for its common tiers for rebates and other incentives.

Our analysis, particularly for energy use, carries the implicit assumption that increases in house size will be balanced by improvements in house envelope thermal performance resulting from better codes, better practices, and better technologies (e.g., next-generation windows).

RECOMMENDATIONS AND NEXT STEPS

The US South uses more than three times as much air-conditioning energy as the Southwest but has much lower program activity. Together, they use 82% of US residential AC energy. Thus, the most fruitful regions for cost-effective cooling savings are likely to be found in southern/southeastern areas with relatively high (or rising) electricity tariffs.

Perhaps the greatest surprise is the tremendous opportunity in moving the 25% of houses with resistance space heating to heat pump technologies, with the potential to save close to two-thirds of the space-heating energy in each house. Better heat pumps, replacing electric furnaces with heat pumps, and replacing built-in resistance heating (e.g., electric baseboard heat) with ductless mini splits could save more than 1% of total projected US electricity in 2030.

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[23] Manufacturers argue that the best metric for global warming is total impact (total equivalent warming impact [TEWI] or life cycle climate performance [LCCP]), which measures both direct (refrigerant leakage) and indirect (fossil fuel combustion) effects, and so credits greater efficiency. Over equipment lifetimes with real-world failures, indirect effects (CO_2) are much larger than refrigerant leaks. The EPA refrigerant regulations are based on the direct effects.

Federal efficiency standards are essentially limited to the refrigeration cycle, but there are many opportunities for additional energy savings, many of which are region or application specific. Research, pilots, and field studies are needed in areas like fault detection and diagnosis (FDD), evaporatively cooled condensers, and system losses in other than (well-studied) attic installations.

Building codes should increasingly recognize the system defects associated with attic installations of equipment and ductwork, eventually precluding their use. In addition, Quality Installation is important. Without it, we will continue to waste some 30% of the energy used by the equipment (Domanski, Henderson, and Payne 2014). However comprehensive QI programs have not yet been brought to scale. We recommend expanding cost-disciplined, wider-scale programs as rapidly as possible; identifying better, more cost-effective procedures; and publicizing the results.

What do these findings mean for program administrators? Cooling savings are worth pursuing in hot regions and heat pump efficiency upgrades are worth pursuing in all regions, as is the conversion of electric furnaces to heat pumps. Cooling savings in other regions require local analysis, as does installation of ductless heat pumps to replace electric baseboard heating units. Promoting Quality Installation makes sense for heat pumps and for air conditioners in hot regions. Cost reductions will be needed to improve the cost effectiveness of Quality Installation for air conditioners in regions that are not hot.

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Chapter 7. Heat Pump Water Heaters

Author: Steven Nadel

MEASURE DESCRIPTION

Residential heat pump water heaters (HPWHs) are storage water heaters that primarily use an electric heat pump to provide heat, but generally include an electric resistance coil for fast recovery when needed. The heat pump heats water at more than twice the efficiency of resistance heat; it does this by taking heat out of the ambient air. Overall, most HPWHs operate at a coefficient of performance of more than two, meaning that for every unit of electricity consumed, more than two units of heat reach the hot water.

HPWHs have been marketed for decades but had small sales and were known for technical problems. Earlier designs were generally produced by small firms that did not have expertise in consumer products. In the past decade, the major water heater manufacturers have all brought HPWH models to the residential market. Makers now include AO Smith, Bradford-White, General Electric, Rheem, and Vaughn.[24] Units range in size from 40 to 120 gallons of storage capacity, with some manufacturers producing just one size (typically 50 gallons), some producing two sizes (typically 50 and 80 gallons), and some producing a broader product line (e.g., adding 40-, 66-, and/or 120-gallon options).

Under federal water heater efficiency standards that took effect in April 2015, electric water heaters with more than 55 gallons storage capacity will need to be heat pump units. The exception is for units of 75 gallons and more that meet the requirements for grid-enabled water heaters as contained in legislation passed by Congress in April 2015.

HPWHs can work in many applications, although there are some limitations. Since HPWHs operate by taking heat out of the surrounding air, they need sufficient air that is not too cold. As a result, they cannot be placed in small closets.[25] Nor can they be used outdoors or in unheated garages in cold climates (for instance, one manufacturer rates its equipment to operate down to an ambient temperature of 35°F). Integrated HPWHs are generally a bit taller than conventional water heaters, as they need room for the heat pump. As a result, they will not fit in under-the-counter and some other space-constrained applications. Since HPWHs cool the ambient air, they are generally effective dehumidifiers—often a valued side benefit. In general, they need some way to dispose of condensate.

The efficiency of HPWHs depends on the ambient temperature of the surrounding air—the higher the air temperature, the more efficient the heat pump. Thus, standard heat pump water heaters work particularly well in warm climates. However HPWHs can be engineered to work well in cold climates. The Northwest Energy Efficiency Alliance (NEEA) has developed a specification for units optimized for use in colder climates, and products from multiple manufacturers are available that meet this specification (NEEA 2015b). This specification has three tiers: Tier 1 with minimum specifications, and Tiers 2 and 3 with

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[24] These are all the manufacturers with products qualifying for ENERGY STAR certification as of July 2015. This includes only the main companies and not all their brands. Additional manufacturers are likely in the future.

[25] However some manufacturers have developed ducting kits to supply air to HPWHs in closets. A louvered door on the closet can be another option.

higher performance and features designed to make them appropriate for more homes. The various tiers are shown in figure 7-1. Here "NCEF" means northern climate energy factor. This efficiency rating differs from the standard energy factor (EF) rating in that it includes a test at 50°F ambient conditions and also incorporates the compressor cutout temperature below which the heater shifts into electric resistance mode.

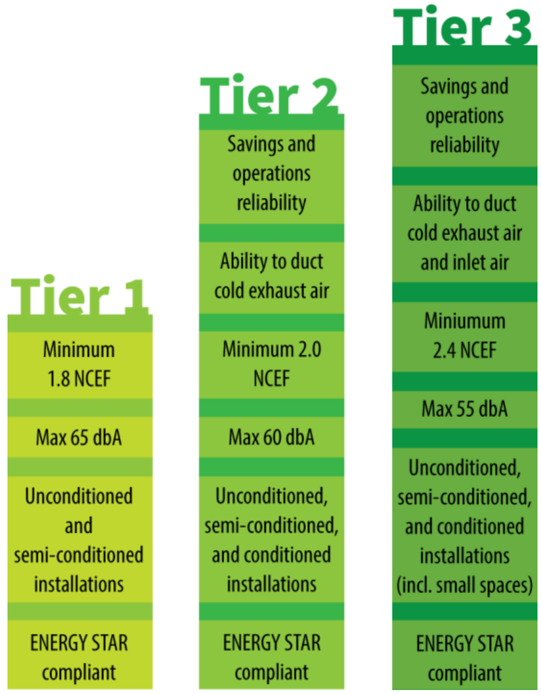

Figure 7-1. Northern climate HPWH specification tiers.
Source: NEEA 2015b.

More-advanced HPWHs are likely to enter the market in the future. Efficiency levels are improving (e.g., more units are being introduced at NEEA Tier 2 and 3 levels), and even more advanced water heaters now being sold in Japan may enter the US market. By late 2008, more than 1.5 million EcoCute split-system water heaters had been installed in Japan. EcoCute water heaters use carbon dioxide (CO_2) as the refrigerant. Without subsidies or incentives, the units are expensive in Japan, over $4,000 each, but hot-water use is high there, and power is expensive. Bonneville Power Authority is funding laboratory and field work though Washington State University (WSU 2013; Larson and Logsdon 2013), and work has started on field studies of integrated CO_2 water heating and space conditioning equipment (D. Hales, NEEA, pers. comm., 2014).

In addition to HPWHs, another option to reduce electric hot-water energy use is to integrate the water heater with an air conditioner or space-heating heat pump. When operated in cooling mode, air conditioners and heat pumps give off substantial amounts of heat that can be used to heat water. Such systems are common with ground-source heat pumps but could potentially be applied in the future to air-source systems. For example, Rheem now markets such a system for commercial applications with high water-heating loads (www.rheem.com/h2ac/). In past decades, both Carrier and Nordyne (now Nortek) offered residential systems, but neither sold well, and both are now off the market. Multihead ductless split systems can implement this easily, by having one head be a water heater that can accept heat removed from air by other heads. The primary barriers to offering such systems in the US are marketability and regulatory issues—for instance, could the efficiency of the water heater be tested with the current federal test method.

EXPERIENCE TO DATE

There are now probably several hundred programs to promote HPWHs, offered primarily by electric utilities. From our research it appears that most of these programs have had limited participation. For example, a look at the DSM Insights database as of March 2015 shows very few programs with more than 1,000 participants. In 2013, the last year for which data are published, EPA reports that 1% of electric water heater sales were HPWHs (EPA 2014).

However a few programs have been much more successful than most. In the paragraphs below we discuss three of these.

NEEA has led a major effort to develop and promote HPWHs since about 2010. The effort has included field tests, development of the northern climate HPWH specification discussed above, market research, installer training, assistance to utilities to develop their own programs, and direct promotion and incentives from NEEA. Currently many of the northwestern utilities offer incentives (41 as of March 2015), and both the utilities and NEEA promote HPWHs. NEEA also provides its own complementary incentives during specific promotion events. The NEEA incentives go to water heater distributors, while most of the utility incentives go to end-use customers. In interviews, several water heater manufacturers stated that they consider the upstream distributor incentives to be particularly valuable. A reported 6,633 HPWHs were sold in the Northwest during the 2012–2014 period, with sales steadily increasing: 872 were sold in 2012, 2,379 in 2013, and 3,384 in 2014 (Kresta 2015).

Key findings from a NEEA-commissioned market study provide some useful insights (NEEA 2013). This research found the following:

- Key drivers for HPWH purchases are energy savings, lower monthly operating cost, and rebate availability. The main marketing messages to end users include energy savings and return on investment.
- Barriers to HPWH adoption (first cost, low awareness) are typical of new energy efficiency products.
- Market actors have a wide range of views regarding future HPWH sales and unit and installation prices.
- Nearly all Tier 2 HPWHs were installed by contractors, while more than half of Tier 1 units were installed by the homeowner.
- Emergency replacements accounted for only 13% of HPWH installations.[26]

[26] This illustrates another barrier: a substantial majority of water heater purchases are emergency replacements. Given the short time for making decisions, the limited stocking of HPWHs, the unfamiliarity of many installers with HPWHs, and limited availability of incentives or financing, the emergency replacement market is a challenging one for HPWHs (F. Lebrasseur, marketing manager, GE Appliances, pers. comm., June 2015).

- Households that installed Tier 1 and Tier 2 HPWHs report high levels of satisfaction.
- Northwest utility representatives believe HPWHs are well suited for new construction, particularly the Tier 2 models.
- Distributors that do not stock HPWHs believe they are currently too risky to stock (in terms of the barriers preventing installations). Less than half actively market HPWHs.
- Installers source HPWHs from distributors. Installers do not stock HPWHs but indicate that this does not hamper their use as an emergency replacement option.

Energize Connecticut, a program jointly run by the state's utilities, took off in 2014 using an upstream approach that works through distributors. The program provides rebates to the distributors and to retail stores (currently $400 per HPWH plus a $20 processing fee) and also encourages and assists the distributors and retail stores in reaching out to their customers. The distributors and retailers must inform their customers that there is an upstream rebate. Manufacturers report that early in the program the distributors and retailers would keep some of the rebate, but over time competition has meant that more of the rebate is passed on to customers. Distributors are required to collect information on where the water heaters are installed and report this information to the program so that each installation can be assigned to a particular utility. Many distributors have done promotions, with help from manufacturers and the utilities, such as offering training programs and hosting special counter days that focus on educating installers as they come in to pick up water heaters and other supplies. And the utilities have had circuit riders who provide training and information to distributor and retailer staff. They emphasize that this communication has been very important. Distributors appear to like the program and emphasize the importance of having simple explanations of the programs so they know what they need to do. In 2014, 1,391 rebates were provided, more than six times the number provided during a customer mail-in rebate program in 2013 (Parsons and Pernia 2015; Ryan 2015).

An aggressive HPWH rebate program is also offered by utilities in Massachusetts and Rhode Island. In these states the rebate goes to the customer so that administrators can limit the program to those who currently have electric water heaters or who are doing new construction. (The program does not include fuel switching for customers who currently have oil or gas water heaters, and administrators were concerned that without customer-specific rebates, some fuel switching would be incentivized.) The program uses a mail-in rebate. The rebate was $1,000 for a HPWH in 2013 and 2014 to help the program get started, but was reduced to $750 in 2015.[27] In 2013 and 2014, nearly 7,000 rebates were issued by the two largest utilities. Participation was higher in 2013 than in 2014 (I. Diagana, National Grid, pers. comm., March 23, 2014; W. Stack, lead program manager, Eversource, pers. comm., March 6, 2014). Participation may have been influenced by the availability of federal tax

[27] Information on the current program is available at: www.masssave.com/~/media/Files/Residential/Applications-and-Rebate-Forms/CS_MA_HPWH_Rebate_FINAL.pdf.

credits through most of 2013, while in 2014 the federal tax credit was not enacted until December (F. Lebrasseur, marketing manager, GE Appliances, pers. comm., June 2015).

The Massachusetts and Rhode Island utilities are probably not alone in wanting their programs to be able to track sales to individual customers. Tracking to individual customers can be important where service territories are such that customers of one utility frequently shop in the service territories of other utilities, or, as with Massachusetts and Rhode Island, where program operators have additional specific criteria. The manufacturers we interviewed strongly prefer upstream rebates to mail-in rebates. One of them noted a hybrid approach being used in Maine in which one rebate goes to the distributor, incentivizing it to promote HPWHs, and a second, smaller rebate is mail-in, allowing program operators to identify individual consumers and make sure they meet all program criteria. This manufacturer also noted that with data from Nielsen Spectra, programs can carefully examine where individual distributors are selling products and thereby can estimate the portion of sales from each distributor going to homes in specific utility service territories. One manufacturer representative also noted that in his experience, HPWH rebates need to be at least $400 to get end-user attention.

ENERGY SAVINGS

Relative to an electric resistance water heater, heat pump water heaters reduce energy use by about 50%. Savings can be greater than 50% in warm climates and can be less in colder climates. For example, a 2015 analysis of field data in the Northwest (NEEA 2015a) concludes that HPWHs reduce electricity use by one-third to one-half (midpoint is 42% savings). Savings are in the lower end of this range in houses where the water heater is in fully conditioned parts of the home and causes a home's main heating system to work harder. They find no significant space-heating interactions with installations in garages and unheated basements.

More detailed information on savings as a function of geography, water heater size, and location of the water heater is provided in detailed modeling by Maguire et al. (2014). This study reports average savings in source Btu, with savings ranging from about 8–22 million Btu per household per year. Using the conversion factors contained in the study, 8-22 million Btu works out to about 700–1,900 kWh per household per year. This study looked at single-family homes using HPWHs with a COP of about 2.0 and did not consider space-heating interactions. Results are summarized in figure 7-2.

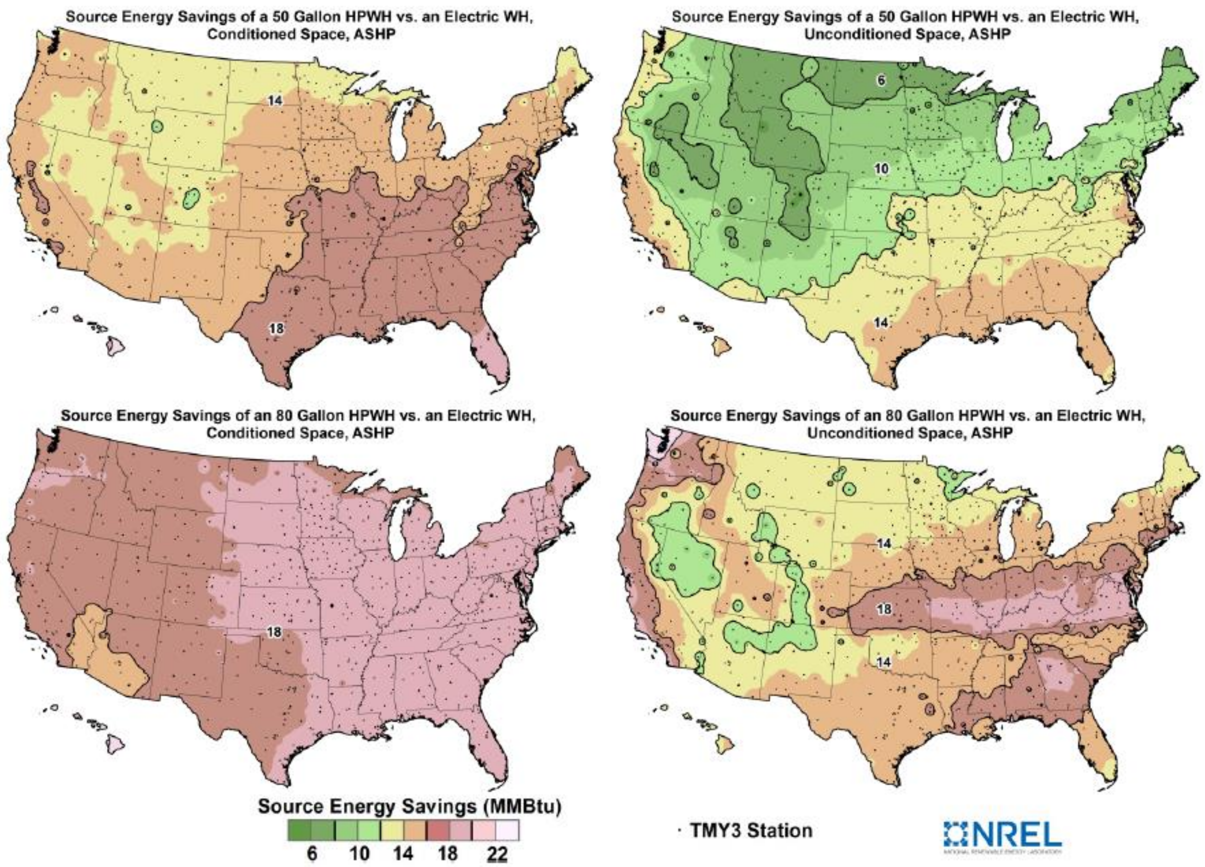

Figure 7-2. Source energy savings of HPWHs as a function of geography, tank size, and location in conditioned or unconditioned space. *Source:* Maguire et al. 2014.

On a national basis, we estimate in our midrange case that HPWHs can reduce US electricity use in 2030 by 0.6%, as shown in table 7-1.

Table 7-1. Electricity savings in 2030 from HPWHs

	Value	Unit	Comments
	147	TWh	2030 electricity available to grid from EIA 2014
x	80%	of energy use covered	Smaller water heaters not included
x	50%	average savings	Discussed in text
x	50%	participation rate	Based on ramp-up to standards that take effect in 2026
x	95%	net-to-gross ratio	5% of savings would happen anyway (standard assumption for this report)
=	28	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.6%	of US electricity use	

Our low and high cases are summarized in tables 1-4 and 1-5 in Chapter 1, finding total 2030 savings of 0.5% and 1.0% of US 2030 electricity use, respectively. These cases vary in the effective date of new standards—2028 in the low case, 2026 in the medium case, and 2022 in the high case.[28]

COSTS AND COST EFFECTIVENESS

Installed product costs are now in flux. Discussions with industry experts indicate a typical installed cost of about $1,500 today, outside of major programs. In 2009, DOE estimated an installed cost of $1,435 (expressed in 2008 dollars) for a unit with a COP of 2.0, assuming HPWHs are required by federal standards. But in recent years prices have come down, driven by competition among manufacturers and sometimes among distributors, retailers, and installers. NEEA reports an average cost of $1,063 for Tier 1 units in programs in the US Northwest, but as competition increases, it expects similar prices in the future for Tier 2 and 3 equipment (D. Kresta, Northwest Energy Efficiency Alliance, pers. comm., March 12, 2015). Based on these limited data points, we use $1,500 for current cost and $1,100 for future cost, where future cost is being achieved today in locations with heavy promotion.

Another uncertainty is estimating baseline energy use for electric water heaters. EIA, in its 2009 RECS survey, reports 2,663 kWh per year on average for all electric water heaters. However this includes quite a few small water heaters, such as under-counter units used in small apartments, that are unlikely to be replaced by heat pump water heaters. If we look only at homes and apartments larger than 1,000 square feet, this average increases to 2,876 kWh per year. And if we look at households of three or more people, the prime market for these units, this average increases to 3,539 kWh per year. Table 7-2 presents our cost-of-saved energy calculations and sources. Using the 2,876 kWh figure, we estimate a cost of saved energy of about $0.08 per kWh when using the $1,100 installed cost. This declines to $0.066 per kWh for households of three or more with the $1,100 cost but increases to $0.11 per kWh if we use the $1,500 cost and 2,876 kWh baseline.

Table 7-2. Cost of energy saved through HPWHs

	Value	Unit	Comments
	2,876	kWh per household	From 2009 RECS (EIA 2011) for homes of 1,000 square feet or more
x	50%	average savings	Discussed under energy savings
=	1,438	saved/new home	
	$1,500	current cost	Discussed in text
	$1,100	long-term cost	Discussed in text
	13	year measure life	From DOE 2010 Technical Support Document for water heater standards
	$0.111	per kWh	CSE based on current cost
	$0.081	per kWh	CSE based on long-term cost

[28] The same 2021 date is used for the high savings case for several of the products in this study. For water heaters, such a quick effective date is unlikely; even in an aggressive case, the effective date is likely to be 2022 or later.

UNCERTAINTIES

As of April 16, 2015, the minimum efficiency allowable for electric water heaters larger than 55 gallons effectively requires heat pump technology. Most programs we talked to stated they will still provide incentives for these units in 2015, but many programs may not provide incentives for such large units in 2016. Incentive programs will still have huge potential for smaller units, typically 50 gallons nominal. Legislation passed in April 2015 allows continued production of specialized, grid-enabled resistance water heaters larger than 75 gallons for use exclusively in utility demand-response programs. Some also fear that light-duty commercial water heaters (characterized by short warranties and high-temperature thermostats) will be sold into the residential market to subvert the federal standards; this loophole will likely be closed by new federal test procedures that take effect later in 2015.

For the longer term, a major uncertainty is whether and when the federal government will update water heater efficiency standards to require HPWH levels of performance, and if it does, how large a share of the market will be exempted from such a requirement (e.g., units with storage capacities of 25, 30, or 35 gallons or less). Other substantial uncertainties are future installed costs (will costs go up or down from the present $1,100 found in the Northwest program?) and energy performance of models (will the present COP of about 2.0 continue to prevail, or will performance and energy savings increase?). The midrange analysis is based on a COP standard of 2.0 effective in 2026 that applies to 80% of electric water heater energy use, with an average future installed cost of $1,100 per unit.[29]

RECOMMENDATIONS AND NEXT STEPS

HPWHs are now available from many manufacturers; the products are improving, and prices are coming down. However, market share is still very small in most parts of the country due to high initial cost and unfamiliarity with the products among most installers and homeowners. Programs in the Northwest and New England should be emulated in other regions; they are now showing ways to significantly increase market share, including

- Extensively involving distributors through training and upstream incentives
- Paying substantial incentives of at least $400 per unit

For cold climates, extra technical provisions are useful, as developed and promoted in the Northwest. As sales increase, products and prices should continue to improve, making it possible for DOE to consider new efficiency standards that could require HPWH levels of performance, perhaps for units of 30 or 40 gallons storage capacity or more.

Incentive programs generally target products that are more efficient than those mandated under federal and state equipment efficiency standards. Given that the new DOE minimum efficiency standard essentially requires that water heaters with capacities greater than 55 gallons be heat pump models, except for grid-connected units, the prime market for heat pump water heater incentive programs will be units of 55 gallons or less (presently

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[29] About 77% of electric water heater shipments are of tanks larger than 30 gallons (DOE 2009).

produced by several manufacturers) as well as grid-connected heat pump water heaters greater than 55 gallons (there are no current products, but we would expect some current products greater than 55 gallons to have grid-enabled features added).

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Chapter 8. Residential Retrofits

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MEASURE DESCRIPTION

Many programs addressing residential energy use have targeted particular building systems or components, such as individual appliances and HVAC equipment, and basic shell measures (insulation or spot air sealing). Other programs have used a whole-house approach, which aims to systematically address the biggest problems as identified on a house-by-house basis (Amann 2003). The focus of this section is the whole-house approach to residential retrofits, which relies on diagnosis of home performance problems to determine how to most effectively reduce energy load and meet the needs of the homeowner. A whole-house approach will usually include many of the components of the single-measure programs mentioned above, but differs by the use of analysis to determine appropriate measures. The approach also aims to include a suite of improvements to the building, rather than a single measure, to substantially improve the building's energy performance.

Whole-home retrofit programs focus predominantly on improvements to the thermal envelope and HVAC systems that address heating, cooling, and water heating (which account for about 65% of the energy used in an average home) (EIA 2013). In past experience, whole-home retrofit programs have achieved actual total energy savings of 10–20% (Brook et al. 2012), usually by reducing heating, cooling, and/or water heating loads by 20–35% (Neme, Gottstein, and Hamilton 2011). While there is significant potential to save more than this, rarely do existing whole-home programs achieve savings greater than 30% (Cluett and Amann 2014).

More in-depth projects to improve the energy performance of existing residential homes to levels that rival high-efficiency new construction are referred to as deep energy retrofits. These aim to save 50% or more of the energy used onsite in a home as compared with actual pre-retrofit usage or an estimate of energy use based on housing and climate characteristics. These savings are realized through improvements to the building shell including insulation and air sealing, and often through upgrades to high-efficiency heating, cooling, and hot-water systems suited to the smaller energy load of the house (Cluett and Amann 2014). These projects require more substantial construction efforts and are often paired with a home renovation or addition.

As discussed next, while there is experience with whole-house programs, such programs have yet to achieve significant participation levels. Finding ways of increasing participation in whole-building retrofits is key to driving increased savings in this sector.

EXPERIENCE TO DATE

Retrofit activity in the residential sector has grown in recent years, spurred by an increase in utility and state program activity, including programs supported by the American Reinvestment and Recovery Act (ARRA). However there is significant opportunity for additional savings. Jurisdictions with leading whole-home retrofit programs, such as Austin, Massachusetts, New Jersey, New York, Oregon, Vermont, and Wisconsin, have reached roughly 0.5% to 2% of single-family homes (Neme, Gottstein, and Hamilton 2011).

Much higher participation has been achieved in some small localities, where residential retrofit services were intensively marketed and utilities provided significant financial assistance. Examples include the Hood River Conservation Project in Hood River, Oregon, which reached 85% of eligible homes, and the Espanola (Ontario) Hydro Electric Commission project, which reached 70% of eligible homes (York et al. 2015).

To take one example, leveraging $508 million in ARRA support and other funding, the Better Buildings Neighborhood Program (BBNP) spurred nationwide energy efficiency program innovation over a three-year period starting in 2010. Programs that received grant funding from BBNP were responsible for 138,323 assessments of residential single-family homes and 75,110 upgrades to homes during this period (DOE 2015). Homeowners spent an average of $7,027 on upgrades estimated to save an average of 24% of whole-home energy use, according to modeling. In practice, pre and post utility data estimates indicate savings of about 15% (Hoffmeyer 2015). Some programs included in these estimates did not target comprehensive improvements and relied predominantly on direct install measures, with program costs at around $1,000.

Home Performance with ENERGY STAR (HPwES) is a well-established national platform for delivery of whole-home retrofit work. Many of the programs that received BBNP funding used the HPwES platform, and a majority of the existing whole-home retrofit programs in the United States leverage HPwES program resources. More than 400,000 homes have been upgraded as a result of the HPwES program since 2002, with over 2,100 participating contractors and 48 program sponsors nationwide (Jacobsohn et al. 2014). The ENERGY STAR brand is widely recognized not only among consumers but among sponsors, contractors, and trade allies.

HPwES programs focus on assessing how improvements to the entire home energy system can work together to deliver energy savings and ancillary benefits such as health and comfort. While the focus of HPwES is on the whole home as an energy system, delivered services are sometimes limited to multiple individual product replacements due to customer resource constraints, sometimes resulting in lower project energy savings (York et al. 2013). A commonly used model for HPwES programs involves an energy audit that leads to recommendations for energy-efficient measures that the homeowner can then choose to undertake. Programs can vary considerably in terms of market strategies and tactics, types of consumer incentives (rebates or financing) offered, percentage of measures that are field inspected, site energy saved, use of midstream incentives for contractors, and cost per project (Jacobsohn, Moriarta, and Khowailed 2013).

While the highest-performing HPwES programs are able to produce estimated whole-house energy savings of 30% or greater, savings vary considerably depending on program design and scope. Projects average savings of 22 MMBtus, which is 23–32% of total household energy consumption, depending on the region. HPwES has reported an average program sponsor cost of $3,500 per project, with 57% of reported costs going to homeowner incentives, 14% to contractor incentives, and 29% to administrative costs. Average homeowner project cost was $5,600, with a range of $600 to $17,000 (Jacobsohn, Khowailed, and Grubbs 2014).

Programs that achieve savings greater than 50% are less common. One utility-scale deep energy retrofit program and several research and development projects have demonstrated energy savings possible through these initiatives. Initial deep retrofit efforts in Massachusetts and Rhode Island through National Grid are achieving reported average savings of 58% relative to baseline energy use. While the market penetration for deep energy retrofits is currently very small, and while improvements are very costly, this program type is promising for a number of reasons. For one thing, it can fill a niche in a program portfolio by helping the most committed homeowners make significant energy improvements. For another, it can build the capacity of the local workforce to offer improvements at the time of other planned renovations, such as a basement remodel, a siding or roofing job, or the replacement of an aging HVAC system (Parker et al. 2014).

Existing deep energy retrofit projects shed light on the added costs of including high-efficiency building shell upgrades to an existing project. In a number of retrofits from National Grid's Deep Energy Retrofit Program, the incremental performance improvement cost of air sealing and adding roof insulation to a roofing job was about 30% of the total project cost, while the incremental cost of adding insulation during a siding replacement was 45–60% of the total project cost (Cluett and Amann 2014). Table 8-1 illustrates the range of costs associated with improving the building shell to high performance standards during the time of roof or siding replacement.

Table 8-1. Incremental improvement costs for roof and siding replacements

Component	Total measure cost (per sq. ft.)	Incremental performance improvement cost (per sq. ft.)	Percentage of cost toward energy improvement
Roof/attic: unvented attic with closed-cell spray foam	$17.75	$5.19	29%
Roof/attic: exterior insulation and framing cavity insulation	$22.22	$7.44	33%
Above-grade wall: rigid foam insulating sheathing with air-permeable framing cavity insulation	$10.41	$4.46	42%
Above-grade wall: rigid foam insulating sheathing with ccSPF cavity insulation	$17.73	$11.59	65%
		Average	42%

Measure costs reflect builder proposals and estimates prior to construction. *Source:* Neuhauser 2012.

Increasing the number of projects undertaking high-performance building shell improvements during already planned upgrades and maintenance to the home has the potential to considerably reduce the cost of saved energy from residential retrofit improvements.

ENERGY SAVINGS

Our medium-case scenario estimates a reduction of US 2030 electricity consumption by 1.0%, assuming 15% of existing buildings achieve an average savings of 20%. For a high-case scenario, we assume whole-home savings of 20% and a participation rate of 20%. We estimate savings for this case to be 1.3% of US 2030 electricity consumption. In the low case, we assume whole-home savings of 20% and a participation rate of 10%, which would result in savings of 0.7% of US 2030 electricity consumption. Table 8-2 shows our medium-case calculations.

Table 8-2. Electricity savings in 2030 from residential retrofits

	Value	Unit	Comments
	1,526	TWh	2030 residential electricity consumption from EIA 2014.
x	100%	of energy use covered	Whole-building energy use. All systems and loads may be addressed through comprehensive retrofits: lighting, HVAC, miscellaneous end uses, and so on
x	20%	average savings	Well-documented, achievable, demonstrated potential, as discussed above. Leading-edge projects can achieve 50% or more.
x	15%	participation rate	Assumes significant, consistent program push to reach this share of buildings by 2030; this is a long enough cycle to include energy retrofits at the time of other renovations. 1% participation per year.
x	95%	net-to-gross ratio	Standard assumption for this report
=	43	TWh	
/	4,327	TWh	Projected 2030 U.S. electricity consumption from EIA 2014
=	1.00%	of US electricity use	

COSTS AND COST EFFECTIVENESS

We estimate costs associated with energy retrofits based on examples from existing programs. Projects that were a part of the Better Buildings Neighborhood Program averaged a cost of $7,027, with average measured savings of about 15% of whole-home energy use (24% modeled). This varies by climate and program design. Data from select mature HPwES programs offer comparable estimates (Plympton et al. 2010). An HPwES program sponsored by Austin Energy had an average project cost of $6,800, with average whole-home energy savings estimated at 16% (Neme, Gottstein, and Hamilton 2011). NYSERDA's HPwES program had an average project cost of $7,700, with average whole-home savings of 23% (Plympton et al. 2010). Based on this data, we estimate projects saving 20% of energy used in the home to have a cost of about $7,000.

We estimate long-term costs based on the premise that targeting the highest energy users and including energy improvements in already planned upgrades can lead to more cost-effective savings than what programs are achieving today. We include multiple benefits in our calculation, at a value of 50% of the value of energy savings (Amann 2006).[30] Table 8-3 shows our calculations.

Table 8-3. Cost of energy saved through residential retrofits

	Value	Unit	Comments
	13,136	kWh/home	Average single-family household consumption from EIA 2013
x	100%	in covered end uses	Discussed under energy savings
x	20%	average savings	Discussed in text
=	2,627	kWh saved/home	
	$7,000	current cost	Based on current retrofit program experience
	$6,000	long-term cost	Based on integrating energy efficiency with other planned improvements
	70%	of costs not for electric	Accounts for home energy use that is not electricity (52%) (EIA 2013) plus nonenergy impacts
	15	year measure life	From DOE Better Buildings Neighborhood Program
	$0.077	per kWh	CSE based on current cost
	$0.066	per kWh	CSE based on long-term cost

UNCERTAINTIES

The costs of achieving significant energy savings in residential buildings, particularly deep energy savings, and adoption of lower-load high-efficiency equipment are not well known. There is also a need to devise better ways to estimate energy savings and measure outcomes after retrofit. At present, many efforts to model pre-retrofit energy use overestimate energy use, resulting in inaccurate baselines against which to measure savings and, therefore, overestimations of savings.

RECOMMENDATIONS AND NEXT STEPS

Innovative approaches are needed to scale up participation in retrofit programs. Programs should leverage customer energy use data and other program data to target customers who could benefit most from retrofit work. Utilities can look for ways to leverage smart meter data to better understand how energy is used in individual homes, and target those homes as a result. For example, a home that has very high electricity consumption because of an old electric heating system and bad insulation or air sealing would likely benefit from a retrofit program offering insulation and air sealing upgrades more than a home with a similar electricity load where most of the load comes from electronics and entertainment systems. Opportunities to leverage smart meter data to disaggregate the end uses of electricity would provide utilities a better means of targeting customers.

[30] "Multiple benefits" is a term used to describe the impacts of energy efficiency improvements beyond energy savings to the program participant, the utility, and society. They are also referred to as nonenergy benefits, nonenergy impacts, and co-benefits.

In addition, the residential retrofit market can grow through development of channels for incorporating energy-saving upgrades during other planned home maintenance and upgrades. Existing program experience with the National Grid Deep Retrofit Program shows that pairing building shell energy efficiency improvements with roofing, siding, and/or additions or renovation jobs can provide a much more cost-effective application of efficiency improvements (Cluett and Amann 2014).

Programs should be developed based on regional specifics. Energy loads differ by climate, so a program targeting the heating load would likely lead to fewer savings in Florida than in New England. In addition, the way energy is used in homes is changing: In 1993, 24% of home energy was used for appliances, electronics, and lighting. By 2009, these applications used 35% (EIA 2013). While it will be useful to address these loads in all climates, focusing on appliances, electronics, and lighting will be particularly worthwhile in milder climate zones where heating and cooling loads are limited. Also, regional housing stock characteristics should be considered. For example, Austin Energy designed a retrofit program to include duct sealing because many homes in the region had leaky ductwork in unconditioned attic spaces, where energy losses were high.

Measurement and verification of actual energy use pre- and post-retrofit can be used to evaluate and validate retrofit efforts and provide clear examples to customers from contractors on the types of improvements that can bring real savings. Pre- and post-retrofit analysis of energy use can also help contractors better understand what measures and methods of installation are most effective.

Last, many existing home performance projects are limited in scope by the up-front cost to the homeowner. Programs should explore opportunities to provide financing so homeowners can complete more comprehensive projects. An opportunity lies in adding on more comprehensive efficiency improvements during other home renovations when owners are already financing or refinancing their home.

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Chapter 9. New Construction Programs Targeted Beyond Current Codes

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MEASURE DESCRIPTION

It is generally much less expensive to incorporate energy efficiency measures in a new home or commercial building when it is constructed than to build them inefficiently and undertake energy efficiency retrofits later. In most states, energy codes require a variety of energy efficiency measures, but there is much more that can be done to exceed the code. Furthermore, codes are regularly updated, and new construction programs can improve understanding of and experience with new efficiency measures, making it more likely they will be added to future codes.

Most state codes are based on national model energy codes developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the International Code Council (ICC). ASHRAE's 90.1 standard is the leading basis for commercial building codes, as many states adopt it directly, and it also forms the foundation of ICC's International Energy Conservation Code (IECC) for commercial buildings. IECC is the leading code for residential buildings. Both the ASHRAE standard and IECC code are revised every three years through a consensus process at ASHRAE and a proposal and voting process at IECC. These processes were last completed in 2013, with the next processes wrapping up in 2016 and 2019. Thus, the most recent versions are ASHRAE 90.1-2013 and the 2015 IECC (completed in 2013 but dated 2015). About 40 states have adopted ASHRAE 2007/2009 IECC or their equivalent, while about a dozen have adopted ASHRAE 2010/2012 IECC (Gilleo et al. 2014). The 2013/2015 codes are so recent that only a few states have adopted them so far.[31] Based on these adoption rates, for this analysis we use the ASHRAE 2007 standard/2009 IECC code as our base, while recognizing that some states have more stringent codes and some have less stringent codes.

The stringency of the model codes has increased substantially in the past decade, primarily through increases in the efficiency of individual building components such as insulation, windows, lighting, and heating, ventilating and air-conditioning (HVAC) systems. As a result, while there are some opportunities for further improvements to building components, to achieve large energy savings in the future will require better integration and optimization of different building systems, as well as paying more attention to areas of building energy use that are either not fully included or only partially included in current codes (e.g., air infiltration, duct leakage, plug loads, and other, miscellaneous loads). Several voluntary whole-building programs provide pathways for achieving these higher levels of savings, including the ENERGY STAR new homes program, the DOE Zero Energy Ready program, and the New Buildings Institute Advanced Buildings program (for commercial buildings).[32]

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[31] Maps showing the status of state building codes are compiled by the Buildings Code Assistance Project (BCAP) and can be found at energycodesocean.org/code-status.

[32] "Zero net energy" describes a building that on an annual basis meets all of its energy needs on site. To do this, the building must be built very efficiently ("zero energy ready"), and some form of onsite renewable energy

For single-family homes and low-rise multifamily buildings, the current ENERGY STAR specification is only slightly more stringent than the 2012 IECC code. This chapter focuses on the energy saving improvements that can be implemented over the 2015–2030 time frame, with a particular focus on the levels of efficiency contained in DOE's Zero Energy Ready program. For a typical home this represents 35–40% energy savings relative to the 2009 IECC, as shown in figure 9-1, which compares the average Home Energy Rating System (HERS) score of typical homes under different codes and program specifications.[33]

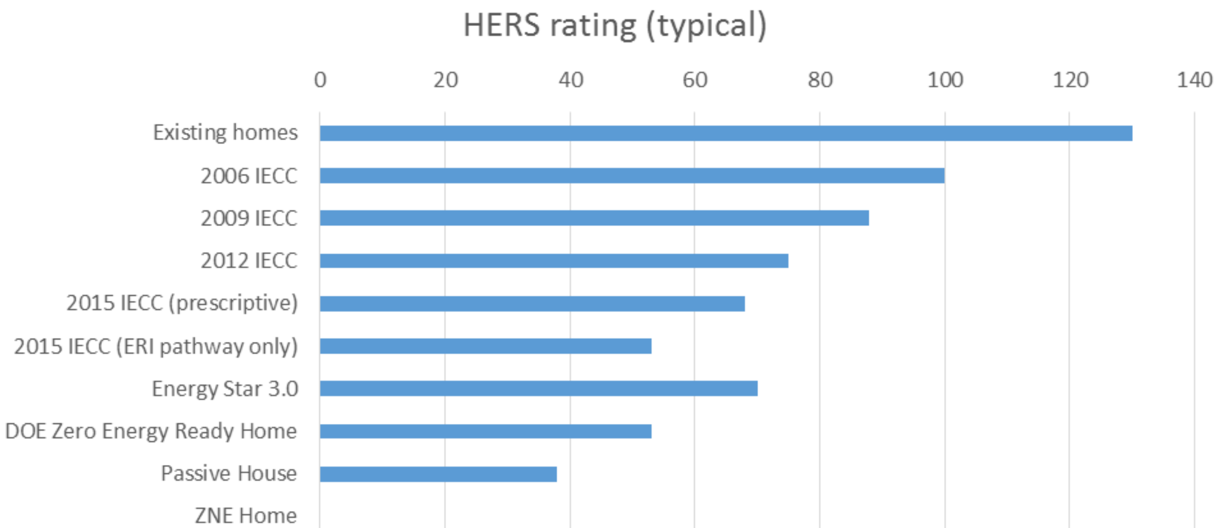

Figure 9-1. Comparison of home energy performance. ***Source:*** **EIA 2013.**

Table 9-1 gives additional details on some of the requirements of the Zero Energy Ready program and how these compare with ENERGY STAR and the various model codes.

must be used, such as solar electric cells. Only by building efficiently can energy needs be reduced enough that onsite systems can provide the needed energy cost effectively.

[33] The Home Energy Rating System (HERS) can be used to rate the efficiency of a home. A home that meets the 2006 IECC has a HERS score of 100. A zero energy home has a HERS score of zero. A HERS score of 50 means a home uses half the energy of a home meeting the 2006 IECC.

Table 9-1. Requirements for residential building envelope components

2006 IECC	2009 IECC	2012 IECC	2015 IECC	ENERGY STAR 3.0	DOE ZERH*
Airtightness (ACH_{50})					
None	≤7.0	≤3.0 to ≤5.0	≤3.0 to ≤5.0	≤3.0 to ≤6.0	≤1.5 to ≤3.0
Duct leakage (CFM_{25}/100 ft^2 conditioned floor area)					
None	Total ≤12 OR leakage to outdoors ≤8	Total ≤ 4, blower door verified	Total ≤ 4, blower door verified	Total ≤6 OR leakage to outdoors ≤4	All ducts within thermal and air barrier boundary
Insulation, ceiling					
R-30 to R-49	R-30 to R-49	R-30 to R-49	R-30 to R-49	2009 IECC	2012 IECC
Insulation, wall (wood frame)					
R-13 to R-21	R-13 to R-21	R-13 to R-20+5 or 13+10	R-13 to R-20+5 or 13+10	2009 IECC	2012 IECC
Insulation, floor					
R-13 to R-30	R-13 to R-30	R-13 to R-38	R-13 to R-38	2009 IECC	2012 IECC
Insulation, basement wall					
R-0 to R-10/13	R-0 to R-15/19	R-0 to R-15/19	R-0 to R-15/19	2009 IECC	2012 IECC
Windows, U-factor					
1.20 to 0.35	1.20 to 0.35	NR to 0.32	NR to 0.32	0.60 to 0.30	0.40 to 0.27
Windows, SHGC					
NR to 0.40	NR to 0.30	NR to 0.25	NR to 0.25	NR to 0.30	NR to 0.25
Skylights, U-factor					
0.60 to 0.75	0.60 to 0.75	0.55 to 0.75	0.55 to 0.75	0.55 to 0.70	ENERGY STAR

* Zero Energy Ready Home. *Source:* Amann 2014.

For commercial and high-rise residential buildings, projects that follow Tier 3 in the Advanced Buildings New Construction Guide from the New Buildings Institute (NBI 2014) will save about 35–45% relative to ASHRAE 2007 (Frankel et al. 2014). This is a building performance pathway that, unlike many codes, also addresses plug loads. NBI is also working on a Tier 4, which will be zero net energy (ZNE) ready. Building on Tier 3, Tier 4 will address building operations and tenant interactions.

For our analysis, we use 40% savings relative to ASHRAE 2007—the midpoint of estimates for NBI's Tier 3. This performance is also about the level of savings that ASHRAE is targeting for its 2016 standard.[34] This level of savings can be most easily achieved by taking a whole-building energy modeling approach. However ASHRAE is also working on a component and systems approach including consideration of component improvements involving lighting power densities, duct systems, service hot-water systems, and economizers, complemented with improved building commissioning procedures and use of system performance metrics (H. Misuriello, visiting fellow, ACEEE, pers. comm., October 31, 2014).

EXPERIENCE TO DATE

In the residential sector, the DOE Zero Energy Ready Home program was launched in 2013 but built upon a previous program, the Builder's Challenge, launched in 2008. To date, 542 participating homes have been reported, with additional commitments from builders for at least 3,000 more homes (including dwelling units within eligible multifamily buildings). A number of utilities and utility-funded program operators are promoting the program, including National Grid, Eversource Energy, all the California utilities, the New Jersey Clean Energy program, and the New York State Energy Research and Development Authority (NYSERDA). In addition, the state of Colorado provides an $8,000 mortgage incentive for zero energy homes. All of these programs are still in an early phase, so we are just starting to get information on program experience and lessons learned (S. Rashkin, chief architect, Business Technologies Office, DOE, pers. comm., July 22, 2015).

Perhaps the most active program is the Low-Rise Residential New Construction program operated by NYSERDA. The agency has been running variations on this program for many years, and thus many builders and developers in the state are familiar with the program. In recent years, about 2,000 dwellings per year have been completed under the program. Since 2014 the program has included three tiers. The first tier is based on ENERGY STAR 3.0. The second tier is based on ENERGY STAR 3.1, which for New York State is similar to the DOE Zero Energy Ready specification. The third tier embodies the second-tier criteria while securing increased building performance by requiring a more rigorous (size-adjusted) HERS Index, calculated prior to incorporating the impacts of solar photovoltaic (PV) electricity generation, plus the installation of enough PV capacity to ensure a post-PV HERS Index of 10 or less.[35] The program includes extensive outreach to and training opportunities for builders, developers, HERS raters, and other energy consultants, as well as HVAC contractors. It also offers incentives of $2,500–3,000 per dwelling unit for Tier 2 and $4,000–8,000 per dwelling unit for Tier 3. In 2015 Tier 2 has taken off and accounts for about 65% of program applications. In addition, program administrators are expecting more than 100 Tier 3 completions in 2015. Based on recent builder commitments, about 90% of the expected 2016 completions will meet Tier 2 requirements and more than 200 completions will meet or exceed the Tier 3 criteria (P. Fitzgerald, project manager, NYSERDA, pers. comm., July 15, 2015).

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[34] ASHRAE is targeting 50% savings for covered loads relative to ASHRAE 2004. ASHRAE 2007 saves about 8% relative to ASHRAE 2004 (Misuriello 2010), leaving a little more than 40% additional savings if ASHRAE meets its goal. We round to 40%.

[35] Program details are available here: www.nyserda.ny.gov/PON2309.

In the commercial sector, the NBI Advanced Buildings program has been working with several program administrators including Efficiency Maine, Efficiency Vermont, Energy Center of Wisconsin, NYSERDA, and several of the Massachusetts program administrators (R. DiNola, executive director, New Buildings Institute, pers. comm., October 31, 2014).

Some of the leading commercial new construction programs also emphasize achieving large savings using a whole-building integrated design approach. Notable examples include programs run by Commonwealth Edison, Efficiency Vermont, National Grid, Xcel Energy, and California utilities, the latter under the statewide Savings by Design moniker. Further information about some of these efforts can be found in York et al. 2013. A few program administrators have standardized program offerings that support achievement of ZNE goals. The California utilities and Energy Trust of Oregon both have a Path to Net Zero initiative within their commercial new construction programs and provide educational platforms to accelerate market transformation and the adoption of net zero strategies. Efficiency Vermont recently started a pilot program to research and promote ZNE buildings.

Energy Trust of Oregon's program is probably the most advanced. Energy Trust serves approximately 1.5 million gas and electric customers in Oregon. In 2009 Energy Trust New Buildings began its Path to Net Zero pilot, which resulted in eight completed buildings that achieved their energy goals and revealed that a design-focused program approach can lead to net zero buildings, as documented in the pilot's process evaluation (Dethman et al. 2014). Many early lessons learned in pilot implementation were incorporated into New Buildings' market transformation efforts, used to develop content delivered through the program's Allies for Efficiency training series on net zero topics (built around peer-to-peer exchange), and ultimately positioned the market for a full-scale Path to Net Zero relaunch in late 2014.

According to the program manager, Energy Trust's Path to Net Zero program design strategy has two keys: (1) early target-setting to position building owners and teams to set and achieve net zero goals and (2) community-building around net zero to support broad market adoption. Administrators have found that the greatest opportunity to identify and influence deep savings is pre-schematic design, where the program supports quick early simulations called "shoebox modeling," energy use intensity (EUI) targeting, and energy-related studies (e.g., daylighting studies and computational fluid dynamic modeling) that inform final energy modeling and savings calculations. A follow-up on this work is done halfway through the preparation of construction documents, when the program conducts a project review and makes final recommendations to keep projects on track to achieve their original savings targets. Ten months into the Path to Net Zero launch, 30 building owners are pursuing net zero targets; several buildings will be completed in 2015 (J. Iplikci, Energy Trust of Oregon, pers. comm., July 21, 2015).

As market acceptance of net zero grows from early-stage adoption, Energy Trust plans to continue addressing market barriers through its net zero community-building strategy, empowering allies with resources and analytic tools, leveraging examples of net zero buildings in local communities, and featuring the project teams. It is looking at developing a Net Zero Circle of Fellows to grow the number of professionals advancing net zero design practice and create a resource in the market. Net Zero Fellows will educate owners, designers and contractors with limited net zero experience, equipping them to achieve net zero energy projects. As these strategies and tactics are developed, Energy Trust plans to leverage them to build market demand through its creative marketing campaign "Reasons to Love Zero" (J. Iplikci, Energy Trust of Oregon, pers. comm., July 21, 2015).[36]

NBI maintains a database of commercial buildings that meet ZNE criteria.[37] As of January 2014 it has documented 160 projects plus an additional 53 ultra-low-energy buildings that can be considered ZNE ready. Of these, 32 buildings have had their performance verified as zero net energy. Most of the other buildings are either too new to verify or have not gone through a verification process. NBI's January 2014 review found that the number of ZNE buildings had more than doubled since a 2012 review, implying the number of projects is significantly higher today. In early 2014 NBI found projects in 38 states and 2 Canadian provinces representing 16 building types in a wide variety of sizes (Cortese and Higgins 2014).

ENERGY SAVINGS

At a national level, in our midrange case we estimate that new construction programs leading to code changes can reduce US 2030 electricity consumption by 1.9%, assuming 75% of states ultimately adopt codes at this level of performance by 2030. We also implicitly assume that code compliance at these levels will be the same as current code compliance, since our savings are calculated on the basis of current new building performance. We assume that as stronger codes are adopted, jurisdictions motivated to adopt these stronger codes will make more effort to ensure code compliance, keeping compliance rates constant despite the challenges of meeting stronger codes. More than 70% of the estimated savings are in commercial buildings because there is much more commercial than residential new construction and due to the higher percentage savings we estimate for commercial buildings. The three cases differ in the speed with which code adoption occurs, which affects the cumulative participation rate—a key variable for which there is great uncertainty. We use the cumulative participation rates discussed in Chapter 1 for low, medium, and high savings, multiplying by 75% in each case to reflect the assumption that 25% of states will not adopt these codes. Based on these cumulative participation estimates, the savings are 1.1% of 2030 electricity consumption in the low savings case and 2.6% in the high savings case. Table 9-2 shows the calculation of these savings for the midrange case.

[36] See energytrust.org/commercial/construction-renovation-improvements/path-to-net-zero.aspx.

[37] See newbuildings.org/getting-to-zero-buildings-database.

Table 9-2. Electricity savings in 2030 from new construction programs leading to code changes

	Value	Unit	Comments
Residential			
	1,526	TWh	2030 residential electricity consumption from EIA 2014
x	14%	new	1.2 million new homes/year (average of last 10 years from Census Bureau)/132.8 homes (2013 American Housing Survey) * 16 years
x	75%	of energy use covered	Code-covered energy uses are now 65% of new home electricity use (RECS 2009 [EIA 2011]), but we estimate this will increase to 75% as additional end uses are added.
x	37%	average savings	Derived from figure 9-1
x	50%	participation rate	For states adopting strong codes
x	75%	states adopt	About 80% have adopted 2009 IECC.
x	95%	net-to-gross ratio	Standard assumption for this report
=	21	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.5%	of US electricity use	
Commercial			
	1,517	TWh	2030 commercial electricity consumption from EIA 2014
x	31%	new	From EIA 2014
x	90%	of energy use covered	Code-covered energy uses are now 84% of new commercial building electricity use (2003 CBECS), but we estimate this will increase to 90% as additional end uses are added.
x	40%	average savings	Discussed in text
x	50%	participation rate	For states adopting strong codes
x	95%	net-to-gross ratio	Standard assumption for this report
x	75%	states adopt	About 80% have adopted 2007 ASHRAE 90.1.
=	60	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	1.4%	of US electricity use	

COSTS AND COST EFFECTIVENESS

Costs—particularly projected future costs—are difficult to measure with any precision. For residential new construction, the best available cost estimates indicate an incremental cost for a Zero Energy Ready home of about $6,000 relative to a home meeting the 2009 IECC. This includes about $2,000 to meet the 2012 IECC (Mendon et al. 2013) plus an additional $4,000 to meet the Zero Energy Ready specification (DOE 2013).[38] Absent any good data on

[38] Another recent study (Maclay Architects 2015) estimates much higher current costs ($15,000 for a single-family home), but this is for substantially better performance than we model here. Maclay Architects looks at a home

future costs, we estimate that over time this cost can be reduced by one-third as builders become more familiar with Zero Energy Ready techniques and as improved techniques and products are developed.

For commercial new construction, we work from a 2015 report by Maclay Architects that estimates the incremental cost of a ZNE-ready open office building to be $9 more per square foot than a building that meets ASHRAE 90.1-2013. The Maclay Architects building uses 72% less energy than the building that meets the ASHRAE 2013 code. Our analysis is based on a building that uses only about 25% less energy than the 2013 ASHRAE code. Prorating the $9 per square foot cost based on relative energy savings, we find that a building that saves 25% relative to the 2013 ASHRAE code might cost $3 more per square foot.[39] We have no good data on future costs, but as with new homes, we estimate that over time these costs would come down by one-third.

Costs and cost of saved energy are based on many estimates. Here we provide the details on this calculation so that readers may modify the calculation as needed, such as substituting local or regional data. At a national level, as calculated below, we estimate that residential new construction efforts leading to code changes will cost 4.4-6.6 cents per kWh saved, while commercial efforts will cost 1.6-2.4 cents per kWh saved. Table 9-3 shows the calculations.

Table 9-3. Cost of energy saved through new construction efforts leading to code changes

	Value	Unit	Comments
Residential			
	13,739	kWh/new home	From EIA 2013
x	75%	in covered end uses	Discussed under energy savings
x	37%	average savings	Discussed in text
=	3,813	saved/new home	
	$6,000	current cost	~$2,000 to go from 2009 to 2012 IECC (per Mendon et al. 2013) plus $4,000 for zero net energy ready (DOE 2013)
	$4,000	long-term cost	We estimate cost will decline by 1/3.
	25%	of costs not for electricity	Based on % of new home primary energy use that is not electricity from EIA 2013
	45	year measure life	NW Council 2015a
	$0.066	per kWh	CSE based on current cost
	$0.044	per kWh	CSE based on long-term cost

that reduces energy use by 67% relative to the 2012 IECC while our analysis focuses on a home that only saves about 30% relative to the 2012 IECC.

[39] $9 * 25/72 = $3.12. We round down to $3 since the lower savings are commonly easier and less expensive to achieve.

	Value	Unit	Comments
Commercial			
	16.9	kWh/sf	From 2003 CBECS (EIA 2015) for newest buildings
x	90%	in covered end uses	Discussed under energy savings
x	40%	average savings	Discussed in text
=	6.1	saved/sf	
	$3	current cost/sf	Prorated from Maclay Architects 2015 as discussed in text
	$2	long-term cost/sf	1/3 reduction as discussed in text
	14%	of costs not for electricity	Based on % of new building primary energy use that is not electricity from 2003 CBECS (EIA 2015)
	45	year measure life	NW Council 2015b
	$0.024	per kWh	CSE based on current cost
	$0.016	per kWh	CSE based on long-term cost

UNCERTAINTIES

One large uncertainty is the level of code adoption in the states, particularly at the very high efficiency levels discussed in this section. Code adoption will be affected by the economic impacts of these improvements as well as the success of efforts to train designers and builders in zero net energy. Code adoption can also be challenging in some states due to opposition from home builder associations concerned about increasing the first cost to build a home. Some states also leave code adoption to local jurisdictions, which means that code adoption can be inconsistent and on average slower. On the other hand, some jurisdictions in these states do move to more advanced codes and on a quicker schedule, thus laying the groundwork for more widespread adoption. But even when codes are adopted, they need to be followed. We assume future code compliance will be about the same as for current codes, but as codes are tightened such an assumption is far from certain. We band this uncertainty with our three different cases—low, midrange and high savings. Another big uncertainty is the long-term costs of meeting these levels of performance. Cost data are limited so far, and while costs can be expected to decline, it is unclear by how much. Our analysis includes two costs—current estimates and a guesstimate of potential future costs.

RECOMMENDATIONS AND NEXT STEPS

Going forward, two tracks should be pursued. First, current model codes and model programs should be adopted. This includes states adopting the latest versions of the model codes (e.g., ASHRAE 90.1-2013 and the 2015 IECC) if they have not already done so, and program operators taking advantage of model programs such as DOE's Zero Energy Ready Home Program and NBI's Advanced Buildings Program, in order to achieve direct energy savings and lay the groundwork for additional energy savings from future code upgrades. Program administrators can urge and support building code updates. In an increasing number of states they receive energy savings credit for these actions (Misuriello et al. 2012).

Second, efforts need to be expanded to grow the state of the art for advanced energy-efficient design and construction techniques. This includes improved materials documenting approaches for reaching NBI Tier 3, development of NBI Tier 4, and completion of the 2016 ASHRAE 90.1 standard and the ZNE codes in process for California's Title 24. It also includes studies on the costs of achieving these advanced performance levels and, to the extent costs are high, efforts to promote cost reductions. Code compliance efforts need to be improved as codes cover more end uses and demand deeper savings. Additional programs promoting these levels of performance would be very useful, as would additional demonstration projects, particularly for building types such as retail where there are limited examples of ultralow-energy buildings.

In addition, it would be useful to have complementary policies that help create a market for higher levels of efficiency, such as building labeling and disclosure policies and development of model stretch codes based on the high levels of performance discussed in this chapter. Such stretch codes can be promoted to those projects and jurisdictions that are interested in going beyond current national codes.[40]

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[40] For more on stretch codes, see newbuildings.org/stretch-codes.

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Chapter 10. Miscellaneous Energy Loads

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MEASURE DESCRIPTION

In this section, we discuss the energy saving potential from key miscellaneous energy loads (MELs) in commercial and residential buildings. EIA estimates that MELs consume more than one-third of electricity used in residences and about 40% of electricity used in commercial buildings (EIA 2014). Energy consumed by MELs, most often characterized as "other" in energy end-use estimates, has been growing every year and is projected to grow faster than any other category in the next couple of decades, as shown in figures 10-1 and 10-2 below (EIA 2014). MELs are composed of a long and diverse list of appliances and equipment such as consumer electronics, computers and peripherals, elevators, escalators, medical devices, and many others.

For the purposes of this study and our broader work in this area, ACEEE considers MELs to be all energy loads other than those serving critical building functions (e.g., providing shelter and habitable conditions) or principal building activities. In a 2013 report, we analyzed a broad set of more than 30 miscellaneous products used in the residential and commercial sectors (Kwatra et al. 2013), following up with a more targeted paper in 2014 (Amann and Kwatra 2014) that recommended energy efficiency strategies for select top MELs. We draw upon both studies to analyze the opportunity in two parts: plugged-in devices and other MELs.

Plugged-In Devices

Even by conservative estimates, there are more than three billion devices plugged into our homes and commercial buildings, and many of these are MELs (Kwatra et al. 2013). While at a single-device level they often go unnoticed on consumer energy bills, together as a category they offer large savings opportunities. Besides, many plugged-in devices can be grouped together with others that share similar usage characteristics. Therefore, it is likely more effective to devise energy saving strategies for plugged-in devices in a comprehensive and systematic manner.

These devices are expected to consume even more energy in the future, even as many conventional energy loads, such as lighting and HVAC, become more efficient. While it is difficult to analyze every plugged-in device, we focus on three of the largest and most ubiquitous ones: televisions, set-top boxes, and personal computers. All three are common in homes and commercial buildings, and we find that strategies to tackle them are applicable to other, similar products.

Other MELs

There are several large energy end uses that typically fall in the "other" category, such as distribution transformers, water treatment and distribution infrastructure, cellular phone towers, and commercial cooking equipment. We, and others, have analyzed most of these in other publications (Kwatra et al. 2013). In this report, we give an overview of two very different products that are both significant energy users: medical imaging equipment and ceiling fans. Unlike plugged-in MELs, each of these has unique energy-use characteristics and deserves a specific energy efficiency approach.

Growing Energy Use

Figure 10-1 depicts the forecast average annual change in energy consumption by end use in residential buildings from 2012 to 2040. Energy loads like lighting and space heating are expected to consume less energy, primarily as a result of more efficient technologies, while "other uses" are expected to grow the most. Similarly, in commercial buildings, "other uses" and non-PC office equipment are the two highest-growth categories (figure 10-2).

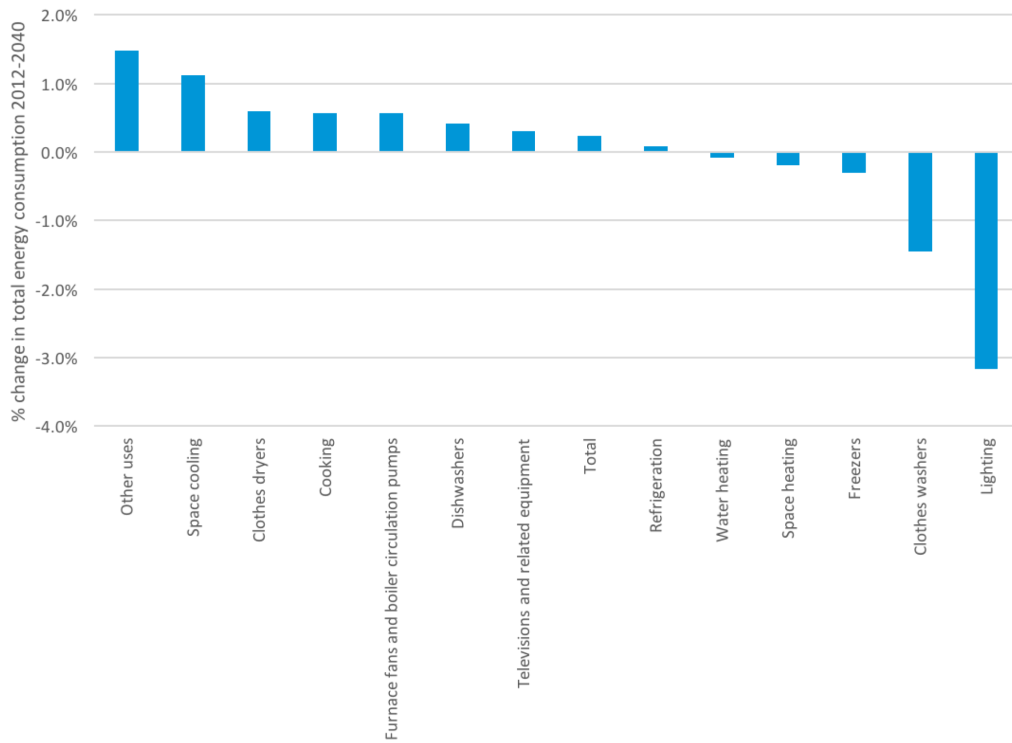

Figure 10-1. Projected change in residential energy consumption by end use, 2012–2040. *Source:* EIA 2014.

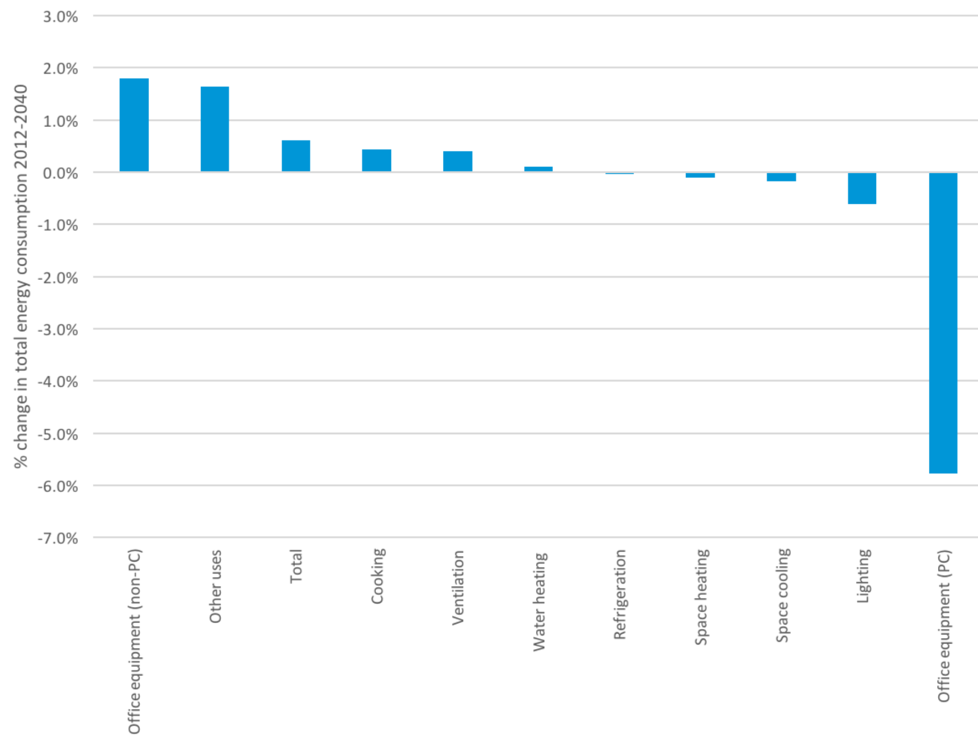

Figure 10-2. Projected change in commercial building energy consumption by end use, 2012–2040. *Source:* EIA 2014.

ENERGY-SAVING STRATEGIES

For commercial buildings, a good first step toward energy management of plug loads is to establish a baseline energy consumption metric. The New Buildings Institute (NBI) has developed a set of plug load energy use metrics on behalf of the California Energy Commission (NBI 2013). These metrics help analyze power drawn by plug loads at various times when a building is in an occupied or an unoccupied state. The NBI methodology measures plugged-in equipment energy power density in watts per square foot of commercial building space. Reference values for weekday power density (24-hour workday), occupied power density (6 a.m. to 6 p.m.), and weekend power density (24-hour weekend day or holiday) can be used to benchmark other, similar commercial buildings. Given the unpredictability of duty cycles, the energy power density metric is not quite as useful as lighting power density, but it does enable benchmarking and identification of opportunities to reduce plug loads. Despite the availability of power management software including enterprise-level approaches, a significant number of devices (e.g., PCs, monitors, imaging equipment) are left on during evenings and weekends. Addressing this is one of the largest and easiest opportunities to reduce plug load energy consumption in commercial buildings.

In residential buildings, plug load audits can be included as a part of energy audits routinely offered by many ratepayer-funded programs. Residential customers can also make use of simple power meters and home energy usage data from their utility to estimate their plug load energy use and identify opportunities to save energy by using advanced power strips and timers and by unplugging devices. Tools like Green Button and online resources like www.unplugstuff.com can be incorporated into program offerings to give customers more information and control over their MELs (Delforge, Schmidt, and Schmidt 2015).

While federal energy efficiency standards do not currently cover many plug loads, they could be expanded to cover more products. Federal standards for external power supplies and battery chargers already reduce energy use across a wide range of plug load devices. State standards offer additional opportunities for product-level standards or for horizontal standards such as the standby power standards already in effect in the European Union.[41] Some states prescribe minimum energy efficiency requirements for products such as televisions (e.g., California) and battery chargers.[42] The ENERGY STAR labeling program covers more products and has been effective in driving the penetration of more efficient models.

The way a product is used can often determine a large part of its overall energy consumption. Just by being connected to a power supply all the time, plug-in products waste a lot of energy even when not in active use. The International Energy Agency estimates that globally 400 TWh of energy is wasted every year just through the energy consumption of devices in stand-by mode.[43] This is equivalent to 133 Rosenfelds.[44] Program interventions targeting education and behavior change, such as the Opower and Home Energy Analytics platforms, are important and can also be used with complementary technology like occupancy and motion sensors. Offices and home entertainment centers usually have a number of computer peripheral devices or consumer electronics that can be easily managed with the help of advanced power strips that incorporate energy control techniques such as infrared, occupancy sensors, current sensors, and time-based controls.

Ceiling Fans

Ceiling fans deserve a special mention in our current discussion as they present a major energy saving opportunity in US households. Approximately 82.6 million US homes have ceiling fans, with one-third of these using four or more fans (EIA 2013). Electricity use for ceiling fans is projected to increase through 2030, as newly constructed homes tend to have more ceiling fans installed, and more new homes are being built in warmer areas where ceiling fans are used more intensively (EIA 2007). The best units on the market have moved to permanent magnet (PM) direct current (DC) motors, which, when combined with improved fan blade design and balanced and sealed bearings, can reduce motor power requirements by 65–70%. Overall savings from switching the current stock to the most efficient on the market can reduce energy consumption by as much as 84% (see table 10-2 below).

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[41] See www.eceee.org/ecodesign/products/standby.

[42] For California's TV standards, see www.energy.ca.gov/appliances/2009_tvregs/.

[43] See www.iea.org/media/here.pdf.

[44] A Rosenfeld is a unit of energy efficiency named after Dr. Arthur H. Rosenfeld. One Rosenfeld represents savings of 3 billion kWh per year, the amount generated by a typical 500-megawatt coal-fired power plant.

Medical Imaging Equipment

Medical imaging equipment—including magnetic resonance imaging (MRI), computed tomography (CT), and X-ray equipment—represent a key set of MELs in the health care sector. This equipment has a very high power draw even during idle periods, which account for the majority of the equipment duty cycle. Almost all major manufacturers are signatories to the European Self-Regulatory Initiative and have developed equipment that provides high-level features while actively scanning but uses much less energy in low-power modes. In the US, an ENERGY STAR specification and test procedure for medical imaging equipment are currently under development (EPA 2015). The Medical Imaging and Technologies Association (MITA 2014) estimates that 11,200 kWh can be saved per CT machine and 28,000 kWh per MRI machine every year from proper use of efficient equipment. Those energy savings translate to cost savings of about $1,650 and $4,125, respectively.

EXPERIENCE TO DATE

Plugged-in equipment and other MELs have not received as much policy or program focus as major energy loads such as lighting, refrigeration, water heating, and space conditioning. However, as buildings strive to meet zero net energy targets and as savings from traditional end uses have diminished, MELs are receiving increasing attention as the next big frontier for efficiency. Indeed, MELs become the largest loads in highly efficient or ZNE homes, given the attention typically paid to shell, insulation, windows, doors, and HVAC equipment to minimize the size of needed photovoltaic (PV) systems.

Standards and Labeling

Of the products addressed in detail in this chapter, only ceiling fans have a federal energy conservation standard in place. This standard has been in effect since 2007, and a rulemaking is currently under way to update it in line with technological advancements. California, followed by some other states, enacted state-level standards for televisions that came into effect in 2011 and 2013. At the federal level, under the EnergyGuide labeling program, DOE has established a test procedure for televisions that manufacturers are required to use for product labels. In December 2013, DOE, pay-TV service providers (cable, satellite, and Telco), manufacturers, and efficiency advocates announced a voluntary agreement for set-top boxes (STBs) (Voluntary Agreement 2014).

ENERGY STAR specifications have been in place for computers, televisions, ceiling fans, and set-top boxes for several years. A specification is under development for medical imaging equipment specifically targeting energy consumption in idle modes of operation.

Program Activity

Program sponsors allocated an estimated $74 million to consumer electronics promotions in 2014 (EPA 2014). Many of these programs complemented retail outreach efforts with consumer rebates along with retailer rebates and, to a lesser degree, manufacturer incentives for high-efficiency products. In 2014, programs in at least 16 states offered more than 50 promotions for televisions (e.g., for ENERGY STAR–qualified and ENERGY STAR Most Efficient models), including retailer incentives and consumer rebates ranging from $4 to $50 per unit sold (EPA 2014). Incentives for computers have been more limited. In 2014, programs in nine states provided retailer incentives or residential and commercial customer rebates ranging from $5 to $15 for ENERGY STAR–qualified computers (EPA 2014). At least seven states had programs incentivizing advanced power strips in 2014, with rebates and markdown incentives ranging from $10 to $15 (EPA 2014). DOE recently published a specification for advanced power strips that should help determine program incentives.[45]

Set-top boxes have a unique distribution model: service providers work closely with manufacturers to tailor boxes to their needs and offerings and then purchase and deploy the boxes in customer homes. As a result, this product has presented a challenge for program administrators, and program implementation has been very limited. Recent program offerings have included incentives targeted to local service providers for the purchase of more efficient STBs, and incentives to customers and service providers for the replacement of non-ENERGY STAR boxes and for upgrades to a whole-home system using thin clients (NEEP 2013).

Other program activity targeting MELs includes customer rebates for the purchase of ENERGY STAR–qualified ceiling fans. Mail-in or instant rebates of $12 to $40 have been offered in as many as 19 states over the past decade (Amann and Kwatra 2014). Many of these programs target fans and add-on ceiling fan light kits. Programs focused only on best-in-class ceiling fan efficiency and performance offer the opportunity for significantly greater energy savings, and potentially higher cost effectiveness, than those rebating all ENERGY STAR models.

A growing number of utilities are working with hospitals and other health care facilities to reduce energy consumption; to date these efforts have focused on facility benchmarking and upgrades to lighting, HVAC, and other building systems.[46] The emergence of energy efficiency ratings for medical equipment can help create a market for more efficient products and provide a mechanism for program administrators to add medical equipment to their program offerings.

ENERGY SAVINGS

Table 10-1 summarizes per unit electricity consumption along with estimated savings potential for key MELs discussed in this chapter. Switching to the most efficient products currently commercially available can save approximately 47% of total energy consumption. While this chapter focuses on five key MELs, our overall savings estimates take into account characteristics of the 20 largest residential and commercial MELs such as video game consoles, microwave ovens, and vending machines. Total annual energy consumption of the top residential and commercial MELs from Kwatra et al. (2013) is 29% of total MELs as per EIA's *Annual Energy Outlook* (EIA 2014). We use this figure for our calculations below. Based on these savings and total energy use for MELs in tables 1-3, 1-4, and 1-5 in Chapter 1, we estimate the total US energy savings available under three scenarios: high, medium, and low

[45] The specification is available here https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/Advanced_Technical_Power_Strips_FINAL%20040915_508.pdf

[46] Some leading examples would be National Grid's strategic energy management plan with the Lifespan Hospitals in Rhode Island, Center Point Energy's Healthcare Energy Efficiency Program in Texas, and the Healthcare Energy Efficiency Program run by the Investor Owned Utilities in California.

participation rates. Details on the midrange case are given below and indicate available savings of 3.4% of US projected 2030 electricity consumption. The low and high cases modify the participation rate to 37% and 75%, respectively, and find savings of 2.5% and 5.1% of 2030 electricity consumption.

Table 10-1. Electricity savings in 2030 from key MELs

	Value	Unit	Comments
	2,285	TWh	2030 MELs energy consumption in the residential and commercial sectors per Annual Energy Outlook (EIA 2014)
x	29%	of energy use covered	Proportion of MELs energy consumed by key MELs based on Kwatra et al. (2013) and as discussed in the text
x	47%	average savings	As per Kwatra et al. (2013)
x	50%	participation rate	For program interventions targeting key MELs leading ultimately to minimum efficiency standards on many of these products
x	95%	net-to-gross ratio	Standard assumption for this report
=	148	TWh	
/	4,327	TWh	Projected 2030 U.S. electricity consumption from Annual Energy Outlook (EIA 2014)
=	3.40%	of US electricity use	

COSTS AND COST EFFECTIVENESS

It is difficult to calculate the incremental costs for products such as computers, televisions, and medical equipment. More efficient products often offer other key features, so it is not accurate to attribute the cost differential to energy efficiency alone. Table 10-2 presents estimates of current and long-term costs associated with efficiency.

Table 10-2. Cost of energy saved through key MELs

	Energy per unit (kWh)				Incremental cost ($/unit)		Costs assigned to other benefits	Average measure life (years)	Cost of saved energy ($/kWh)	
	Current	With measure	Energy savings	Energy savings	Current	Long-term			Current	Long-term
Computers	120[a]	27[b]	92	77%	30[c]	2[d]	0	5	0.075	0.005
Televisions	166[e]	53[f]	114	69%	81[g]	41[h]	0	10	0.092	0.046
Ceiling fans	152[i]	24[j]	128	84%	700[k]	140[l]	80%[m]	14	0.11	0.022
Set-top boxes	142[n]	65[o]	77	54%	NA		0	5		
Medical imaging equipment	93,000[p]	55,800[q]	37,200	40%	NA		0	20	NA	NA
Average				65%					0.093	0.024

[a] Urban et al. 2014. [b] Kwatra et al. 2014. [c] CEC 2015 and industry comments. [d] CEC 2015. [e] Kwatra et al. 2015. [f] Kwatra et al. 2015. [g] Equals 1.63 *49.7. The first figure is from average incremental cost per watt of on-mode power consumption (Eddy and Ting 2014); the second figure is average on-mode power of all products in ENERGY STAR 6.1 QPL. This is comparable to Xcel Energy's deemed savings calculations cost estimate for TV 5.1, which was $100 (Xcel Energy 2015). [h] 50% decrease. [i] Amann and Kwatra 2014. [j] Amann and Kwatra 2014. [k] Difference between average 52" ceiling fan ($200) and ENERGY STAR Most Efficient BigAss Fans Haiku series ($900). Price comparison from Amazon.com and BAF store. [l] Assuming 80% decrease as permanent magnet (PM) motors and sensors become more common. [m] Difficult to quantify, but many other attributes exist such as improved aesthetics, remote control, and occupancy sensors. Assuming 20% cost toward PM motors and sensors (based on comments during ceiling fan rulemaking). [n] Amann and Kwatra 2014. [o] DOE 2013. [p] Kwatra et al. 2015. [q] Kwatra et al. 2015.

Current costs for several of these measures are above 9 cents per kWh and may not be cost effective for many programs. However there are large opportunities for cost reductions. Such cost reductions should be a priority for near-term efforts.

UNCERTAINTIES

Our savings estimates, based on the best currently available technology, have a high likelihood of changing. Historical trends for consumer electronics, computers, and some other common MELs suggest the per unit energy consumption should steadily decrease over time (with the exception of televisions, as new models increasingly transition to ultrahigh definition and ever-larger screen sizes). Hence, our estimates of energy savings are conservative for these products. Long-term evolution of form factors, such as notebooks to tablets or even to large-screen phones, in response to consumer preferences is also fraught with uncertainty. TVs and computers of today look very different from those of 15 years ago and will likely continue to evolve in the future. New content-delivery technologies such as over-the-air and streaming over the Internet will have a large influence in shaping TVs, set-top boxes, and other entertainment products. Another significant uncertainty is the current and long-term cost of these products.

RECOMMENDATIONS AND NEXT STEPS

Since a majority of plugged-in devices and other MELs are not subject to federally mandated energy consumption standards, there is a significant opportunity for efficiency program activity to drive the market toward more efficient products.

Treating MELs (specifically plugged-in devices) systematically as a group can help bring attention to their relatively large energy consumption. Plug-in benchmarks such as power density metrics can help in establishing a baseline and making savings more visible, but it is important to note that efforts to reduce the nominal watts per square foot of plug loads should be accompanied by efforts to scale down when and how they are being used.

Product labeling programs such as ENERGY STAR play an important role in differentiating more efficient products and helping consumers make a choice to save energy and lower their utility bills. In the commercial and institutional sector, labeling programs facilitate development and use of energy-efficient procurement initiatives. Some program administrators play an active role in the specification development and revision process. Increased involvement can help make the labeling programs even more responsive to technological advancements and program savings goals.

Small per unit incentives such as those offered for many electronics products are unlikely to have much impact on consumer purchase decisions for relatively high-ticket items like computers and televisions. Therefore, emerging technology, premium, and other types of incentives targeted toward accelerating the development, introduction, and stocking and promotion of high-efficiency products and components may hold more promise than further reliance on consumer incentives for incremental efficiency improvements for some products. These efforts can also play an important part in bringing down prices and improving the cost effectiveness of high-efficiency products. As an example, program administrators could work together—perhaps through one or more of the regional energy efficiency organizations—to provide a large, lump-sum incentive to any computer manufacturer that commits to meeting a leading-edge efficiency level in a large majority (80–90%) of its products (Amann and Kwatra 2014).

Similarly, standards and labeling programs can make a significant impact by setting minimum performance standards and differentiating the most efficient products. Products such as televisions, computers, and ceiling fans are already at different stages of rulemaking for state or federal standards. For these products and others not covered by standards, ENERGY STAR specifications can facilitate ratepayer-funded initiatives.[47] In 2015, EPA launched a pilot of the ENERGY STAR Retail Products Platform in partnership with seven program sponsors. The platform was developed as a coordinated national effort to reduce the cost and complexity of retailer involvement in efficient product programs. A national

[47] ENERGY STAR programs are in place for televisions, computers, ceiling fans, and set-top boxes. A new ENERGY STAR specification is under development for medical imaging equipment. EPA has scoped out the potential for a specification for elevators and, pending funding, plans to develop a spec in 2016 (K. Kaplan, EPA, pers. comm. July 10, 2015).

launch of the program is expected in 2016 with the goal of large-scale reductions in plug load energy consumption.

As the per unit energy consumption of new products continues to decline, savings can also come from getting the biggest energy users out of homes and offices (through take-back programs) and changing user behavior by encouraging better power management practices, reduced usage, device switching, and other behaviors.

Addressing growing MELs will require broad market approaches as well as a much larger number of sector-specific efforts to reduce energy use by specialty or niche equipment. Attention should be given to improvements in components, power management, and strategies that can work in other applications/products.

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Chapter 11. Advanced Commercial Lighting Design and Controls

Author: Jennifer Amann

MEASURE DESCRIPTION

Recent advances in lighting technology coupled with the adoption of new efficiency standards and code requirements for lighting have resulted in significant improvements in the efficiency of lighting in the commercial sector. Improvements in fluorescent lighting have driven average efficacy levels higher—from 51 to 70 lumens per watt (lpw) between 2001 and 2010 (DOE 2012). The emergence of and rapid efficacy gains in LED lighting will continue this trend, with efficacy of general-service linear fixtures forecast to reach 91 lpw in 2015 and 109 lpw in 2020 (DOE 2014). DOE forecasts more rapid growth in LED adoption in the coming years such that LEDs will grow from 8% of commercial sector sales (by lumen-hour) in 2015 to 82% of sales in 2030; in the industrial sector, sales are forecast to grow from 3% in 2015 to 87% in 2030 (DOE 2014).

As light source efficiency gains are widely adopted in the market and captured in codes and standards, opportunities for energy savings from simple lamp and fixture replacements diminish. The opportunity for lighting savings thus shifts to advanced lighting design and lighting controls, strategies that have been underutilized in the past.[48]

Advanced lighting design strategies seek to optimize lighting performance in terms of light level, light quality, and flexibility to meet the needs of building occupants across the range of tasks that they perform. LED technologies offer new and improved functionality that enhances lighting design opportunities. For example, some new LED lighting systems allow occupants to adjust color temperature according to their preferences and to improve mood, alertness, visual acuity, and task performance. In addition, advanced lighting systems incorporate user-friendly system monitoring and management to minimize the likelihood that controls will be overridden or disabled, provide data for tracking energy and cost savings, and facilitate participation in demand response programs.

Specific design strategies address

- Lamp and fixture selection, including light source, lumen output, and wattage
- Fixture placement to optimize spacing and orientation
- Task lighting to allow for reduced ambient light levels
- Control strategies including scheduling, tuning, occupancy sensing, daylight dimming, personal control, and load shedding

EXPERIENCE TO DATE

Advanced lighting design projects cut energy consumption by shrinking the connected lighting load through reduction in the number of fixtures, reduction in ambient light levels (e.g., by lowering number of lamps, lamp wattage, and/or ballast factor), and incorporation

[48] The discussion and analysis in this chapter focus on national opportunities and savings. In states with more advanced codes with strong control requirements (such as California), savings available for utility programs will be lower.

of control strategies. Increases in task lighting load associated with task-ambient strategies are more than offset by reductions in overall lighting load. In combination, these strategies have the potential for significant energy savings.

Williams et al. (2011) conducted a meta-analysis of 88 papers and case studies presenting a total of 240 controls-related savings estimates. They determined best estimates of the energy savings potential of controls to average 24% for occupancy (including occupancy sensors, time clocks, and energy management systems), 28% for daylighting, 31% for personal tuning (dimmers, bi-level switches, computer controls), 36% for institutional tuning (dimmable ballasts, on-off or dimmer switches for non-personal lighting), and 38% for multiple approaches.

Optimization of control strategies as part of a lighting redesign can yield even higher savings, although the savings vary widely by application. In the first year of its Advanced Lighting Controls program, Sacramento Municipal Utility District (SMUD) achieved savings of 50–90% in 14 lighting retrofits in commercial offices and industrial facilities (Parks 2013). In another California project, an advanced office lighting retrofit coupled with luminaire-level lighting controls resulted in lighting system energy use of 1 kWh/sf/year, a savings of 74% relative to the average of 3.9 kWh/sf/year for small offices statewide (NBI 2014). Task-ambient approaches incorporating fixture retrofits or replacements to reduce ambient lighting coupled with low-wattage LED task lamps (typically 8-12W each) can reduce load by 38-73% depending on the application and existing fixtures (Walerczyk 2013).

While lighting programs have long served as a mainstay for commercial energy efficiency programs, the emphasis has been on prescriptive rebates for installation of high-efficiency lamps and, to a lesser extent, controls. Dozens of program administrators offer prescriptive incentives for the purchase and installation of occupancy, daylight dimming, and time clock controls. The most common offering is a set dollar amount per sensor or control, but incentives based on a set amount per watt of load controlled is also common. Despite these incentives, controls remain an underutilized technology. Only 30% of commercial lamps are used with a control of some kind (DOE 2012).

Custom programs have typically been used for major renovation/lighting retrofit projects, but these can be costly to administer and have proved hard to scale. Massachusetts is offering a variation on the typical custom program to increase adoption of advanced controls. The Mass Save Networked Lighting Controls Initiative offers an up-front incentive of $0.50/sf for qualifying projects.[49] Projects are required to achieve energy savings of more than 40% relative to baseline kWh usage.[50] To increase the likelihood that controls will be used properly and savings realized, the program requires commissioning and customer training (Sondhi 2013). This approach is a better match for the market as well because it makes the process simpler and more accessible for decision makers. Knowing the incentive

[49] To qualify, projects must cover at least 25,000 square feet and have at least 150 fixtures controlled by the networked controls.

[50] Baseline is defined as the IECC 2012 or Massachusetts Stretch Code lighting power density multiplied by the assumed hours of occupancy for each controlled space type.

in terms of dollars per square foot going in makes it easy to factor the incentive into tenant improvement budgets and the quotes provided by the lighting design/installation firm. Customers can apply for additional performance incentives if their lighting design exceeds code by 15% or more, but they are not eligible for prescriptive lighting incentives.

ENERGY SAVINGS

In our midrange case we estimate advanced lighting design and controls programs can reduce US 2030 electricity consumption by 1.3%. Table 11-1 shows our calculations.

Table 11-1. Electricity savings in 2030 from advanced lighting design and controls

	Value	Unit	Comments
	268	TWh	2030 commercial lighting electricity consumption from EIA 2014 plus an additional 5% to account for opportunities in industrial sector
x	68%	of energy use covered	According to DOE (2012), 72% of commercial lighting energy use is linear fluorescent (LFL) and 14% is high intensity discharge (HID). Industrial sector energy consumption is split 60%/40% between HID and LFL. Assume advanced lighting design and control appropriate for 75% of LFL and HID applications (and applicable to LEDs in the same applications).
x	65%	average savings	Based on results from SMUD Advanced Lighting Controls Program.
x	50%	participation rate	In the long term, these levels of performance can be incorporated into building codes.
x	95%	net-to-gross ratio	
=	56	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	1.3%	of US electricity use	

COSTS AND COST EFFECTIVENESS

The cost of advanced lighting design and controls varies widely depending on the specific application, size of the project, sophistication of the project and controls strategy, and other factors. Sources reveal a wide range of costs even for specific project types. Lighting controls add an estimated $0.50 to $2.00 per square foot to lighting project costs (Nelson 2014; LBNL 2013). The initial proof of concept for luminaire-level lighting control retrofit projects found costs ranging from $1.71 to $3.11 per square foot (Cortese and Scherba 2013). Incorporating additional lighting system elements, including advanced lighting design, increases costs. For example, task ambient lighting retrofit projects range from $120 to $560 per office or $1.20 to $4.70 per square foot (Walerczyk 2013). For the Mass Save Sustainable Office Design program, incremental costs for advanced lighting design and controls is estimated at $2.00 per square foot based on the results of 13 test projects completed in vacant office spaces (Sondhi 2015).

For this analysis, we assume the current incremental costs for advanced lighting design and controls at $2.00 per square foot. We assume costs will drop significantly over the long term as controls and related equipment costs fall and as standardized designs for advanced lighting projects reduce individual project design costs. Table 11-2 shows our calculations.

Table 11-2. Cost of energy saved through advanced lighting design and controls

	Value	Unit	Comments
	4.3	kWh/sf/yr	DOE 2012 weighted average for commercial lighting applications
x	68%	in covered end uses	Discussed in text under energy savings
x	65%	avg. savings	Discussed in text
=	1.9	kWh/sf/yr saved	
	$2.00	current cost	Incremental cost per square foot based on Mass Save Sustainable Office Design program: equipment, installation, and designer costs (designer required)
	$1.00	long-term cost	Assume 50% cost reduction with standardized designs
	0%	of costs not for electric	
	15	year measure life	
	$0.102	per kWh	CSE based on current cost
	$0.051	per kWh	CSE based on long-term cost

UNCERTAINTIES

Data on project costs and energy savings vary widely depending on the size and scope of project, application, sophistication of project design, materials chosen, and so on. To date, data on projects incorporating advanced design and controls together are limited. As more project data are compiled, estimates for costs and savings for specific applications will improve. Further savings and better data on system performance and savings are anticipated with the adoption of enhanced building-level monitoring and control (see Chapter 12).

RECOMMENDATIONS AND NEXT STEPS

Advanced lighting design and controls offer opportunities for programs to continue to realize significant savings from commercial-sector lighting. To capture these savings, programs should increase market capacity to deliver advanced lighting design projects through education and training of the design community and lighting contractors. These efforts, coupled with demonstration projects and innovative pilot programs, will help improve cost effectiveness—an important consideration given that our analysis estimates the current cost of saved energy at $0.10 per kWh.

Promising program types for further consideration and piloting include shifting from set incentives for specific components to project-based incentives determined by measured energy performance, offering additional incentives for audits and design expertise, targeting new programmatic channels (e.g., tenant build-outs), and education and training. New programs will need more field data on the most effective strategies, actual energy savings, and user acceptance as well as better project cost data to optimize program design and incentive levels. Finally, new approaches for covering controls and actual performance in codes and standards can help drive broader adoption and accelerate savings.

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Chapter 12. Advanced Commercial Rooftop Air-Conditioning Units

Author: Harvey Sachs

MEASURE DESCRIPTION

The commercial buildings category is extremely diverse, including office buildings, schools, warehouses, retail, worship spaces, and more.[51] Air-conditioning can be provided by residential-type equipment (in very small facilities), commercial unitary air conditioners (CUAC), very sophisticated large-scale chilled water systems, and many specialty approaches such as water-source heat pumps. This section focuses on CUAC. Almost this entire category is packaged rooftop units (RTUs), which cool the majority (57%) of all air-conditioned commercial floor space (EIA 2015). Together, these units use about 0.9 quads of energy per year in cooling mode (Navigant 2011).

Aside from the fact that they are almost always roof mounted, CUAC (and heat pumps) are characterized more by diversity than similarity. At the small end, commodity units may have a single-stage compressor. As size increases, the number of compression stages increases, typically with the addition of more and larger hermetic scroll compressors. Smaller units tend to be single-zone, constant air volume with fixed-speed condenser fans. As size increases, staged airflow and variable-air-volume air distribution appear. These features allow larger RTUs to approach, through direct expansion, the sophistication of smaller, built-up chilled water systems in sizes larger than about 30 tons.

System diversity extends to heating capabilities. In general, as building sizes increase, cooling loads increase more rapidly than heating loads: Again as a generalization, larger buildings (using larger equipment) have smaller surface-to-volume ratios and larger internal heat gains from people, lighting, and equipment. Heating loads may be met by gas-paks, which are non-condensing gas furnace sections generally installed downstream of the cooling coils. Alternatively, some RTUs are heat pumps, reversing the refrigeration cycle to provide warm air to the building. And some use electric resistance heating. The Department of Energy rates gas-paks by thermal efficiency (current minimum is 80%) and heat pump heating by COP (coefficient of power), which is the ratio of heat output to power input, both expressed in watts. According to discussions with manufacturers, because such a small fraction of RTUs are heat pumps, optimizing performance for either energy efficiency ratio (EER) or integrated energy efficiency ratio (IEER) does not generally lead to high heating COPs. Indeed, there is little correlation, and COPs are generally in the range of 3.3–3.7 (DOE 2015b). The ASHRAE 90.1-2013 minimum values are 3.25–3.3 for 47°F and 2.05–2.2 for 17°F (ASHRAE 2013).

Commercial RTUs are generally larger than 5.5 tons (65,000 Btu/hr). There are also residential-style split and packaged units smaller than 65,000 Btu/hr, which are differentiated from similar residential equipment by requiring three-phase power (residential equipment is single phase). This small commercial equipment is rated like its

[51] The Commercial Buildings Energy Consumption Survey (CBECS) includes 16 major classes (EIA 2015).

residential counterparts, with seasonal energy efficiency ratio (SEER) and heating season performance factor (HSPF) for cooling and heat pump heating, respectively.

Commercial AC efficiency for units larger than 65,000 Btu/hr is in transition in 2015. Until recently, EER, a steady-state, full-load measure, has been the legal metric. ASHRAE 90.1 has moved to a multipoint metric (IEER, for integrated energy efficiency ratio), and the Department of Energy is expected to adopt the same metric in a current rulemaking.

Diverse application needs also affect manufacturing and marketing. In general, the smaller the capacity, the more models available and the more units sold. However, even at small capacities, units are typically available with large numbers of optional features, many of which affect performance and efficiency. One major option that is widely adopted is the economizer, which enables use of outside air instead of all or part of the refrigeration circuit whenever the outdoor air is cooler and/or has lower enthalpy than the indoor air.[52] In cooler climates, this can save 20–30% of annual energy. Other options include number of cooling stages, number of refrigerant circuits, air handler design (to match system external static pressure), and staged condenser fans.

Capacity Classes

Many utility programs adopt both EER and IEER requirements. EER helps manage load peaks, while IEER correlates better with annual energy savings (since peak loads are rare compared with part loads). Regulated CUAC is commonly grouped in four size classes:

- Under 65,000 Btu/hr (generally residential-rated [SEER])
- 65,000–135,000 Btu/hr
- 135,000–240,000 Btu/hr
- 240,000–760,000 Btu/hr

As described below, minimum energy efficiency levels are lower for larger units.

Legal Minimums: ASHRAE 90.1 and DOE

Standards for commercial heating, ventilating, and air-conditioning (HVAC) equipment involve multiple steps. On a three-year cycle, ASHRAE, with the Illuminating Engineering Society (IES), releases a revised version of standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, currently ANSI/ASHRAE/IES Standard 90.1-2013 (ASHRAE 2013). When (or if) states or other "authorities having jurisdiction" adopt a specific version of 90.1, it governs what can be *installed* in new buildings or major retrofits.

In addition to the minimum energy performance levels it establishes, 90.1 is notable for its emphasis on specific energy-saving prescriptive requirements. Depending on system type, these can include variable airflow, exhaust air heat recovery, specific controls (including demand-controlled ventilation for some spaces), economizers, and even damper leakage. The savings from these features (and their application requirements) vary with equipment

[52] Enthalpy is the internal energy of a packet of air—that is, the sum of its (sensible) temperature and its moistness, the theoretical energy that would be released if the water vapor it contains were condensed to liquid.

capacity and climate zone but can easily provide savings of 20% or more beyond the refrigeration cycle savings of incremental adjustments to IEER specifications.

In contrast, after each adoption of a 90.1 version, the Department of Energy (DOE) carries out a "determination analysis" to test whether the ASHRAE minimum efficiency levels are the most stringent that are technologically feasible and economically justified. DOE certified the overall 90.1-2013 values in September 2014 and subsequently began a more detailed review of the RTU efficiency values. Based on this review, DOE began a rulemaking, proposing significantly more stringent minimum efficiency standards than in 90.1-2013 for equipment that can be *manufactured* for sale in the United States.

Both the ASHRAE and DOE processes include formal procedures for judging cost effectiveness of proposed minimum efficiency levels. However the dual activities have led to issues that are relevant for program designers. The first is that the ASHRAE process is supported by extensive simulations funded by DOE and carried out by a national laboratory as a neutral resource. It is also a consensus process, with manufacturers and other interest groups participating. The ASHRAE process also has a simpler economic analysis than is used for DOE standards. The DOE standards process is supported by different analyses and simulations carried out by different contractors, including a more detailed economic analysis, and the results differ significantly. In mid-2015 DOE undertook a formal negotiated rulemaking to better understand the divergences and reach a consensus on appropriate stringency. This effort was successful, as discussed below.

For program developers, there is a much more critical issue. As noted above, ASHRAE's standard 90.1 includes extensive suites of *prescriptive* features, in addition to the equipment stringency levels. In strong contrast, the enabling legislation seems to allow DOE to set *either* a performance level (such as EER or IEER) *or* a prescriptive requirement, but not both. *ACEEE strongly recommends that incentive programs include both tier-appropriate performance levels and the appropriate prescriptive requirements from ASHRAE 90.1-2013.* As voluntary programs, these can be required (and incentives given) at least until 90.1-2013 is adopted by the authority having jurisdiction where the equipment is installed.

In the data tables that follow, we illustrate efficiency levels in IEER values. For simplicity, we show values only for air conditioners with resistance or no heating. Other heating sections decrease IEER slightly because of the additional fan power required to force air through the heating section. We tabulate only mainstream RTUs, excluding specialty products, the very small, and the very large. Units smaller than 65,000 Btu/hr are basically residential machines with three-phase power, are rated with the SEER residential metric and are incorporated in our discussion and analysis in Chapter 6. The largest units, larger than 760,000 Btu/hr, are sold in relatively small numbers with great potential for custom specifications.

Some Possible Program Levels

As noted above, industry practice and DOE standards are in transition from a peak load metric, EER, to an integrated measure heavily weighted by part-load performance. For this reason, the current federal minimum standards have limited value as a baseline for computing savings from more advanced products. In addition, the market basket of units sold has an efficiency average that is above the legal minimum, so the legal minimum is lower than a sales- and capacity-weighted average.

Table 12-1 shows three potential references for developing program levels.

Table 12-1. Capacity classes and proposed part-load efficiency levels for CUAC, with data sources (all IEER unless otherwise noted)

	Capacity, Btu/hr		
Minimum	65,000	135,000	240,000
Maximum	<135,000	<240,000	<760,000
DOE NOPR[1]	14.8	14.2	13.5
DOE NOPR Max Tech[2]	19.9	18.4	15.5
ASHRAE 90.1-2013[3]			
EER	11.2	11	10
IEER, pre-2016	11.4	11.2	10.1
IEER, after 1/1/2016	12.9	12.4	11.6
CEE 2012[4]			
Tier 1	13	12.5	13.2
Tier 2	14	11.3	12.3
ASRAC 2015[5]			
2018	12.9	12.4	11.6
2023	14.8	14.2	13.2

[1] Notice of Proposed Rulemaking: DOE 2014a. [2] DOE 2014b. [3] ASHRAE 2013. [4] Revised Consortium for Energy Efficiency (CEE) High-Efficiency Commercial Air Conditioners (HECAC) Tier levels were under consideration in mid-2015, pending issuance of DOE rule, so they were not available for this compilation. [5] Appliance Standards and Rulemaking Federal Advisory Committee.

DOE NOPR are the values proposed by DOE. As discussed above, DOE convened a negotiated rulemaking, largely because the industry believed that the underlying analyses had large systematic errors.

DOE Max Tech is the most efficient product (in terms of the current test procedure) that can be offered with technologies available in the market today. This formulation explicitly excludes features that save energy but are not visible to the rating method, which views only the refrigeration cycle. Below, we evaluate that limitation in the context of two competitive challenges, DOE's RTU Challenge and the Western Cooling Efficiency Center's Western Cooling Challenge (Brambley 2013; WCEC 2015b). Both utilize other features that save energy.

For the equipment referenced here (mainstream RTUs with resistance or no heating), 90.1-2013 includes three different minimum performance levels, all listed here, as part of the shift from EER to IEER. Until January 1, 2016, equipment can be rated by either EER or IEER, providing a transition period to ease the burden of re-rating equipment. After that date, the more stringent IEER levels will be the only acceptable metric.

The Consortium for Energy Efficiency (CEE 2012) develops efficiency tiers at increasing performance levels. These tiers are offered as guidance for coordinated utility and other public benefits incentive programs, with the goal of establishing national consistency. Such consistency simplifies industry efforts to respond to the opportunity these rebates offer to increase sales of more efficient products, which are presumably more profitable.

CEE's tier levels are based largely on the number of models on the market and estimates of energy savings: "These tiers are based on considerations outlined in the initiative that may include, for example, energy savings potential, market readiness or penetration, or technical feasibility" (CEE 2015). Feedback from manufacturers is utilized in the development process. As of mid-2015, CEE is revising its criteria, with emphasis on the transition from EER to IEER as the underlying metric.

RTU Challenges

Because the test method evaluates only one aspect of increasingly complex and sophisticated RTUs, both DOE and the Western Cooling Efficiency Center have organized competitions to recognize advanced units that use additional features, not reflected in the test method, to improve savings.

DOE HIGH PERFORMANCE ROOFTOP UNIT CHALLENGE

In January 2011, DOE released the design specification for 10- to 20-ton capacity rooftop units as part of the High Performance Rooftop Unit Challenge. Qualifying units would reduce annual energy use by about 50%, depending on location and application specifics (DOE 2015a). The primary features of the RTU Challenge models are IEER ≥ 18, specified direct digital control (DDC) capabilities, and operational fault detection (DOE 2012). The Daikin Applied Products Rebel was the first unit to qualify, with IEER 20.6, and claimed two-year payback (Daikin McQuay 2012). A Pacific Northwest National Lab study estimated that the Rebel reduces energy use by 40–50% (varying by city modeled) relative to the current DOE and ASHRAE minimum efficiency standard for this equipment (Wang and Katipamula 2013). The Carrier WeatherExpert line of 3- to 23-ton units show IEER performance up to 21, 15% better than the challenge level, so savings should be comparable to the Daikin Rebel unit (Carrier 2013). Several other manufacturers have products in development.

The specification was developed in collaboration with the Commercial Building Energy Alliance (CBEA), major purchasers of the target units. Although CBEA members indicated "strong interest in potentially purchasing products that comply with the specification" (DOE 2012), May 2015 interviews with knowledgeable staff at both Daikin and Carrier suggest that sales to date have been lower than they had anticipated.

THE UC–DAVIS WESTERN COOLING CHALLENGE

This is another significant effort, aiming to save at least 40% of annual energy use and also reduce peak loads at least 40% through innovative technologies that supplement or replace vapor compression. These technologies could include "indirect evaporative cooling, variable speed fans, multiple stage compressors, evaporatively cooled condensers, and use of part-load operating modes that can provide reduced capacity cooling at much more efficient operating modes" (WCEC 2015b). In addition, there are prescriptive requirements, including the ability to sense and communicate performance degradation.

To date, the program has certified two products. The 20-ton Trane Voyager DC

> adds the DualCool™ evaporative pre-cooling package to a high efficiency Voyager model rooftop unit. DualCool . . . then circulates evaporatively cooled sump water through a heat exchanger coil at the outdoor air inlet to reduce the ventilation cooling load. The DualCool components increase the nominal cooling capacity by 20%, while improving efficiency of the vapor compression system. For typical commercial applications, the Voyager DC cuts peak electrical demand for cooling by 40%. (WCEC 2015c)

Similarly, the 5- to 8-ton Coolerado H80 hybrid system

> couples indirect evaporative cooling with two stage vapor-compression cooling. The indirect evaporative cooler can operate alone or it can act as a pre-cooler for the vapor-compression system. When the compressor operates, exhaust from the indirect evaporative cooler is used for condenser cooling. The indirect evaporative cooler used for the system is an integral device with multiple air pathways that exchange heat and mass to cool supply air without the addition of moisture. Motorized dampers control the balance of outside air and return air, and the system operates with a minimum outside air fraction of approximately 45%. (WCEC 2015a)

Laboratory testing indicates the Coolerado H80 could outperform the federal standard by 65%.

These units—and the program—work because the West is dry. It takes significant amounts of energy to evaporate (boil) water. Both units use evaporation to cool air, whether by pre-cooling the air that cools the condenser or by indirect evaporation (with a heat exchanger) to cool the ventilation air. Of course, this raises questions of the water–energy nexus. Pistochini and Modera (2011) suggest that efficient systems combining evaporation and vapor compression can use less water per unit of cooling than the consumptive water use associated with power generation. Torcellini, Long, and Judkoff (2003) showed that consumptive water use for power generation is particularly high for hydroelectric plants in the arid West, so evaporative cooling with advanced equipment may be an important component of energy-efficient and water-efficient strategies.

EXPERIENCE TO DATE

The Consortium for Energy Efficiency is in the process of revising its commercial air-conditioning and heat pump (HECAC) program, with different performance tiers and different minimum efficiency requirements for these tiers. Revisions are expected to be finalized in late 2015, using input from the simultaneous federal rulemaking. The top tier could be at a level similar to that of DOE's Rooftop Challenge. To date, this program has been based exclusively on measured performance, without the additional prescriptive features of ASHRAE 90.1-2013.

Many utilities and other program operators offer incentives for high-efficiency equipment—see www.advancedrtu.org/financial-resources.html. However, as best as we can determine, all of these programs promote moderate improvements relative to current energy efficiency standards, and none of the programs currently have higher incentives for levels similar to that of the Rooftop Challenge. This could change if the new CEE program includes a new top tier.

ENERGY SAVINGS

As our baseline for programs, we assume the IEER efficiency levels of ASHRAE 90.1-2010, without its prescriptive requirements for controls, economizers, and so on. This is the baseline DOE used in its most recent analysis for this equipment. DOE can require either EER or IEER as a rating method, but it can adopt only one metric, or a prescriptive measure. It cannot require both a performance metric and prescriptive features. We show that very large savings are available through programs that require climate-appropriate prescriptive features as well as higher IEER values.

For this report we use the DOE Technical Support Document Life Cycle Cost Analysis (DOE 2014). We use the energy savings and costs that this document assumes for the Max Tech level as a proxy for the DOE Rooftop Challenge level. Including features like economizers and advanced controls/diagnostics instead of just focusing on the refrigeration cycle might allow units that are more cost effective than the DOE Max Tech unit, which excludes these features. The Challenge RTU has a minimum IEER of 18, which compares with 18.4 for the comparable-capacity Max Tech unit. We have used DOE energy use analysis, recognizing that various DOE assumptions (explored by industry in the 2015 Negotiated Rulemaking) probably significantly underestimated annual fan energy for non-cooling purposes (ventilation and heating).

In our midrange case we estimate that more stringent minimum efficiency levels for better RTUs could reduce total US 2030 electricity consumption by 0.9%. Table 12-2 provides the details of our calculations.

Table 12-2. Electricity savings in 2030 from more stringent minimum efficiency levels for RTUs

	Value	Unit	Comments
	336	TWh	2030 commercial sector electricity use for AC, ventilation, and heat pumps. From EIA 2014. Heat pump share of space heating from 2003 CBECS (EIA 2015).
x	57%	of energy use covered	Rooftop units as % of total (DOE 2014a)
x	58%	average savings	Derived from DOE NOPR Technical Support Document for Max Tech level (DOE 2014b)
x	37%	participation rate	Based on ramp-up to standards that take effect in 2029
x	95%	net-to-gross ratio	Standard assumption for this report

	Value	Unit	Comments
=	39	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.9%	of US electricity use	

For the low- and high-savings cases, we used 25% and 50% participation rates, respectively, resulting in savings of 0.6% and 1.2% of projected 2030 US electricity use.

COSTS AND COST EFFECTIVENESS

Table 12-3 shows the cost of energy saved through more stringent minimum efficiency levels for better RTUs. As with energy savings, we used the ASHRAE 90.1-2010 IEER values for the baseline, and the DOE 2014 Technical Support Document, Chapter 8, for costs. Again, the Max Tech level is a proxy for units that include the prescriptive features of both ASHRAE 90.1-2013 and those of the DOE RTU challenge, notably economizers, direct digital controls, and onboard diagnostics.

Table 12-3. Cost of energy saved through more stringent minimum efficiency levels for RTUs

	Value	Unit	Comments
	6,357	kWh saved per unit	Derived from DOE NOPR TSD for Max Tech level (DOE 2014b)
	$5,408	current cost	Derived from DOE NOPR TSD for Max Tech level (DOE 2014b)
	$4,101	long-term cost	Estimate 25% cost reduction
	15	year measure life	From DOE 2014 TSD (DOE 2014b)
=	$0.083	CSE based on current cost	
=	$0.062	CSE based on long-term cost	

UNCERTAINTIES

Our estimates are subject to significant uncertainties due to multiple challenges facing this industry in the period between today and 2030. During this period efficiency standards will probably be reviewed twice. For the core vapor-compression air conditioners and heat pumps, manufacturers argue that under the rating methods currently used, cost-effective energy efficiency will be increasingly difficult to achieve. The most effective avenue to greater savings probably lies in changing the rating methods, so they include savings attributable to total annual use of high-efficiency fans, better controls, fault detection and diagnostics (FDD) to limit and find field issues as they develop, and tests that fully value performance in different climates. These will all take time. Manufacturers, caught between the present federal EER and the to-be-adopted IEER, must design to EER and hope to maximize IEER in the process—although the measures utilized do not always correlate completely. This chapter establishes that efficiency can be improved remarkably. The question is whether program operators can gain enough confidence in requiring both the IEER metric (and EER for some programs) and the prescriptive features of ASHRAE 90.1-2013. Programs that restrict themselves to program metrics implicitly undervalue the large opportunities available.

A second upcoming challenge is the transition from the current low-ozone-depletion refrigerants, predominantly HFCs like R-410A, to alternatives that also have low global warming impact.[53] Some alternatives will have flammability challenges; others will have efficiency concerns. Some high-cost synthetics have emerged, but it is likely that different applications will utilize different refrigerants—increasing engineering challenges and costs. In some cases, manufacturers will offer *indirect* or *secondary refrigerant* systems, which keep challenging refrigerants outside the building and transport energy with water or other fluids. Again, this is an engineering challenge.

With these challenges and opportunities, projecting the efficiency levels that can be justified for 2030 is challenging. We have chosen to rely on a DOE estimate of costs, but we then assume future cost reductions based on expectations that control and variable-speed drive costs will come down and that test procedures will be revised to consider additional savings opportunities. The degree of future cost reductions is highly uncertain.

RECOMMENDATIONS AND NEXT STEPS

The CEE equipment efficiency tier approach makes sense, and it should be continued.

Federal standards are essentially limited to the refrigeration cycle, but there are many opportunities for additional energy savings, many of which are region or application specific. Since legislation would be required to allow federal standards to include both performance metrics (IEER) and prescriptive elements such as economizers, programs must begin to include the well-analyzed, consensus, prescriptive features in ASHRAE 90.1 to gain all cost-effective savings.

As an example of the value of including both kinds of features and cost effectiveness in program design, we recommend adoption of the DOE RTU Challenge specification (IEER 18 plus prescriptives) and/or the Western Cooling Challenge, as appropriate for the region served by the program.

For many voluntary programs, peak loads exacerbated by poor air-conditioning remain a major challenge. In these areas, it is important to continue using an EER specification in addition to the IEER value. For this, we recommend at least the EER values in ASHRAE 90.1-2013, Table 6.8.1-1. These are 11.2, 11.0, and 10.0 for small (65,000–135,000 Btu/hr), large (135,000–240,000 Btu/hr), and very large (240,000–760,000 Btu/hr) units with no heating or resistance heating. These values can be decremented by 0.2 EER for units with other heating, such as warm-air furnaces or heat pumps.

[53] As stated in a footnote in Chapter 6, manufacturers argue that the best metric for global warming is total impact (total equivalent warming impact [TEWI] or life cycle climate performance [LCCP]), which measures both direct (refrigerant leakage) and indirect (fossil fuel combustion) effects, and so credits greater efficiency. Over equipment lifetimes with real-world failures, indirect effects (CO_2) are much larger than refrigerant leaks.

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Chapter 13. Smart Commercial Buildings

Author: Sameer Kwatra

The power of information and communication technology (ICT) applied to energy use in buildings presents an enormous opportunity to save energy. Smart buildings have energy systems that communicate with other subsystems and with the power grid, and they can adapt in response to the needs of the occupants.

In general, ACEEE uses the word "smart" for equipment, appliances, or networks that have the ability to communicate digitally—to send and receive information, and in most cases modify their behavior based on this communication. Several enabling technologies help define smart buildings: smart lighting, smart HVAC components, advanced building energy management systems, smart meters, and other smart components.[54] We discuss savings from each of these in this section.

However even larger savings are possible when such interconnected devices are designed to optimize performance at the level of the whole building or beyond. Elliott, Molina, and Trombley (2012) apply the term "intelligent efficiency "to this systems-based, holistic approach to energy savings, enabled by information and communication technology and user access to real-time information.[55] Figure 13-1 shows how various smart technologies can work together to create an intelligent system. The system boundaries can be extended in either direction, with a smart grid on the supply side and intelligent facilities on the demand side.

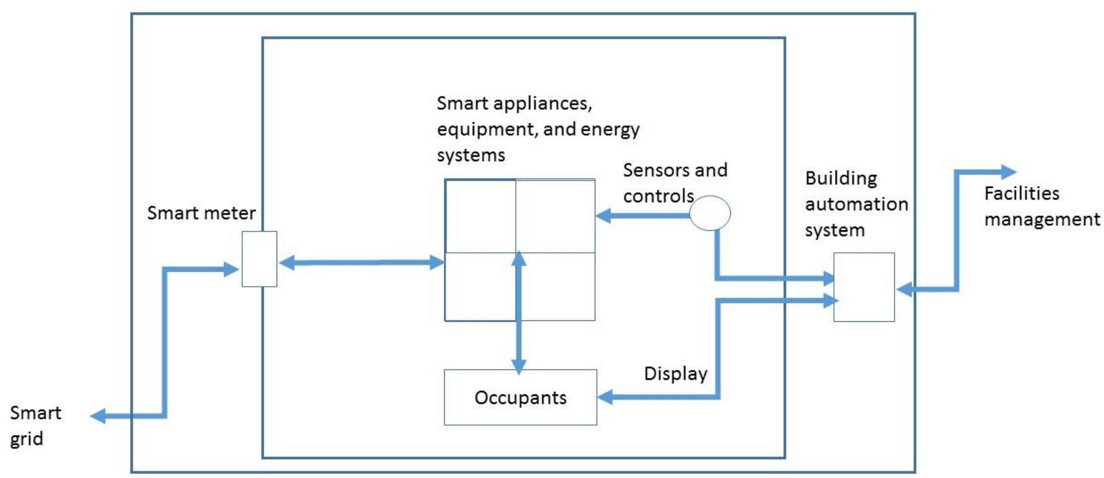

Figure 13-1. Intelligent efficiency approach to smart buildings. *Source:* Kwatra and Rogers 2014.

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[54] Building automation system (BAS) and building management system (BMS) are other, similar terms; they usually describe a system incorporating access control and security in addition to energy management.

[55] For a quick description of how intelligent efficiency uncovers significant savings, refer to Chapter 17, which examines smart manufacturing.

MEASURE DESCRIPTION

We group smart building elements into the following categories: advanced building energy management systems (BEMS), smart lighting, smart HVAC, and other smart building components. Although there are benefits from each of these on their own, for true system-level benefits, these technologies have to work together. Our savings estimation incorporates interaction among various systems to a certain extent; however, more research is needed to refine these estimates.

Advanced Building Energy Management Systems

Automation systems enable monitoring and control of a building's energy systems centrally and remotely. New-generation BEMS also have the capability to provide automated fault detection and diagnostics (ADD). In addition to enhancing energy efficiency, ADD systems have the potential to reduce operations and maintenance costs and equipment downtime (Capehart and Brambly 2015). The energy savings due to intelligent efficiency is the difference between a system that is occasionally optimized and one that is always optimized and continuously improving (Rogers et al. 2013). Research done by the Pacific Northwest National Laboratory (PNNL), the National Institute of Standards and Technology, the Natural Resources Defense Council, and Energy Design Resources found savings of 13–66% from intelligent building automation systems that have ADD, historical analysis, and predictive capabilities (Wang et al. 2011; Snoopily 2010; Henderson and Walter 2013).

Smart Lighting

When the BEMS has information on current and future occupancy, it can not only switch lights on and off at optimal times and vary light levels, but also do a comparative analysis of whether the impact on HVAC energy use that results from lightening smart windows and letting in sunlight will be smaller or greater than darkening the windows and turning the lights up. Analyses by the Northwest Energy Efficiency Alliance (NEEA 2013) and claims by Osram Sylvania (Osram Sylvania 2013) indicate potential savings of 40–75% beyond what is possible with standard occupancy-based lighting controls.

Smart HVAC

Technologies now on the market enable each subset of a BEMS to self-optimize. For example, advanced control strategies for packaged HVAC systems that customize air-conditioning to the needs of the occupants using technologies such as multispeed fans and demand control ventilation, result in cost savings of 24–32% depending on the building type (Wang 2011).

Other Smart Building Components

Smart windows that lighten or darken depending on the intensity of sunlight are commercially available. Such windows can reduce space-conditioning and lighting loads and improve the work environment by reducing glare. A study by the Lawrence Berkeley National Laboratory found that smart windows alone have the potential to reduce energy use for cooling by 19–26% and lighting by 48–67% (Lee 2006).

Many other types of smart equipment are available today, including advanced power strips for managing plugged-in devices; smart ceiling fans that inform and regulate the thermostat; smart elevators with destination dispatch controls; and grid-interactive televisions, refrigerators, and dishwashers. Most commercial buildings generally have regular load profiles (occupied, non-occupied, weekend), so all these smart devices have a large potential to align building energy use for maximum efficiency and peak-load management. Research by PNNL indicates that electric utility customers could realize 10% energy savings through transactive controls (Katipamula et al. 2006).[56]

EXPERIENCE TO DATE

There have been a limited number of energy efficiency programs to date offering a suite of intelligent efficiency or smart building measures. However leading efficiency programs are seeking new approaches to gain greater energy savings from each customer, and an emerging trend is to create programs that capture savings from multiple systems in one project, such as whole-building retrofits and building automation. What is promising about including smart automation and controls in efficiency programs is that if done right, it will not only provide additional savings but also enhance measurement and verification capabilities.

Intelligent efficiency provides an opportunity to move from device-based energy efficiency programs to comprehensive, performance-based programs. Performance information is reported to the program administrator, and the incentive paid is based on actual energy saved. Programs may provide the bulk of the incentive up front, based on forecast energy savings, and later release the balance as actual performance is reported. That balance may increase or decrease depending on whether more or less energy has been saved than forecast, and it may be released over a period of one or more years.

The New Jersey and New Hampshire Pay for Performance (P4P) programs have seen excellent results using this strategy (Kwatra and Essig 2014). The programs provide incentives for the installation of multiple measures that result in a minimum of 15% source energy reduction based on whole-building simulation. To ensure deeper savings across all systems, energy savings from lighting upgrades are capped at 50% of the total. Cumulatively, from 2009 to mid-2014, the New Jersey program had achieved 95 million kWh and 21 MW of savings (Rooney 2014; G. Coleman, TRC, pers. comm., February 6, 2014).

Pacific Gas & Electric's Commercial Whole Building Demonstration builds on this pay-for-performance strategy but uses interval meter data and a whole-building approach to validate savings rather than relying on calibrated simulation alone. The goal is to prove that a whole-building approach, if properly designed, can be technically robust enough for regulatory program requirements in California. Launched in late 2013, the demonstration is designed to deliver energy savings of 15% or more on average. For projects to date, about half of the measures and the predicted energy savings can be attributed to energy management systems (L. Carrillo, PG&E, pers. comm., July 10, 2015).

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[56] The term "transactive" describes controls that manage the supply, distribution, and demand of energy (usually electricity) based on the value of a triggering transaction such as the time-of-day price. For a basic discussion of how this works, see www.gridwiseac.org/about/transactive_energy.aspx.

Other programs are looking to integrate information technology tools as a catalyst for achieving and measuring energy efficiency. The existing facilities program administered by the New York State Energy Research and Development Authority (NYSERDA) now provides incentives for the installation of information gathering technologies that provide critical data to monitor and alter building operation. Incentives are provided for systems that enable ongoing optimization and monitoring rather than merely the installation of occupancy or motion sensors.[57]

Utilities also have a role to play in demonstrating the power of big data to help customers reduce energy usage. Some utilities and the commissions that regulate them are already considering how this might evolve. The California Public Utilities Commission held an information exchange event in April 2013 to educate commissioners and staff on the availability of energy consumption data and how it can be utilized to evaluate the effectiveness of policies and programs (CPUC 2013).

Several utilities and grid operators have come together to form the Open Automated Demand Response Alliance and a new protocol, OpenADR, for communicating demand response information.[58] OpenADR is an open and standardized way for electricity providers and electricity system operators to communicate demand response signals with each other and with their customers using a common language over an existing network such as the Internet.

Inclusion of intelligent efficiency in energy performance contracts is also increasing. DOE is investigating the use of performance contracts to fund upgrades in IT and data centers (Ye and Seidel 2013). Johnson Controls includes BEMS in most of its performance contracts because of the additional energy savings they provide and because they simplify performance monitoring (C. Nesler, vice president, Johnson Controls, pers. comm., September 9, 2013).

ENERGY SAVINGS

In a 2013 report, *Intelligent Efficiency: Opportunities, Barriers, and Solutions* (Rogers et al. 2013), ACEEE determined that the commercial sector stands to save $30 billion to $60 billion if investments in intelligent efficiency measures are made at a rate 1–4% greater than the current level (figure 13-2). The analysis estimated effects of a select group of smart energy efficiency measures that have the most promise for near- and medium-term implementation in the commercial sector.

[57] For eligibility and incentive details, see www.nyserda.ny.gov/All-Programs/Programs/Existing-Facilities-Program/Monitoring-Based-Commissioning-Incentives.

[58] An OpenADR Alliance overview can be found at: www.openadr.org/about-us.

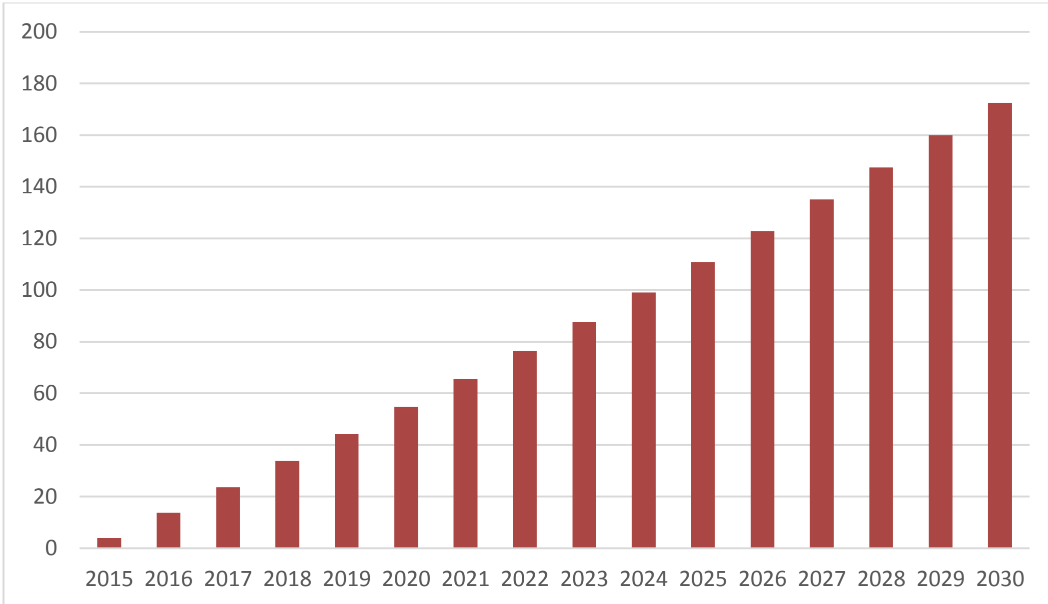

Figure 13-2. Potential reductions in commercial sector electricity use (TWh) with greater intelligent efficiency investment. ***Source:*** **Adapted from Rogers et al. 2013.**

The analysis aggregates marginal gain in energy efficiency attributable to intelligent efficiency as separate from the efficiency gains provided by the enabling technologies alone. For a detailed discussion of the methodology of savings and cost estimates, see the related discussion in Chapter 17 of this report, which examines smart manufacturing.

For this analysis, we scaled back the 2013 analysis to an end point of 2030. Energy savings from smart commercial building technologies will vary by technology and by type of building. There are estimates in the literature that range from 10–40%. We selected 20% for our mid-case estimate due to its conservative nature and due to our evaluation of the quality of the research backing up that estimate. Participation rate is a function of time, and based on our 2013 analyses, we have assumed 35% of eligible commercial building floor area will participate in installing intelligent efficiency measures by 2030. This yields a savings of 50 TWh, or 1.2% of US projected energy use in 2030. To be conservative, we limited our calculations to buildings 50,000 square feet and larger; we expect smart building techniques will most likely be applied in these buildings first. Since our analysis here does not include savings from buildings smaller than 50,000 square feet, these numbers are lower than those projected in the 2013 report. Our high estimate includes a higher participation rate (50% by 2030), and higher savings per building (30%), resulting in 108 TWh savings in 2030, equivalent to 2.5% of projected US use. Our low case assumes 15% savings and 25% participation, yielding savings of 27 TWh, or 0.6% of projected US energy use. All three cases are summarized in tables 1-3, 1-4, and 1-5 in Chapter 1. Table 13-1 below shows details of the medium case.

Table 13-1. Electricity savings in 2030 from smart commercial building technology

	Value	Unit	Comments
	1,517	TWh	2030 electricity available to grid from Annual Energy Outlook (EIA 2014)
x	50%	of energy use covered	Buildings above 50,000 square feet in floor area (EIA 2015)
x	20%	average savings	Estimate based on Rogers et al. (2013)
x	35%	participation rate	Scaled back to 2030 from estimate of 50% in Rogers et al. (2013)
x	95%	net-to-gross ratio	Standard assumption for this report
=	50	TWh	
/	4,327	TWh	Projected 2030 U.S. electricity consumption from AEO (EIA 2014)
=	1.17%	of US electricity use	

COSTS AND COST EFFECTIVENESS

A range of costs is associated with smart building components. For instance, building automation systems start at $100,000 and can go into the millions of dollars. Lighting upgrades for a typical midsized building can range from $500,000 to over $1 million, and HVAC retrofits from $1 million to $2 million. Not all of this cost should be attributed to the "smart" measure; we are interested in the incremental cost-benefit of selecting a smart option versus a standard one. This is difficult to estimate; we assume 50% of the costs can be assigned to other benefits.

For the purpose of our analysis, we have chosen $0.5 million as the cost for a typical smart building energy measure for a midsized (200,000-square-foot) commercial building with an energy use intensity of 16.4 kWh/sf (EIA 2006). Annual savings of 20% on average, as consistent with Rogers et al. (2013), translates to 656,000 kWh of savings in a year. As discussed in Chapter 17, we estimate that the cost of installing smart measures will decrease by 25% with time.

With these inputs we estimate the cost to save energy from a typical smart building measure as $0.037/kWh based on current prices and $0.028/kWh in the long term (table 13-2).

Table 13-2. Cost of energy saved through typical smart commercial building measures

	Value	Unit	Comments
	16.4	kWh/sf/yr	Average electricity use for commercial buildings larger than 100,000 sf (EIA 2006)
x	20%	average savings	Rogers et al. 2013
=	656,000 kWh	annual savings per building	Assumes typical 200,000-square-foot commercial building
	$500,000	current cost	Discussed in text (derived from Rogers et al. 2013)
	$375,000	long-term cost	Estimate 25% reduction
	15	year measure life	ERS 2005
	50%	% of cost assigned to other benefits	Estimate
	$0.037	CSE current	
	$0.028	CSE long-term	

UNCERTAINTIES

As discussed above, there is substantial uncertainty as to the average energy savings per building, the participation rate by 2030, and how much of the building sector is worth targeting by 2030 (e.g., whether 50,000 square feet is a reasonable building size threshold, or whether the threshold might be higher or lower). Increasingly, several of these measures are offered in the form of subscription to a cloud based software service. Hence the costs are incurred over a period of time rather than up front. This distributed payment could slightly lower the cost of saved energy estimates, as would a greater than 25% decline in costs within the time frame we have used. To summarize, we have greater confidence in our savings and measure-life estimates and a higher uncertainty around the costs.

RECOMMENDATIONS AND NEXT STEPS

With the potential to produce a step change in energy efficiency and the associated cost savings throughout the economy, intelligent efficiency is a promising strategy for government policies and ratepayer-funded efficiency programs to encourage.

Research and demonstration. To better understand the incremental benefits of "smart" versus "standard," more research is required, especially on moderate-cost approaches for small- and medium-size buildings. Demonstration projects for different building types and geographies, such as those undertaken in federal buildings, can go a long way in establishing credibility in savings from smart buildings.

Whole-building performance-based programs. Currently many utility programs are based on a prescriptive approach that emphasizes efficiency for individual components. Shifting to a whole-building performance-based approach offers the potential for maximum efficiency gains (Kwatra and Essig 2014). Systems-based intelligent efficiency applications are best positioned to provide the analytical rigor and the technological control needed to optimize whole-building energy performance.

Interoperability of networks. Scores of manufacturers are involved in building and manufacturing automation, and many of them have their own software programs. These programs are often not consistent in how they communicate energy data (ODVA 2011). While there are already several industry-led efforts to develop interconnection standards, more work needs to be done to ensure scalability of smart building solutions.

Common protocols for determining and attributing energy savings. Smart buildings have the ability to measure and report their energy use information almost in real time. There is a need to develop common communications protocols for building energy management and control systems as well as acceptable protocols for regulatory approval of intelligent efficiency program evaluation, measurement and verification (EM&V). ACEEE is researching this for a forthcoming report.

Creating awareness. The many companies engaged in developing and selling intelligent efficiency products and services can seek opportunities to collaborate on noncompetitive research and development as well as to educate about and create awareness of the benefits of ICT. Activities such as those by the Information Technology Industry Council to bring awareness to information technology issues within policy circles and by the Energy Information Standards Alliance to develop a common communication framework for equipment to generate, communicate, and use energy data are examples of what is helpful and necessary to move the adoption of intelligent technologies forward.

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Chapter 14. Comprehensive Commercial Retrofits

Author: Dan York

MEASURE DESCRIPTION

Existing commercial buildings offer a large potential for energy savings through improving the energy efficiency of equipment, systems, and envelopes. Buildings generally have long lives; the turnover of building stock is relatively slow. This means that large numbers of existing buildings were designed and built at times when technologies, materials, and building practices were not as advanced as those available today. For example, 44% of the commercial building floor space in the Energy Information Administration's *2012 Commercial Building Energy Conservation Survey* were built before 1980, preceding most building energy efficiency codes (EIA 2015a). Without major upgrades to older, inefficient components and systems, many older buildings perform poorly in terms of energy use. Today buildings are capable of yielding high-performance environments with low—even net zero—energy consumption. Building codes continue to advance in terms of their requirements for energy-efficient design and construction, targeting higher energy performance today than in earlier periods. We address new commercial building construction and codes in another section of this report.

A recent ACEEE research report examined the promise and potential for comprehensive commercial building retrofit programs (Kwatra and Essig 2014), sometimes referred to as deep retrofits. These building projects and programs are distinguished by their focus on the design and performance of entire, multiple building systems as opposed to individual equipment components. Higher savings can be achieved due to improved system efficiencies and interactive effects. For example, redoing lighting systems can typically greatly reduce lighting energy use, which also greatly reduces the building's cooling load. This provides an opportunity for downsizing space cooling (air-conditioning) equipment and systems. As Kwatra and Essig (2014) observe:

> These [building] systems are interrelated; changes in one often affect the energy use in the others. Maximum efficiency gains can be achieved by analyzing the building as a whole and taking into account the interactive effect of the energy use of its various systems.

Addressing such interrelated systems is done by what is known as integrated design, an approach that can be taken for both renovations and deep retrofits to optimize systems performance and building energy efficiency.

Since comprehensive commercial retrofits are clearly major building projects, they can span several years from inception to completion, either as a single undertaking or in distinct phases over many years. Ideally such retrofits are done in conjunction with other major building renovation projects, which typify the life cycles of most buildings as occupancy and building needs change over time or old, obsolete equipment and systems need to be replaced and upgraded.

The energy savings possible through comprehensive retrofits are very specific to a given building and the types of changes that are made. However typical comprehensive retrofits of commercial buildings can yield savings of 20–50% or more compared with pre-retrofit energy use. Some projects go ever farther and achieve net zero energy—essentially minimizing building energy use through high energy efficiency such that all energy needs can be supplied from onsite renewable energy sources. The proven ability of deep retrofits to bring existing buildings, at times of major renovation, to the exemplary level of energy use necessary to be net zero is documented in the national *Getting to Zero* database of net zero buildings (NBI 2014).

EXPERIENCE TO DATE

There are many examples of buildings that have undergone comprehensive retrofits. The New Buildings Institute (NBI) has documented dozens of deep retrofits, which it defines as those projects that achieve 50% or greater savings. Such examples demonstrate clearly that 50% savings in existing buildings are realistic and proven (Higgins 2012). In a study of nine existing buildings in the Northwest that underwent deep efficiency projects, NBI found that seven of the nine used 50% less energy than the national average for comparable buildings in similar climates (NBI 2011). As an initial part of the study, NBI compiled a set of 50 existing building projects, all of which achieved energy savings of 30% or more from implementation of two or more energy efficiency measures. The Rocky Mountain Institute similarly provides case studies of comprehensive retrofits that have achieved high energy savings (RMI 2015). A prominent example of what is possible through comprehensive energy retrofits is the Empire State Building in New York City. A comprehensive retrofit of the building resulted in 38% energy savings (Smith and Bell 2011).

While these sets of case studies illustrate what is possible on the leading edge of building retrofit practices, more modest but still significant savings from comprehensive building retrofits can readily be achieved. The range of energy savings for projects examined in ACEEE's research on comprehensive commercial building retrofits is 10–40% of baseline energy use (Kwatra and Essig 2014).

Programs are needed to accelerate and increase the number of commercial buildings undergoing retrofits each year. Current building stock (as measured in square feet) is being retrofit at the rate of approximately 2.2% per year, and the average retrofit is reducing energy use by 11% (Zhai et al. 2011).[59] This low rate of change and modest savings achieved per project suggest a large potential for energy savings from comprehensive retrofits.

The roles that programs can play to accelerate the rates of participation and depth of savings include the following (Kwatra and Essig 2014):

- Raising awareness of the opportunities comprehensive commercial retrofits can provide to building owners, tenants, and operators
- Identifying buildings that offer the best opportunities for significant, cost-effective savings from deep retrofits
- Creating markets for energy efficiency and high-performance, energy-efficient buildings

[59] The 2.2% figure applies to all types of projects, whether part of utility programs or independent market decisions by owners.

- Assisting with project management, since deep retrofits are more complex undertakings than simpler equipment and system change-outs or upgrades
- Providing technical assistance from experts in comprehensive retrofit projects
- Helping projects move ahead by providing financial incentives that help them meet targets for financial returns from facility improvements and investments. In some cases the available incentives may not be sufficient to move entire retrofits ahead, but may enable certain measures to stay in the integrated package of measures being considered.

Utility and related programs can draw upon a wealth of available tools and materials to improve program effectiveness, visibility, and reach. In particular, EPA's Building Performance with ENERGY STAR® offers utilities and other program partners a variety of resources designed to achieve greater and persistent savings in commercial buildings (EPA 2015a). For program administrators, the core goal is to engage their business customers in an ongoing relationship centered on strategic energy management and continuous performance improvement. While not specifically targeting comprehensive retrofits, program participants are encouraged to undertake such projects where they would be cost effective and deliver other desired building performance outcomes. Key elements of Building Performance with ENERGY STAR available to its program partners include benchmarking of building performance with EPA's Portfolio Manager and engaging local trade ally networks to offer comprehensive services.

Numerous leading commercial building retrofit programs have partnered with Building Performance with ENERGY STAR.[60] Their experiences highlight the value of drawing upon the nationally recognized ENERGY STAR brand and associated tools and resources designed specifically for commercial building owners, operators, and trade allies (EPA 2015a). Successful strategies taken by program partners include

- Moving from buildings to portfolios—that is, getting customers to look at all properties as a portfolio
- Using benchmarking as a mechanism for discovery of building performance
- Acting as a trusted adviser
- Helping all customers do more: serving a wide variety of customer classes, building types, and experience levels
- Reaching and influencing key decision makers, typically at the corporate executive level, by using the right value propositions and effective communications (EPA 2012)

[60] These programs include Commonwealth Edison and Nicor Gas—Building Performance with ENERGY STAR, National Grid—Rhode Island Whole Building Assessment Initiative, Mass Save Whole Building Assessment Program, Pacific Gas & Electric Building Performance with ENERGY STAR, Wisconsin's Focus on Energy Retail Energy Management Challenge/Building Performance with ENERGY STAR, New Jersey's Clean Energy Program Pay for Performance/Building Performance with ENERGY STAR, MidAmerican Energy Efficiency Partners, Southern California Edison and Southern California Gas—Continuous Energy Improvement, and Consumers Energy Business Solutions.

While the role of utility and related customer programs is important to reach high savings in this market, there also is likely to be an increasing number of comprehensive building retrofits that will occur independently. The growth in demand for buildings certified as being green or otherwise energy efficient, such as by LEED® or ENERGY STAR, is evidence that private markets are growing (USGBC 2015; EPA 2015b).

ENERGY SAVINGS

Table 14-1 shows our midrange calculations for electricity savings in 2030 from comprehensive commercial building retrofits.

Table 14-1. Electricity savings in 2030 from comprehensive commercial building retrofits

	Value	Unit	Comments
	1,517	TWh	2030 commercial electricity consumption from EIA 2014.
x	100%	of electricity use covered	Whole-building energy use. All systems and loads may be addressed through comprehensive retrofits: lighting, HVAC, miscellaneous end uses, and so on.
x	25%	average savings per building	Well-documented, achievable, demonstrated potential, as discussed above. Leading-edge projects can achieve savings of 50% or more.
x	20%	participation rate	Assume significant, consistent program push to reach this share of buildings by 2030. This is a long enough cycle to include energy retrofits at major building change-outs and similar major renovations. This value also accounts for nonprogram-driven projects.
x	0.95	net-to-gross ratio	Assume minimal program free ridership
=	72	TWh	Electricity savings potential
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	1.70%	of US electricity use	

As table 14-1 shows, our midrange savings estimate is 1.7% of US electricity use. Our high estimate is 2.5% and our low estimate is 0.8%. Experience with past programs shows that participation is the key variable. We use a 20% participation rate for our midrange estimate. For our high estimate we use 30% and for our low estimate we use 10%. These rates are significantly higher than that achieved to date but include nonprogram-driven projects. They are lower than more aggressive targets as proposed by initiatives such as Architecture 2030, which calls for at least 50% of buildings to undergo comprehensive retrofits by 2030. To achieve the rates used in our estimates will take a consistent, concerted programmatic push along with corresponding market transformation impacts. Over the length of our study (to 2030) we believe such rates could be achieved.

The savings calculated in table 14-1 are for electricity only, as that is the focus of our study. There would be significant natural gas savings achieved along with these electricity savings, especially in regions with high winter heating loads.

COSTS AND COST EFFECTIVENESS

Comprehensive energy efficiency retrofits are cost effective from the perspective of the building owner when their costs are less than the energy saving benefits. However building owners may undertake comprehensive retrofits for a variety of reasons in addition to energy savings, including improved building performance, changes in building use, equipment failures or necessary upgrades, and market drivers such as demand for green buildings. As noted above, comprehensive building retrofits realize cost-effective energy savings through energy-efficient improvements of key building systems such as lighting, HVAC, and building shell. Each project has unique baseline conditions, measures, and costs. Cost effectiveness from a program perspective differs from that of the owners; program guidelines, budget constraints, and screening may exclude certain measures that an owner might deem worthy. Programs typically may provide financial incentives for selected measures that offset a fraction of their costs. Program costs also may include technical and project management assistance.

Kwatra and Essig's (2014) observation on cost effectiveness is relevant in this analysis:

> Studies indicate that improving energy efficiency in the US commercial building sector is not only cost effective but can also achieve substantial returns. Two separate analyses, one by McKinsey & Co. and the other by the National Academy of Sciences, show that energy consumption can be reduced by 28% by 2020 (Granade et al. 2009) and 32% by 2030 (NAP 2010) in a cost-effective manner. Goldman et al. (2005) reviewed close to 200 commercial retrofit projects and found that the great majority achieved an internal rate of return (IRR) greater than 15%.

Research by Lawrence Berkeley National Laboratory estimates the cost effectiveness of commercial retrofits. Table 14-2 shows the findings in categories that include commercial retrofits, with savings per building most commonly 15–25% of baseline.

Table 14-2. Cost of energy saved in buildings categories that include commercial retrofits ($/kWh)

	Savings weighted average	1st quartile	Median	3rd quartile
Commercial and industrial: custom	0.020	0.011	0.018	0.034
MUSH* and government	0.036	0.033	0.05	0.078

* Municipal, utilities, schools, and hospitals—commercial customers that are the primary market for energy service companies. *Source:* Billingsley et al. 2014.

UNCERTAINTIES

The two key variables in projecting possible energy savings from comprehensive commercial retrofits are the participation rate and the savings per project. Of these, the participation rate is subject to the greatest uncertainty. Historically, comprehensive commercial building retrofit programs have had low participation rates due to numerous barriers to moving these projects ahead.[61] Programs will have to overcome these barriers to serve higher numbers of projects. Programs also need to be designed to help transform markets so that demand for high-performance buildings will drive more comprehensive retrofit projects and grow the skilled workforce who can provide them. Such providers include architects, designers, engineers, contractors, energy service companies (ESCOs), and other building professionals and businesses.

As noted earlier, we expect utility and related customer programs to play a role in accelerating and expanding the market for comprehensive retrofits. However there also needs to be complementary development of private markets for such projects to more fully capture the energy efficiency potential of existing commercial buildings. For example, ESCOs historically have been successful in selected markets (municipal, universities, schools, and hospitals: the MUSH market) by providing financing and guaranteeing savings in conjunction with project management and implementation. ESCO-driven projects and other nonprogram projects will need to grow to reach the participation rates we use in our estimates.

There is much less uncertainty about the other key variable, energy savings per project. There are ample case studies that demonstrate and document high savings from comprehensive retrofit projects (10–50%, and even higher in some cases). Advances in building technologies will help reduce the uncertainty associated with energy savings per project. Such advances can work to achieve higher energy savings compared with existing, less energy-efficient technologies and systems. Applying robust measurement and verification methods, such as those given in the International Performance Measurement and Verification Protocol®, also minimizes the uncertainty of energy savings.[62]

Project costs are key variables that affect the determination and selection of specific measures, which in turn affects the energy savings potential of building retrofits. The cost premiums for higher-efficiency design, building materials, equipment, and systems are likely to be reduced over time as markets respond to increased demand. As these costs decline, additional energy efficiency measures may become more cost effective, yielding higher energy savings from comprehensive retrofits.

RECOMMENDATIONS AND NEXT STEPS

Existing commercial buildings represent one of the largest single sources of future energy savings through comprehensive retrofits. To capture this potential will require a significant

[61] Participation in comprehensive retrofit programs is typically measured and reported by number of projects, not by participation rates. In Kwatra and Essig's (2014) review, participation in large programs (large utility or statewide programs) generally numbers in the hundreds of projects. The largest example given is the NYSERDA Existing Facilities Program (a statewide initiative), which had about 2,074 projects in 2011.

[62] The International Performance Measurement and Verification Protocol was developed and published by the Efficiency Valuation Organization. The associated library of documents includes an overview of current best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects in commercial and industrial facilities (EVO 2015).

increase in the number of such projects completed each year as a result of both utility programs and expansion of this market outside of such programs.

We echo the recommendations made in an earlier ACEEE report on comprehensive commercial retrofit programs (Kwatra and Essig 2014):

- Target underserved markets.
- Transition from incentives to comprehensive solutions.
- Incentivize for deeper savings.
- Streamline project management.
- Phase implementation of projects to mesh with business operations and cycles.
- Use remote energy analytics to help identify efficiency opportunities.
- Develop trade allies as program partners through training, certification, incentives, and program materials.
- Employ consistent, state-of-the-practice evaluation methods and associated technologies to track and verify energy savings and building performance post-retrofit.
- Leverage the very real and significant nonenergy benefits such as health, safety, comfort, and productivity improvements with energy savings benefits in business cases and pro formas to increase demand for comprehensive retrofits.

Of the above recommendations, developing trade allies and creating the business case for comprehensive retrofits are fundamental to transform the building market and achieve the magnitude of impacts we estimate in this study. In addition to efforts from utility and related customer programs, there is a continued need for complementary catalysts to expand the market for comprehensive retrofits—both to increase demand for such services and to increase the supply of qualified contractors and other building professionals. Examples of such efforts include the Department of Energy's Better Buildings Challenge, which seeks commitments and actions from building owners to achieve savings of 20% or higher, and numerous city initiatives, which similarly challenge owners to take steps to greatly increase the energy efficiency of their buildings. Certification programs like the US Green Building Council's LEED ratings and EPA/DOE's ENERGY STAR also help to grow this market and raise the bar for building performance, especially regarding energy efficiency. Increasing adoption of energy benchmarking and disclosure ordinances will also push the existing building market toward energy upgrades and comprehensive retrofits. Energy service companies will continue to be an important and growing part of this market.

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Chapter 15. Commercial and Industrial Strategic Energy Management

Author: Ethan Rogers

MEASURE DESCRIPTION

Strategic energy management (SEM) is a systematic approach to energy management and involves the development of systems to achieve continuous improvement in energy efficiency. It requires workforce education and training and organizational culture change. SEM incorporates the plan-do-check-act (PDCA) approach that has been successfully applied to manufacturing quality improvement for many years through programs such as Total Quality Management (TQM), Six Sigma, Lean Manufacturing, and ISO 9001 (DOE 2014; Kolwey 2013).[63]

Energy management programs exist on a continuum from modest enhancements to maintenance programs to comprehensive efforts that follow the International Organization for Standards (ISO) 50001 standard for energy management and are certified by the Superior Energy Performance (SEP) program administered by the Technical Assistance division of DOE's Advanced Manufacturing Office (DOE 2015). As depicted in figure 15-1, SEM is the first major level that embraces a holistic and systematic approach to energy management. In this chapter, we will focus on programs that fit within this narrower scope.

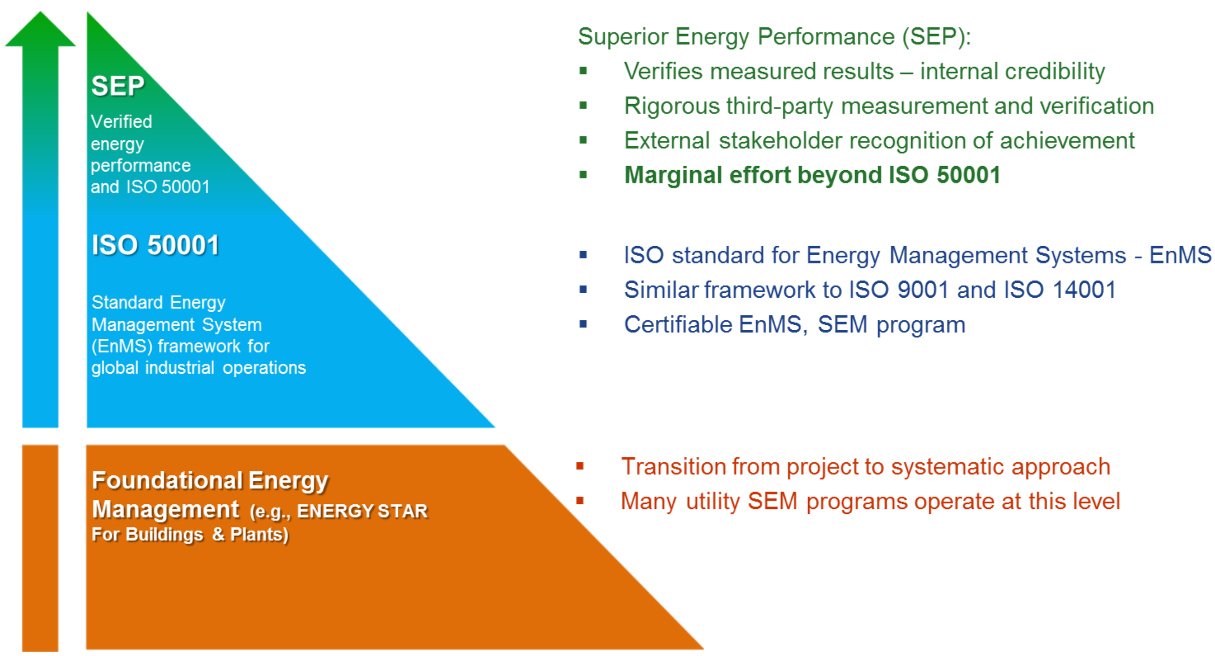

Figure 15-1. Levels of energy management. *Source:* DOE 2015

There is overlap among behavior programs, training programs, and continuous improvement programs in that they all focus on equipping workers with knowledge and skills to identify opportunities and implement solutions. SEM is more comprehensive in that

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[63] PDCA is an iterative, four-step management method used in business for the control and continuous improvement of processes and products.

it provides a structure for systematic and continual efforts to improve energy efficiency. It changes the conversation from possible implementation of sporadic energy efficiency measures to consistent implementation of a steady stream of energy efficiency projects. Its power to transform an organization comes from the alignment of many employees within the organization behind management's support of a multiyear goal. SEM can result in energy savings that ordinary capital measures alone cannot achieve. And because it includes a method for companies to track energy performance, it creates a powerful tool for management to integrate energy efficiency into operational practices (Hossein, Ochsner, and Stewart 2012).

SEM programs have the ability to produce operations and maintenance (O&M) savings and increase the number of capital investments (CapEx). The energy savings from CapEx investments such as improved processes, smart devices and controls, and building retrofits are covered in other chapters of this report. Therefore we do anticipate some overlap, and Chapter 1 describes how we compensate for it.

There are four types of energy efficiency programs that fall within the SEM umbrella: (1) co-funding of energy managers at customer facilities, (2) training staff at industrial facilities on how to implement management systems and procedures for achieving continuous, long-term energy savings goals, (3) training staff to identify and implement low-cost O&M improvements and measuring the associated energy savings, and (4) installation of energy management information systems (EMIS) software program (N. Kolwey, analyst, SWEEP, pers. comm., June 26, 2015). These four types of programs do not exist in isolation. Many programs include multiple elements. The Consortium for Energy Efficiency (CEE) analyzed a dozen programs in 2014 and found that almost all of them included the development of an energy plan and the training of staff, but less than half included an onsite energy manager or EMIS software.

In its industrial strategic energy management initiative, CEE has established three minimum elements for SEM programs (Burgess 2014):

- Customer commitment through policies, goals, and allocation of resources
- Planning and implementation through assessments, mapping exercises, establishing goals and metrics, project registering and tracking, and employee engagement
- System for measuring energy performance that routinely collects, stores, analyzes, and reports

The examples on which our analysis is based meet these minimum requirements. However it is likely that in the future, program administrators will design their programs to accommodate customer needs and interests as well as their own strengths and goals, resulting in a variety of program structures that may not all match the CEE recommendation. Our estimates of national savings are inclusive of the achievements of all types of continuous improvement programs.

Experience to Date

Most of the efforts to organize SEM programs to date have occurred at the national level through DOE and the US Environmental Protection Agency (EPA), or through regional programs in the Pacific Northwest states and British Columbia. DOE started funding demonstration projects around the country in 2000 and in 2007 began the development and testing of the SEP program.

In December 2013, DOE launched the Industrial SEP Ratepayer-Funded Accelerator to work with utility commercial and industrial (C&I) programs to develop initiatives that help customers achieve SEP certification. Such certification requires implementation of the ISO50001 Energy Management Standard and third-party measurement and verification of energy performance improvement (DOE 2015). Data from 10 SEP-certified facilities have shown energy savings of 11.1% above business as usual within two years (McKane 2015).

EPA's Building Performance with ENERGY STAR program uses an SEM approach to encourage building owners to pursue comprehensive retrofits. Its ENERGY STAR for Industry program has worked with manufacturers to adopt plan-do-check-act energy management practices since the early 2000s (EPA 2015a).

In 2002 BC Hydro, a utility in British Columbia, launched the Power Smart Partner (PSP) program. The program provided onsite energy managers for some of BC Hydro's largest industrial customers. In co-funding the salary of an energy manager, the program created the foundation for continuous focus on energy efficiency. The energy managers are responsible for energy budgets, keep track of energy consumption, and work to lower it. Since 2008, BC Hydro has engaged more than 100 customers in the PSP program (DOE 2014; Russell 2013).

In 2005 the Northwest Energy Efficiency Alliance (NEEA) created an SEM program that went beyond a device or project focus and looked at optimizing the energy-consuming systems of C&I customers (York et al. 2013). The program targeted both the supply side and the demand side of the energy efficiency market by forging alliances with industrial firms and by establishing close working relationships with key market players such as utilities, vendors, consultants, and nongovernmental organizations (Hossein, Ochsner, and Stewart 2012). It also integrated common, cross-cutting technologies in the energy management practices of different sectors, beginning with the pulp and paper and food processing industries (Jones et al. 2011; Hossein, Ochsner, and Stewart 2012). After three years of implementation, NEEA and its partners demonstrated actual and persistent energy savings that were distinct from capital improvement investments (Jones et al. 2011). Independent evaluation of food processors that participated in the program identified 3% annual behavior-related energy savings (Cadmus 2011).

Customers participating in Energy Trust of Oregon's (ETO) SEM program have experienced annual savings from O&M improvements ranging from about 2–18% and averaging about 8% (Jones et al. 2011). ETO reports that its SEM program is responsible for 20–25% of the total savings from its C&I programs (Simpkins 2012). The Bonneville Power Administration

(BPA) estimates that its SEM programs (HPEM, and Track and Tune) achieve around 15% of the savings realized from all of its C&I programs in 2012 (Kolwey 2013).[64]

Industrial plants participating in the ENERGY STAR Challenge for Industry, which requires implementation of SEM practices, on average reduce total energy use (from all sources) by 20% over two years (EPA 2015b). The 10 facilities participating in ETO's Industrial Energy Improvement (IEI) program saw an average reduction in energy intensity of 7.9% due to O&M improvements (Jones et al. 2011). The 16 customers participating in BPA's HPEM program and the 14 plants participating in DOE's Superior Energy Performance Pilot programs saw average reductions in energy intensity of 2.7% and 4.0%, respectively, from O&M projects (Burgess 2014). The BPA plants doubled the number of capital investments after joining the HPEM program (Jones et al. 2011) and realized an additional 1.6% reduction in energy use (Cadmus 2013). Puget Sound Energy's onsite energy manager program saw its participants reduce energy consumption by 3– 5% per year (Kolwey 2013). In its analysis of a dozen SEM programs, CEE concluded that programs in the future will achieve average energy intensity reductions of 5.4% (Burgess 2014).

CEE has identified 15 utility SEM programs in the US and Canada (CEE 2015). Table 15-1 describes the details and reports the performance of four of them. It is important to note that all of these programs are part of a portfolio of business customer–focused programs and that they benefit from other programs. In some instances programs do not attempt to attribute savings specifically to SEM.

Table 15-1. SEM incentive and training programs

Utility and program	Customer size threshold	Program description	Incentives	Program savings
BPA—HPEM	18,000 MWh/yr	Provides training and individual assistance to a group of 8–15 companies over a 1-year period	$0.025/kWh for 3 or 5 years, for O&M savings	2010: 5,800 MWh 2011: 8,700 MWh
Energy Trust of Oregon	About 18,000 MWh/yr	Provides training and individual assistance to a group of 8–15 companies over a 1-year period	$0.02/kWh, $0.20/therm, for 1 year for O&M savings, with option for 1 more year at $0.01/kWh, $0.20/therm	2010: 24,000 MWh 2011: 16,200 MWh
Wisconsin Focus on Energy	Greater than 1 MW	Provides training and technical assistance	For capital projects and O&M. Incentives for training and completion of SEM elements.	Goals are established for SEM and savings are tracked

[64] HPEM stands for High Performance Energy Management.

Utility and program	Customer size threshold	Program description	Incentives	Program savings
Xcel Energy Process Efficiency Program	>2,000 MWh/yr savings potential	Provides individual assistance in developing 2- to 3-year energy plan	For capital projects only	2011: 6,600 MWh for capital projects only

Sources: Kolwey 2013; BPA 2012; ETO 2012; Xcel 2011; J. Nicol, energy program' director, Leidos, pers. comm., July 16, 2015.

We did not locate performance data for any existing SEM programs targeting commercial or institutional buildings, but we did learn that DOE is now piloting the SEP program with two major hotel chains and will have third-party–verified data by the end of 2015 (P. Scheihing, program manager, DOE, pers. comm., July 16, 2015).

ENERGY SAVINGS

In our midrange case, detailed in Table 15-2, we estimate that strategic energy management programs can reduce 2030 electricity consumption in the commercial sector by 0.2% and the industrial sector by 0.6%, assuming an average savings per facility of 8%. Our low-range savings scenario assumes an average savings per facility of only 5%, which results in commercial sector savings of 0.1% and industry sector savings of 0.3%. In our high-range scenario, we assume 10% savings per facility, yielding savings of 0.3% and 1.0%, respectively.

Our midrange estimate of 8% savings per facility is inclusive of O&M and CapEx energy measures. It is based on the performance of the ETO, BPA, DOE and EPA programs described above and the programs mentioned in table 15-1. These have recorded facility-level reductions in energy intensity ranging from 2% to 8% from O&M projects only (Jones et al. 2011; Burgess 2014). CEE forecasts an average savings per facility only from O&M projects of 5.4% (Burgess 2014). We estimate that an additional 2 to 3% reduction is realized through capital investments; therefore our low-range savings estimate is 5%, our midrange, 8%, and high-range, 10%.

Our estimate of relevant energy use in the commercial sector is based on the assumption that only larger buildings (greater than 200,000 square feet) will have sufficient energy consumption to warrant a concerted and prolonged effort to manage energy such as required by SEMs.

In the industrial sector, larger, more energy-intensive facilities are likely to be early adopters. Because of their sizable energy budgets, they are more likely to invest in energy management systems on their own. Less sophisticated, less energy-intensive, and smaller firms are the likely target for new SEM programs. So even though these programs serve companies of all sizes, an understanding of the stratification of energy consumption within industry is useful in determining the potential of programs to reduce energy consumption nationally. Small and medium-size manufacturers (SMMs) make up 90% of industrial establishments but account for only 50% of energy use (Trombley 2014). We assume that the middle and upper ranges of this segment, as well as the lower half of the larger, energy-intensive segment, are the primary targets for SEM programs.

The variable that will affect gross savings the most is participation rate. Our participation estimates in the low, medium, and high cases for the commercial sector are 23%, 30%, and 50%, respectively. Our estimates for program participation is influenced by our research on this subject (York et al. 2015), our conversations with people involved in these programs, and the work of others who have studied them (Kolwey 2013; Burgess 2014). We expect much greater participation in the industrial sector; our midrange estimate is 50%. The low and high values for the industrial sector are 38% and 75%, respectively. These values are based on a broad interpretation of engagement in continuous improvement programs.

Table 15-2. Electricity savings in 2030 from commercial and industrial SEM

	Value	Unit	Comment
			Commercial sector
	1,517	TWh	2030 electricity available to grid from EIA 2014
x	20%	of energy use covered	Percentage of commercial floor area in buildings greater than 200,000 sf, from 2012 CBECS (EIA 2015)
x	8%	average savings	Discussed in text
x	30%	participation rate	York et al. 2015
x	95%	net-to-gross ratio	Standard assumption for this report
=	7	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.20%	of US electricity use	
			Industrial sector
	1,270	TWh	2030 electricity available to grid from EIA 2014
x	50%	of energy use covered	Trombley 2014
x	8%	average savings	Discussed in text
x	50%	participation rate	York et al. 2015
x	95%	net-to-gross ratio	Standard assumption for this report
=	24	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.6%	of US electricity use	

COSTS AND COST EFFECTIVENESS

The size of a customer eligible to engage in an SEM program depends on the design of the program. BPA and ETO have an eligibility threshold of 18,000 MWh/year (or 18 million kWh) in energy consumption. This value gives us a lower boundary for our analysis of the industrial sector. We back into an average energy consumption by examining the average savings that have been realized by the BPA and ETO programs. However, because there is a considerable range in energy savings per facility from those programs, some averaging is required. In 2009, the 16 sites involved in the BPA pilot SEM program saved 13 million kWh that were attributable to improvements in O&M. This averages out to 812,500 kWh/year per site. In 2011, ETO's SEM cohort of 10 manufacturers saved 24 million kWh and 163,000 therms. The BPA average is approximately one-third of the ETO average, so for our analysis we selected the approximate midpoint of the two: 1.6 million kWh/year per site for industrial facilities. In our cost of saved energy analysis, we consider only savings from O&M energy measures, as CapEx projects will be funded by other programs. Thus we estimate a 5% annual savings per facility. This translates to an annual energy consumption of 32 million kWh, and this is the value we selected for our analysis.

Our determination of an average annual energy consumption per commercial or institutional facility is more direct. We did not identify any programs targeting the commercial sector, but the program managers we consulted indicated that they intend to address this market within the next few years and that they would court customers smaller than the current industrial program thresholds. Our estimate is that the threshold for program eligibility will be in the range of 5 million to 10 million kWh/year. On the assumption that participating facilities will use between 5 and 25 million kWh/year, we have selected a conservative value of 10 million kWh/year as our average consumption per commercial facility.

There is not a great deal of documentation of the persistence of O&M savings. BPA has the most robust results, having found that its SEM program O&M savings persist and increase by 67% after three years (Burgess 2014). In our analysis, we conservatively estimate that savings persist for only three years.

ETO spent $40,000 to $80,000 in training and coaching services per customer (Kolwey 2013). We use the upper limit of this range in our cost of saved energy analysis and assume that a cost savings of 25% will be achieved over time due to improved techniques and economies of scale. In its cost effectiveness evaluation, ETO assumes a 10-year measure life for capital projects and a 3-year life for O&M measures (Burgess 2014). This value is also assumed in our analysis in table 15-3. In its evaluation, ETO (2012) determined a levelized cost of $0.014/kWh. An analysis of the BPA program by Cadmus (2013) found a total resource cost of 1.00. Our findings on the cost of saved energy for both commercial and industrial (Table 15-3) are compatible with these values.

Table 15-3. Cost of energy saved through commercial and industrial SEM

	Value	Unit	Comment
			Commercial sector
	10 million	kWh per facility	Midrange of SEM program customer size
x	5%	average savings	Discussed in text
=	500,000	savings per facility	
	$80,000	current cost	High cost per facility for ETO program
	$60,000	long-term cost	Anticipate 25% reduction in cost per facility
	3	year measure life	3 years for O&M and SEM per ETO 2012
	$0.059	per kWh	CSE based on current cost
	$0.044	per kWh	CSE based on long-term cost
			Industrial sector

	Value	Unit	Comment
	32 million	kWh per facility	Based on average savings per facility from ETO and BPA programs
x	5%	average savings	Discussed in text
=	1.6 million	savings per facility	
	$80,000	current cost	High cost per facility for ETO's program
	$60,000	long-term cost	Anticipated 25% reduction in cost per facility
	3	year measure life	3 years for O&M per ETO 2012, 10 years for capital projects per ETO 2012
	$0.018	per kWh	CSE based on current cost
	$0.014	per kWh	CSE based on long-term cost

RECOMMENDATIONS AND NEXT STEPS

Strategic energy management programs should be part of any utility or state effort to engage large commercial and industrial customers. It changes the conversation at a facility from whether they will implement energy efficiency projects to a discussion of which ones and when. Although these programs can stand alone, they are much more effective if they are a component of a comprehensive portfolio of programs designed to amplify one another. SEM programs help customers identify, implement, and measure savings from low-cost operations and maintenance improvements. In addition, SEM programs facilitate the implementation of capital projects, which will improve participation in prescriptive and custom rebate programs.

SEM programs should not be one-size-fits-all. Depending on the nature of a business, its energy intensity, and the availability of internal resources, a rudimentary program such as BPA's Track and Tune (which introduce companies to energy management) may be appropriate. Large customers with energy expenses in the millions of dollars per year will be able to support the cost share of an on-site energy manager. They will also be able to commit to long-term energy savings goals that are required by a fully formed, continuous improvement effort.

The performance of SEM programs should be evaluated as part of an entire portfolio of energy efficiency programs. For example, it is possible to give SEM programs credit for energy savings from additional capital projects identified through the SEM training process. While it may be useful for internal purposes to understand the costs of individual components of an SEM program, it should be seen as foundational rather than marginal in its contribution to long-term energy savings by utility customers.

The performance of such programs should also be judged over years rather than months. Continuous improvement programs build momentum within organizations that produces greater and longer-lasting improvements in quality and operating costs than one-time projects. Therefore, performance from SEM programs should be measured over multiple years. This long-term approach to performance evaluation will match the long-term ability of SEM programs to effect significant reductions in energy use by large commercial and industrial customers. This, of course, is the ultimate goal for energy resource acquisition and planning.

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Chapter 16. Energy Performance Labels for Commercial and Industrial Equipment

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MEASURE DESCRIPTION

The energy efficiency community has long been aware of the large opportunity that exists from optimizing motor systems, but the ability of programs to realize these savings has been mostly restricted to larger systems where the savings are of such a magnitude (e.g., denominated in hundreds of horsepower) as to justify the investment in analysis and monitoring that is required for a custom rebate program. Prescriptive rebates have been restricted to efficient products, such as ENERGY STAR appliances and NEMA Premium® motors, that offer modest savings opportunities (relative to system-level opportunities) but to which it is easy to ascribe average savings values. For many years program developers have sought a method to encourage investments in system efficiency through programs with lower administrative burdens than conventional custom programs.

It will soon be possible to develop prescriptive or semi-prescriptive rebate programs for integrated motor-driven commercial and industrial products such as fans, pumps, and compressors. These programs will be built around voluntary performance labels developed by industry collaborations. The labels will convey superior energy performance of control-motor-device combinations, and efficiency programs will be able to ascribe a predictable volume of energy savings based on the size of a system and its application.

For example, the pumps used to circulate hot and cold water through large buildings run at full speed throughout the day unless their speed is modulated by a control system. As shown in Figure 16-1, an integrated control–motor–pump product with the ability to slow down the pump during periods of low water demand, matching speed and load to actual application flow requirements, will use less energy than a conventional system that runs at full speed.

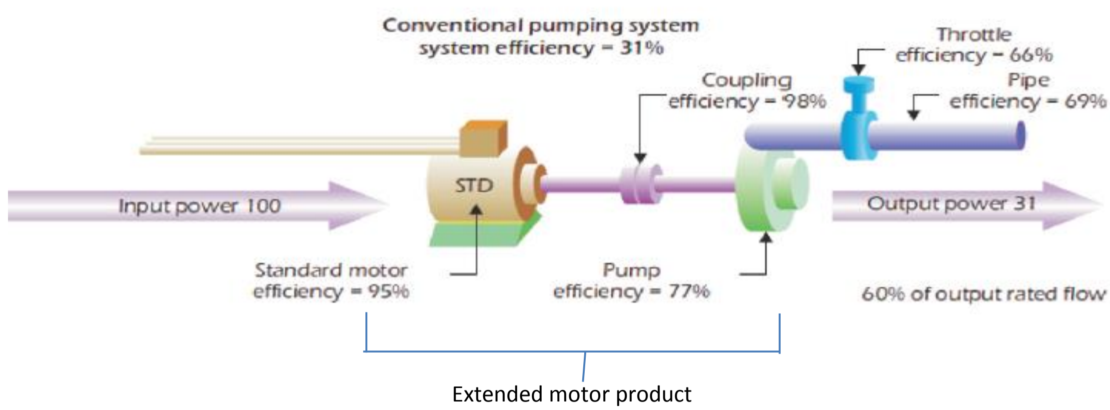

Figure 16-1. Pump system. *Source:* Almeda, Ferreira, and Booth 2005.

By aggregating the performance data of conventional and controlled pumps from a significantly large set of buildings, the average energy savings due to automated control can be predicted. An efficiency program can increase the uptake of such premium pump systems through financial assistance to and education of the supply chain and consumers.

The performance label will identify products that have this capability to reduce energy use through automated and, in some cases, intelligent control. An efficiency program could create an incentive to encourage purchases of such products. The size of the incentive could be tied to the size of the motor driving the product and to its application. Energy savings from a building circulator pump are likely to vary depending on the type of building in which it is placed. Hospitals, for instance, run 24 hours per day, while most office buildings are open only 10 hours per day.

Application for a rebate could be managed through a website, minimizing administrative expenses. A routine sampling of installations could satisfy evaluation, measurement, and verification (EM&V) requirements. The greatest challenge for such programs will be to identify technology and application mixes in their territories that are of sufficient volume and homogeneity to generate savings sufficient to justify a targeted program.

EXPERIENCE TO DATE

The new programs will have the same structure as conventional prescriptive and semi-prescriptive programs. These programs stipulate, or deem, the average savings per device. This type of program is well established and has proved to be very successful. As indicated in matrix of savings opportunities and program types in table 16-1, deemed savings programs are usually device specific, and eligible products can be identified by labels or membership in a specific product class. Savings at the device level are predictable but not as great as at the system level, where process optimization is possible but more complicated program structures are required. As discussed later, there have been a few programs targeting driven equipment, usually for products sold as a package and for which there are established performance labels.

Table 16-1. Potential energy savings by level in motor-driven commercial and industrial systems

Motor system element	System savings opportunity	Method for opportunity identification	Potential program response
Motor	2–5%	Labels (e.g., NEMA Premium)	Deemed savings Eligible product list
Drive	3–10%	Product class	Deemed savings
Driven equipment (pump, fan, air compressor)	10–25% for fans/pumps/ compressors*	Stated performance (AMCA label, CAGI data sheets, HI performance curves)**	Deemed savings Eligible product type Custom program
Extended product: motor-driven package	15–35%	Label (proposed)	Eligible product type Custom program
System supply	15–40%	Performance indicator, e.g., case System assessment	Technical assistance Custom program
Entire system	20–50%+	System assessment (standards)	Technical assistance Custom program

* Compressor efficiency typically due to improved load control capabilities. ** AMCA is the Air Movement and Control Association International. CAGI is the Compressed Air and Gas Institute. HI is the Hydraulic Institute. *Sources:* Rao 2013; UNIDO 2010.

Prescriptive Incentive Program

A typical example of prescriptive programs are those managed by Pacific Gas & Electric (PG&E), a large, investor-owned utility in California. It offers rebates to businesses on more than 100 different items. As both an electricity and natural gas utility, it has prescriptive programs for both types of energy. As demonstrated in table 16-2 below, the incentives are set at a level that is intended to be sufficient to drive demand but less than the cost of the energy saved. The table also shows that incentives can be based on capacity of equipment, size of device, or per unit.

Table 16-2. Examples of prescriptive rebates

Rebate code	Description	Rebate/unit of measure
B85	Ozone laundry system, washing machine capacity	$39/lb
F171	ENERGY STAR commercial glass-door refrigerator, internal volume <15 cubic feet	$75/unit
F188	Commercial convection oven, natural gas	$500/oven
F200	Super-efficient ice machine, 101–300lbs/day	$100/unit
H15	Steam process boiler	$2/MBtu
L1014	400-watt lamps, <244 watt (Tier 1)	$35/fixture
L1013	400-watt lamps, <360 watt (Tier 2)	$20/fixture
R176	Efficient evaporator fan motor, ECM walk-in coolers and freezers*	$75/motor

ECM coolers and freezers have electronically commutated motors. *Source:* PG&E 2015a

Many efficiency program sponsors have built deemed savings programs around high-efficiency motors such as identified by the NEMA Premium label (NEMA 2012). Use of the label simplifies the administration of such programs because the program need only stipulate the performance label rather than define and describe in detail the scope of eligible products.

An example of a program providing incentives for motor-driven products is the PG&E swimming pool pump program. Pools can account for 20% of energy use in residential homes. PG&E offers rebates of up to $100 to customers to install variable-speed pumps that can be adjusted to the most appropriate speed. The amount of the rebate is determined by the size of the pump and whether it is a variable speed pump with controller or just a controller that can be used with an existing pump. Incentives are also provided to the installers of the pumps. This primes the market for these products (PG&E 2015b).

During discussions on the DOE standards process for electric motors, pumps, fans, and compressors, ACEEE and manufacturers of these products have recognized that opportunities for motor system energy savings are much greater than savings from individual components.[65] Out of these discussions has emerged a suggestion for industry to develop voluntary labels for the efficiency of a driven component as well as an extended label that includes the driven equipment (e.g., fan, pump, or compressor), the motor, and associated controls. This product label would reflect a comparative power usage metric of the equipment as it is installed into a motor system application. The trade associations for manufacturers of this equipment are developing testing and labeling specifications for these extended products as a complement to the minimum power usage index of performance standards established through the DOE rulemaking process. These trade associations and their member companies are interested in collaborating with energy efficiency programs across North America to make sure that extended product labels can be used by energy efficiency programs to incentivize motor systems efficiency.

EXTENDED MOTOR PRODUCT LABEL INITIATIVE (EMPLI)

The Extended Motor Product Label Initiative (EMPLI), the collaboration introduced above, is an ongoing effort among energy efficiency advocates, utilities, efficiency program administrators, and manufacturer trade organizations to develop a voluntary performance label for pump, fan, and air compressor products. The labels will communicate to purchasing agents and program administrators motor-driven product combinations that are more energy efficient than conventional products.

The effort includes the National Electrical Manufacturers Association (NEMA), which represents motor and drive manufacturers; the Hydraulic Institute (HI), an association representing pump manufacturers; the Air Movement and Control Association International (AMCA), representing fan manufacturers; and the Compressed Air and Gas Institute (CAGI), an association representing air compressor manufacturers. The trade associations have committed to working collaboratively with energy efficiency programs to accomplish these goals:

- Identify the criteria for labeling and supporting data needed to meet evaluation requirements that programs must have in order to qualify products for deemed savings.
- Develop the testing and labeling specifications that meet these criteria.
- Collect field performance data from a cross-section of existing products deployed in various applications in order to determine the average savings from high-performance products.
- Work with the trade associations to establish performance levels, develop performance labels and encourage their adoption by member companies.
- Develop model prescriptive rebate energy efficiency programs based on the new labels.

[65] DOE has responsibility for establishing minimum energy performance standards for appliances and equipment. Rulemaking related to this authority is currently under way for air compressors, fans, and pumps. See energy.gov/eere/buildings/appliance-and-equipment-standards-program.

- Where component performance labels do not exist in the market, such as for pumps, work with the appropriate trade association to create such labels. Establish linkage between component labels and extended product labels.

The collaborative is engaging in the following activities:

- Convening a working group of stakeholders from the manufacturing and energy efficiency sectors to advance the creation and market adoption of new performance labels
- Developing a road map for the implementation and acceptance of an extended product label for two or more categories of motor system products
- Facilitating a discussion with DOE on how this process could complement the ongoing product regulatory standards process
- Preparing a report and other documentation materials that can be used to form the basis of adoption by energy efficiency programs
- Turning over to stakeholders in the energy efficiency program sector program models and supporting materials

This initiative will release its first labels in late 2015 or early 2016. It will also pilot energy efficiency programs built around the new performance labels.

ENERGY SAVINGS

It is estimated by E-Source that half of all electricity used in the US powers electric motors (E-Source 1999).[66] More than 6.4 million motors are sold in the US each year (US Census 2003). While it will not be possible or even desirable to replace all of these motors through a new generation of efficiency programs, it will be possible to accelerate the uptake of more efficient products.

The commercial sector consumes 1,517 terawatt hours (TWh) per year, and approximately 37% of that is for driving electric motors (EIA 2014). The manufacturing sector uses 1,270 TWh, almost three-fourths of which is consumed by motor-driven systems (Nadel et al. 2002). Combined, 1,451 TWh of energy used each year by motor-driven systems.

We are estimating that approximately 50% of this energy use can be improved through more efficient systems. This is based on the ratio of systems that can be improved through modulation of speed and right-sizing (Nadel et al. 2002).

We estimate that on average a system will realize 7.5% annual energy savings. We base this estimate on the low end of the Lawrence Berkeley National Laboratory (LBNL) estimate of 15–35% savings that can be achieved with label programs for extended motor-driven products (see table 16-1 above) and then attribute half to the performance label (Rao 2013, UNIDO 2010). We attribute the rest of the savings to other improvements to system optimization, such as the building and process control systems discussed in other chapters.

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[66] DOE conducted its last comprehensive analysis of electric motors and the energy they consume in 1994.

Based on these and other data estimates, we prepared three estimates of potential 2030 energy savings. Table 16-3 shows our calculations for the midrange estimate.

Table 16-3. Electricity savings in 2030 from commercial and industrial energy performance labels

	Value	Unit	Comments
	1,451	TWh	2030 electricity available to grid from EIA 2014
x	50%	of energy use covered	Nadel et al. 2002
x	7.5%	average savings	UNIDO 2002
x	39%	participation rate	Midrange estimate
x	95%	net-to-gross ratio	Standard assumption for this report
=	20	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	0.47%	of US electricity use	

We also prepared low and high savings estimates that differ by participation rate, as explained in Chapter 1. With these different participation rates, the 0.5% savings in the medium case increases to 0.6% in the high case and decreases to 0.3% in the low case.

COSTS AND COST EFFECTIVENESS

It is very difficult to determine an average project since the range of equipment sizes is so great and the number of end uses so vast. Recognizing this, we structured our analysis so that readers may insert their own values.

Through our involvement in the EMPL Initiative, we have become aware of many commercial and industrial pump, fan, and air compressor systems. The following discussion is based on a fan example that has been used within EMPLI to highlight the energy savings that are possible when right-sizing a system. In this example, we have two systems capable of delivering 80,000 cubic feet per minute of air at 3 inches of static pressure. The first system has a larger motor that runs a smaller fan at a higher speed. The initial cost of this system is lower because the driver for the cost of the system is the fan and not the motor. But because the amount of energy increases at approximately the cube to the increase in speed, the system with the larger motor and smaller fan will use considerably more energy than the second system.[67] Specifically,

[67] Fan Affinity Laws: The ratio of power consumption (P) to fan velocity (n) of a centrifugal fan is cubed due to the resistance to the fan blade turning that increases as the speed of the fan blade increases. The relationship is represented by the equation $P_1/P_2=(n_1/n_2)^3$. This will be the relationship under ideal conditions. Most systems have losses due to friction and static head that reduce the factorial from 3 to 2.5—or, if the losses are high, 2. Regardless of the exact relationship, small changes in fan speed can produce significant changes in energy consumption.

60 hp system (drive + motor + 50-inch fan) costs $17,600; operating cost: $20,000/year

50 hp system (drive + motor + 60-inch fan) costs $23,800; operating cost: $17,000/year

It is just this type of improvement in customer choice that the new performance label will address. Our cost-of-energy-saved analysis in table 16-4 is based on this example.

Table 16-4. Cost of energy saved through commercial and industrial energy performance labels

Value	Unit	Comments
30,000	kWh saved per system	= (20,000 – 17,000) / ($0.10/kWh) *
$6,200	current cost	Typical incremental cost for a larger fan ($23,800 – $17,600)
$5,000	long-term cost	Estimate 20% savings through better design
13	year measure life	
$0.022	CSE based on current cost	
$0.018	CSE based on long-term cost	

* Typical annual operating cost of old minus new system divided by typical industrial electric rate

UNCERTAINTIES

The penetration of programs centered on new performance labels will depend on the breadth of products covered by such labels. It is likely that a few high-volume products for each product class will be covered. Thinking in terms of the 80:20 rule of thumb—that 20% of the products in a given product category are likely to make up 80% of sales volume (though not necessarily energy use)—we expect that this will capture a significant part of the market. However there are many manufacturers, and not all of them may go to the trouble of certifying all of their top-performing products.

Another uncertainty is how popular performance label–based programs will be across the country. Deemed savings programs have been popular. However the energy savings of these integrated products vary by sector and end use, and both of those vary by geography. Some programs may require time- and resource-intensive data gathering prior to the inclusion of certain products within a deemed savings program, due to the variability of the energy consumption across building types and customer classes. These up-front costs will be a disincentive to adding performance label–based programs to a portfolio. We band this uncertainty with our low, medium, and high scenarios in our energy savings calculations.

As mentioned above, it is very difficult to determine an average project since the range of equipment sizes is so great and the number of end uses so vast. In realization of this fact, our analysis is structured so that readers may insert their own values.

RECOMMENDATIONS AND NEXT STEPS

Voluntary labeling initiatives such as are being developed by the EMPL Initiative are key to successful deemed savings programs. They simplify the administration of the efficiency programs and facilitate additional economic activity by simplifying purchasing decisions.

Performance labels can become purchasing specifications for companies as well as efficiency programs.

Programs can facilitate the development of performance labels through their participation in such initiatives. Their expertise is critical to the development of a performance label that will work for program administrators and evaluators. Public utility commissions and other policymakers should support these private-sector efforts through their participation and provision of financial and technical assistance. Nongovernmental organizations with an interest in energy efficiency should also contribute their time and resources to these efforts.

EMPLI currently is focused on only four product classes—motors/controls, pumps, fans, and air compressors—but is likely to expand into other product areas. Good candidates are any type of device or system that is common in the commercial and industrial sectors and for which there is a range of energy performance. Systems that have been discussed are chillers, elevators, escalators, building management systems, and smart lighting systems. In each of these product classes, innovation in recent years has produced a step change in control sophistication and associated energy efficiency. End users and efficiency program administrators alike can benefit from labels that identify products with potential for superior performance.

In the near term, utilities can work with trade organizations and collaborative efforts such as EMPLI to test programs and verify their ability to produce reliable and measurable energy savings. It is through these demonstration projects that the concept will be proved and broader acceptance made possible.

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Chapter 17. Smart Manufacturing

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BACKGROUND

Smart manufacturing is the integration of all aspects of manufacturing, regardless of level of automation, and all the individual units of an organization for the purpose of achieving superior control and productivity. It is made possible by sensors and devices that communicate with one another and with other systems through networks. It is automated control, integrated manufacturing, and networked companies improving productivity through data gathering and storing, information sharing, and informed decision making. It allows improved measurement, evaluation, and validation. It is enabled by the harvesting of big data to analyze operations, identify faults in systems, understand customer interests, and inform operators (Rogers 2014).

Smart manufacturing has been made possible by the ability of just about any device or object to communicate with any other device, object, or person. This "Internet of things" is enabled by embedded software and common protocols that allow information sharing through and across networks. The ubiquity of mobile broadband–enabled Internet access, sometimes referred to as the "pervasive Internet" (Harbor Research 2011), is making connectivity and networking available independent of location. The "industrial Internet of things" allows manufacturing to move from simple device integration and connectivity to the higher-level challenges of connecting people and devices on a network and having them effectively communicate with one another to improve process, facility, and company performance.

The elimination of barriers to interconnectivity and the falling prices of sensors, networks, and data analysis capabilities enable the creation of new products and services that will improve the productivity of workers and facilities, provide managers with greater visibility and control, and result in energy savings. We have come to call these energy efficiency measures intelligent efficiency (Elliott et al. 2012). Much of the energy saved through the application of smart manufacturing is through intelligent efficiency.

It is estimated that annual spending on manufacturing-sector automation may top $120 billion by 2020 (Cullinen 2013; Navigant 2012). Much of this will be cost effective without financial assistance from energy efficiency programs. Our analysis is focused on utility sector programing intended to increase investments in smart manufacturing by several percent per year.

The industrial sector is not as homogeneous as the commercial sector; therefore, it is much more difficult to identify a limited number of specific types of efficiency measures that will have broad applicability. A next-generation manufacturing process for plastic injection molding, for example, will not have applicability in metal casting or fabrication. With this limitation in mind, we have identified smart process control technologies within manufacturing that have broad applicability across multiple manufacturing sectors.

How Smart Manufacturing Saves Energy

Information and communication technologies (ICT) are enabling energy savings in ways not possible in the past. Through connectivity, devices can share information between themselves and with operators. Energy consumption information, when put in context, becomes knowledge. When combined and compared with historical information, it becomes wisdom. Wisdom in the case of manufacturing is understanding how to optimize a system, process, or facility. This translates to energy savings at the system level rather than the device level. In a conventional energy measure, there is little to no re-optimization after implementation. This often means that savings degrade over time. However a smart system will continually evaluate its operating state, compare it to historical performance, incorporate knowledge of current operating conditions, and identify the optimal operating scenario. As more knowledge of a system is gained over time, new and even more efficient operating scenarios can be identified. This capability is often referred to as machine learning. The residential sector has recently seen the introduction of smart or learning thermostats that monitor energy usage and record people's patterns. Over time they are able to predict the temperature their users want and adjust the heating or cooling to make them comfortable while also reducing energy consumption.

Figure 17-1 illustrates the additional savings from continuous improvement that are possible with a smart manufacturing process-management system. Each of the sharp drops in the top line represents a process-optimization event that included investments in more efficient devices and reprogramming of the control system. Until recently, this has been considered best practice. However, over time, the output of the production process changes, devices drift off their settings, and energy use increases as the process and its component devices are no longer operating optimally. With continuous improvement, not only are components of the process routinely upgraded, but the process-management system continually optimizes control of the process. The space between the top process-optimization line and the bottom line in figure 17-1 represent the additional savings that are possible with continuous improvement.

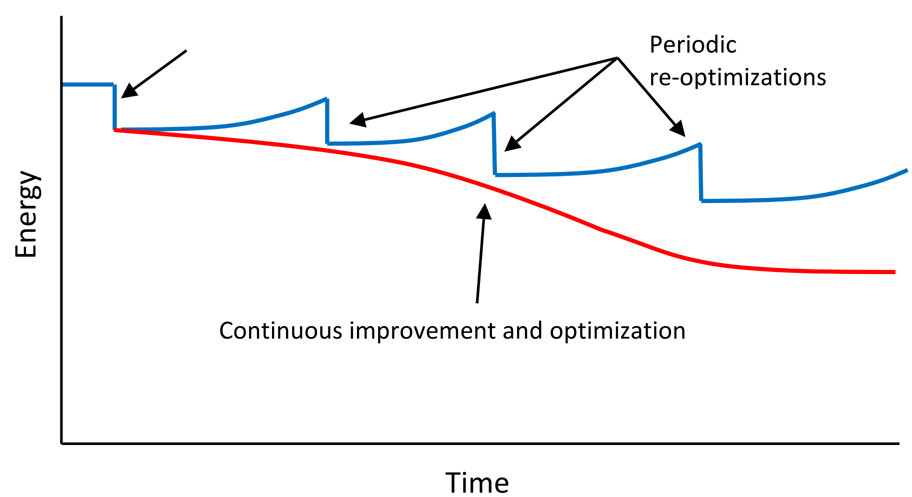

Figure 17-1. Continuous improvement

This type of intelligent control is the focus of the energy measures analyzed in this section. We consider automation projects in the manufacturing sector that include the connectivity and data analytics that make continuous commissioning possible. These projects can target a specific part of a facility, as in the Steelcase example below, or an entire facility, or energy use across multiple facilities.

CASE STUDY: ENERGY SAVINGS THROUGH SYSTEM EFFICIENCY AT STEELCASE

Steelcase, an office furniture supplier headquartered in Grand Rapids, Michigan, had an outdated boiler control system at one of its facilities. Steelcase has an ISO 14001–compliant environmental management system in place that requires the collection of water, air, gas, electricity, and steam (WAGES) data; however, these data were being collected manually. Steelcase installed a process-automation system to control the boiler. The system provides real-time tracking and monitoring of WAGES data. By feeding that information back to operations, the Steelcase facility was able to reduce its energy consumption by 15% and its carbon footprint by 25% (Rockwell 2012).

When combined with current data analysis capabilities, smart manufacturing can enable companies to achieve new levels of energy efficiency. Investments in smart manufacturing will include control systems that can provide energy savings data to manufacturers and their utilities in an automated fashion and with a high degree of confidence. Such a capability will mesh well with utility demand-response and energy efficiency program objectives, and it is therefore likely to be of interest to efficiency program developers and administrators who are in search of new ideas to meet future resource allocation requirements.

MEASURE DESCRIPTION

From the perspective of an energy efficiency program, the difference between a smart manufacturing measure and a conventional energy measure is that the former focuses on control and the latter focuses on devices. A typical prescriptive program will provide incentives for specific devices such as high-efficiency motors. The energy savings that are possible with smart manufacturing are efficiencies gained at the system and facility levels. The volume of such savings can be difficult to predict because there are many variables that will affect the outcome: product mix, product volume, hours of operation, and so on. This will prove a challenge for efficiency programs that are accustomed to providing incentives for energy-consuming assets and for which energy savings can be predicted with some accuracy.

It is therefore likely that most programs that fund smart manufacturing measures will be of a type that enables the bundling of multiple investments. The three existing structures that allow this are custom, self-direct, and strategic energy management programs.

Custom Incentive Programs

Sometimes referred to as standard offers, these programs offer financial incentives to customers for projects with an energy efficiency component too complicated to take advantage of prescriptive rebates. These projects can include new construction; an upgrade, retrofit, or replacement of a building or a production process; and installation of automated control systems. The amount of the financial assistance may be related to the amount of energy saved, or it may be a percentage of the overall project cost. When based on energy savings (the more common method) the incentives are usually allocated on an amount per unit of energy saved (e.g., $/kWh or $/MMBtu), and the total amount is based on either a calculated potential energy savings or realized energy savings. There is usually a cap on the amount of the incentive based on available funds and/or a percentage of the overall project cost.

Self-Direct Programs

Similar to a custom incentive program, these programs provide flexibility to larger, more energy-intensive customers to invest in complex projects with significant potential to reduce energy use or energy intensity. The customer typically self-directs the energy efficiency fees it pays as part of its utility bills toward projects it determines will save energy. In such programs, the program administrator often collects the energy efficiency fees and then returns them to the customer to invest in projects. The administrator usually withholds a small percentage to cover the cost of verifying savings and reporting them to the public utilities commission.

The amount of the funds returned may be related to the amount of energy saved, or it may be a percentage of the overall project cost. It may also be limited by the size of the energy efficiency fee the customer has historically paid. In some cases, if all of the set-aside funds are not used, the program may make the remainder available to other customers for investment.

The rigorousness of the measurement and verification requirements for self-direct programs vary by state, and many states have little or no requirement for companies to document energy savings or determine attribution of those savings. The reason often given is the challenge and expense of establishing an energy use baseline and performing post hoc analysis. This is problematic for resource planning and determination of cost effectiveness. Innovations in data analysis may hold promise for both of these issues.

Strategic Energy Management Systems

As described in Chapter 15, SEM programs engage a facility's workforce in the establishment of a continuous improvement program. Installation and training on the use of Energy Management Information Systems (EMIS) are often part of these programs. These software programs automate the documentation of energy savings, a feature they share with many smart manufacturing systems. To manage the overlap, we limit our analysis in this chapter to programs that focus on capital expenses (CapEx); in Chapter 15, we examined only those programs that focus on operations and maintenance expenses (O&M). However there is still some overlap, and Chapters 1 and 15 describe how we compensate for it.

EXPERIENCE TO DATE

A limited number of energy efficiency programs have targeted intelligent efficiency or smart manufacturing measures. More often, companies just take advantage of existing custom and self-direct programs to fund process-automation projects. These programs have the flexibility to allow the cost of control systems to be included in the initial cost of installation.

Custom Incentive Programs

Through its custom electric program, Northern Indiana Public Service Company (NIPSCO) provides incentives based on electricity reductions in kWh through qualified efficiency improvements at a rate of $0.06/kWh for lighting projects and $0.09/kWh for other projects (NIPSCO 2012a). On the natural gas side of the business, an incentive of $0.60/therm is available for qualified efficiency projects (NIPSCO 2012b).

CenterPoint Energy's Standard Offer incentives are paid on a per kW or kWh reduction basis and vary by energy savings measure. Upon installation, 40% of the incentive is paid, and the balance is paid upon approval of the savings report. All savings must be either predetermined (deemed) or verified by some level of measurement and verification (CenterPoint 2013).

Neither of these examples currently leverages the data gathering, analysis, and reporting capabilities of smart manufacturing. These new technologies as well as improved utility metering technologies could automate data exchange and analysis in the future.

Self-Direct Programs

Rocky Mountain Power (RMP) includes a self-direct program in its portfolio for large commercial and industrial customers. This is a project-based rate credit program that offers up to 80% of eligible project costs back to customers as a credit against the 3.7% cost-recovery mechanism (CRM) charge that all of them pay. Customers are credited with up to 100% of what they have paid in CRM charges. RMP reports that 25% of eligible customers are participating in the self-direct program and that the program has proved to be cost effective (Chittum 2011).

Program Funding of Smart Systems

Smart manufacturing automation systems are relatively new to many sectors of industry and therefore new to energy efficiency programs. What program administrators are seeing and funding are smart lighting projects. This technology is more mature and the energy savings sufficiently documented to be acceptable to public utility commissions and program evaluators.

The features and benefits of these smart lighting projects can be extrapolated to control systems for production systems such as steam, compressed air, and chilled water. Ultimately, production process control systems will be considered and incentivized by efficiency programs.

EXAMPLE: INTELLIGENT EFFICIENCY AND M&V—COMED, SILVER BEAUTY, AND INTELLIGENT LIGHTING SYSTEM

The manufacturing sector has seen the introduction of many smart devices and control systems that can increase production process throughput. Given their complexity, efficiency programs have yet to embrace them. However program administrators are familiar with lighting systems, and a few of them are evaluating smart lighting systems within their existing programs. This experience may lead to inclusion of smart manufacturing technologies in custom programs.

For example, working through its Smart Ideas for Your Business custom incentive program for commercial and industrial customers, ComEd, the Illinois operating unit of Exelon Corporation, provided incentives for a networked lighting system in a local warehouse. The custom program provides businesses $0.05/kWh, up to 50% of costs, for projects that reduce energy consumption. Silver Beauty is a warehouse management company in the Chicago area that took advantage of this program to retrofit the lighting in its 177,000-square-foot #5 warehouse. The new lighting system included LED lights controlled by a reactive and predictive intelligent control system. The system reduced energy consumption by 92%, or about 1.2 million kWh per year (Digital Lumens 2013). The metal halide lights that the company had previously used were inefficient and on most of the time. The new LED lighting system includes much more efficient fixtures and a control system that can save additional energy by dimming or turning off fixtures when workers are not present.

The control system simplified the measurement and validation of energy savings by providing the information to calculate savings automatically. Once a custom incentive is approved and a project installed, the energy savings are validated before payout. This usually takes 60 to 90 days and requires tracking billing charges and comparing them with the baseline estimate. However, because the Silver Beauty control system captures metering and historical data, it was able to provide net energy savings as it happened. The accuracy of the system was confirmed by ComEd's third-party EM&V contractor. This is an example of how new intelligent systems can determine a dynamic baseline, report net energy savings in near real-time, and support the tracking of savings over time. If such a system were equipped with machine learning algorithms, it could actually improve its efficiency over time.

ENERGY SAVINGS

Research by the Smart Manufacturing Leadership Council indicates that ICT-enabled smart process and production control technologies have the potential to improve operating efficiency by 10%, water usage by 40%, and energy usage by 25%. For the purposes of a 2013 analysis, we estimated the average savings realized by to be 20% (SMLC 2013).

In a 2013 report, *Intelligent Efficiency: Opportunities, Barriers, and Solutions* (Rogers et al. 2013), ACEEE determined that the industrial sector could save between $7 billion and $25 billion in energy costs per year by 2035 if investments intelligent efficiency measures were made at a rate 1– 4% greater than the current trend (figure 17-2). Under the same scenario, the commercial sector could save $30 billion to $60 billion. The analysis estimated the effects of a select group of smart energy efficiency measures that have the most promise for near- and medium-term implementation in the commercial and manufacturing sectors. Based on prior research examining the success of efficiency programs to encourage market uptake of energy efficiency measures (York et al. 2014), we estimated that half of the commercial and manufacturing sectors would adopt intelligent efficiency approaches at some level over the next 20 years.

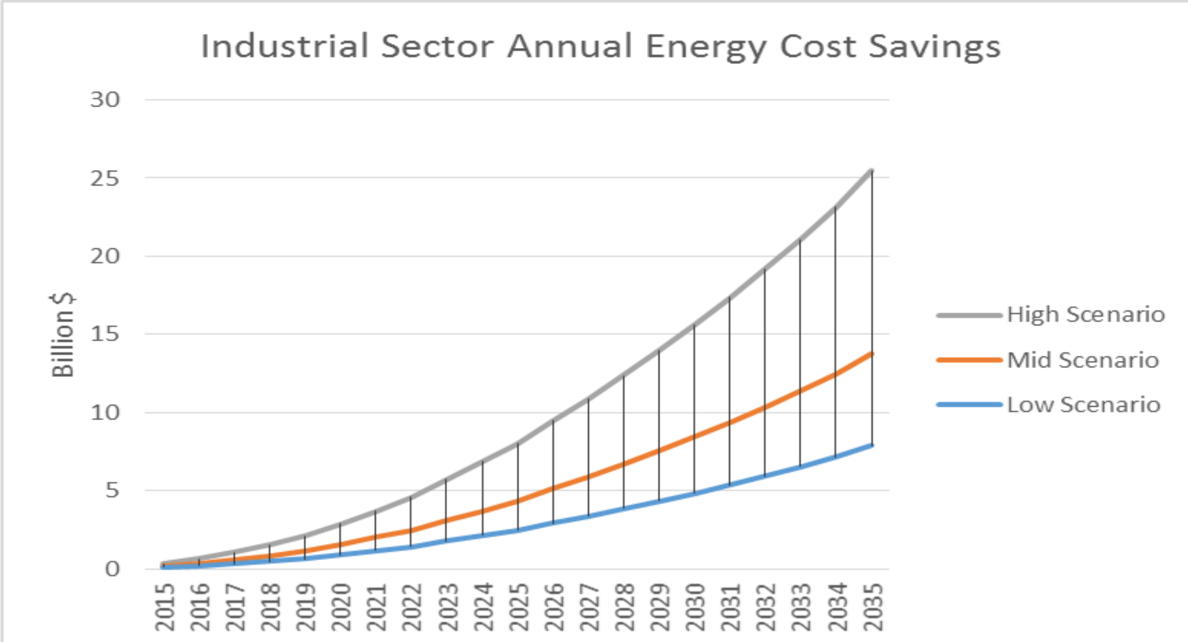

Figure 17-2. Industrial-sector energy cost savings through greater investment in intelligent efficiency. *Source:* Rogers et al. 2013.

As shown in figure 17-3, this increased rate of investment by the commercial and industrial sectors could reduce energy consumption by 240–360 TWh per year.

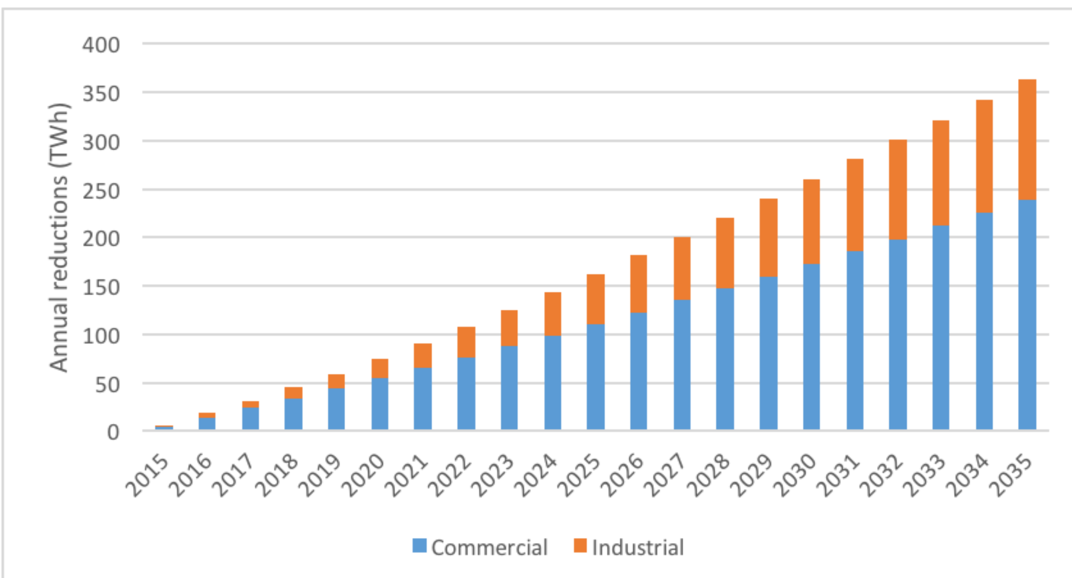

Figure 17-3. Commercial- and industrial-sector annual electricity savings from increased investment in intelligent efficiency. *Source:* Rogers et al. 2013.

As part of the analysis, we separated the marginal gain in energy efficiency attributable to intelligent efficiency from the efficiency gains provided by the enabling technologies alone—in essence, determining when an energy measure is more than a device and becomes an intelligent energy measure that is networked, adaptive, and anticipatory.

We analyzed more than two dozen technologies for their ability to affect energy use in buildings in the commercial and manufacturing sectors. Each of the intelligent efficiency measures considered had broad applicability, was likely to reach more than 25% of its market, and had the ability to produce savings that could be sustained for the life of the product.

When determining the costs of these systems, we included recurring expenses such as licensing or subscription fees, service contracts, preventive maintenance, and other fixed operating costs that will factor into a company's financial analysis. Based on conversations with vendors of manufacturing automation systems, in our analysis we assumed 20% of the original investment as the cost of recurring subscription and services contracts. We also assumed that these investments would have a simple payback of two years because investment hurdle rates in industry tend to be on the low side, and vendors are targeting product and service offerings to meet this criterion. This makes our median scenario rather conservative.

Data from the US Energy Information Agency (EIA) Commercial Building Energy Consumption Survey (CBECS), and Manufacturing Energy Consumption Survey (MECS), as well as data gathered during our literature search and discussions with energy efficiency and facility automation experts, were used to determine the percentage savings a commercial or manufacturing facility might expect for each intelligent efficiency measure.

For this analysis we have modified our assumptions to reflect a shorter time horizon and the narrower scope of energy efficiency programs targeting only smart manufacturing investments. Specifics of the midrange analysis are provided in the calculations below.

In our analysis of electricity savings in 2030, shown in table 17-1, we estimate that 80% of electricity load can be controlled by smart manufacturing technologies. This estimate is based on MECS data and research previously mentioned. Participation by industrial facilities in efficiency programs will vary depending on the nature of the business, its energy intensity, and the details of the program. Therefore, in our 2013 analysis we estimated that half of eligible load would participate by 2035. The values in that analysis have been scaled back to 2030 to be compatible with the other chapters in this report. We have settled on a midrange value of 35% and low and high participation rates of 25% and 50%, respectively. These values drive the projected national electricity savings of 1.1% for the low scenario, 1.6% for the medium, and 2.2% for the high.

Table 17-1. Electricity savings in 2030 from smart manufacturing

	Value	Unit	Comments
	1,270	TWh	2030 electricity available to grid from EIA 2014
x	80%	of energy use covered	Estimated percentage of manufacturing energy use that can benefit from smart manufacturing by 2030 (Rogers et al. 2013)
x	20%	average savings	Estimate of average savings based on SMLC 2013 and Rogers et al. 2013
x	35%	participation rate	Scaled back from estimate of 50% in Rogers et al. 2013 to reflect shorter time frame
x	95%	net-to-gross ratio	Standard assumption for this report
=	68	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	1.6%	of US electricity use	

COSTS AND COST EFFECTIVENESS

The cost of automation varies depending on the size of a facility and the level of control desired by management. Hardware costs include the price of sensors, controllers, computers, communication devices, and memory storage devices. All of these devices require software to run and to communicate with each other. Smart manufacturing software platforms offer apps just like those that can be downloaded to smartphones and computers for personal use. Each of these apps adds cost. Our survey of websites and discussions with people in the industry indicate automation systems start at $100,000 and can go into the millions of dollars. For the purpose of our cost of saved energy (CSE) analysis (table 17-2), we have chosen $1 million for the typical cost of a smart manufacturing energy measure. This cost is inclusive of all software and service contract fees. Our estimate of energy savings is 20% (SMLC 2013), which translates to $200,000 or 2 million kWh (at $0.10/kWh) per year. All other savings that justify the project are not directly energy related. They could include multiple benefits such as productivity, safety, environmental compliance, and product quality.

It is likely that as these systems increase in features and benefits, energy savings will increase. Just as today's systems are superior to those of five years ago in the control they enable, control systems in 10 years will have an even greater ability to extract savings through process optimization. We do expect that the price of these systems will decrease as communications among systems and devices are standardized, as smart manufacturing software platforms transition from proprietary to open access, and as the cost of data storage and data analytics continues to fall. We conservatively estimate that this will lower by 25% the price of a system that can provide today's capabilities. This is likely a conservative estimate when one considers that the prices of computers and cell phones have fallen or stayed flat over the past decade even as their capabilities have increased exponentially.

Table 17-2. Cost of energy saved through smart manufacturing

Value	Unit	Comments
$1 million	average cost per facility	Discussed in text
20%	average savings	
2 million	kWh average savings	20% of $1 million @ $0.10/kWh
$1 million	current cost	
$750,000	long-term cost	
10	year measure life	
60%	Assigned to other benefits	Discussed in text
$0.026	per kWh	CSE based on current cost
$0.019	per kWh	CSE based on long-term cost

Automation upgrades tend to take place when a new product line is launched. This is particularly the case in discrete manufacturing, where product life cycles are tied to models (as with cars and appliances) or technology generations (cell phones and computers). Continuous production processes, such as in the petrochemical industry, can be upgraded incrementally over time. With a range at the low end of 3–5 years and at the high end of 15–20 years, we selected 10 years as the measure life of a typical smart manufacturing automation system in our analysis of the cost of saved energy.

In manufacturing, sometimes energy savings are an ancillary benefit to process improvement. At other times it is the other way around. ACEEE's analysis of nonenergy benefits in the manufacturing sector (Russell 2015) indicates a wide range of associations between energy savings and other benefits such as quality, safety, environmental compliance, and reduced scrap rates. We therefore assume that only 40% of the benefit of these projects can be attributed to energy cost savings and that the remaining 60% is due to other, nonenergy benefits. With a payback requirement of two years, energy cost savings will contribute $400,000 of the $1 million cost recovery. Our analysis in table 17-2 indicates that the current cost of saved energy is $0.026/kWh and predicts that the long-term cost will drop to $0.019.

UNCERTAINTIES

The 2013 analysis applied an estimated energy savings rate to the EIA 2013 Annual Energy Outlook data to forecast energy cost savings over a 20-year period. We performed a sensitivity analysis with an estimate that the error of the 50% target is in the range of +/-50%. This uncertainty is reflected in the low, mid, and high scenarios of figure 17-2, above. The 2013 analysis assumed a relatively modest increase in investments of 1% per year early in the 20-year period, growing to 2% by 2035. These values are our best estimate of an adoption rate profile over time.

Savings from smart manufacturing technologies will vary by technology and by manufacturing sector. There are estimates in the literature that range from 10–40%. We selected 20% due to its conservative nature and due to our evaluation of the quality of the research backing up that estimate.

There are also substantial uncertainties as to costs. We selected a midrange estimate, but costs can be higher or lower. We expect costs to come down over time, perhaps rapidly, but there is uncertainty as to how much and how soon.

Recommendations and Next Steps

Smart manufacturing offers the potential to transform the manufacturing environment. It will enable new levels of process control and energy savings. It will automate the documentation of waste reduction and productivity improvement. That information will be shared throughout the organization and its supply chain in an actionable format that facilitates decision making and the management of the entire manufacturing process. Members of that supply chain will include utilities and efficiency program administrators, and though most companies many not want to share all the details of their energy use with a utility or program administrator, they may be willing to participate in a program that rewards documented demand and consumption reductions.

For the purpose of this analysis, we have assumed that programs would remain structurally similar to custom and self-direct programs. However it is possible that the structure of programs targeting the industrial sector could move toward a pay-for-performance model. Bilateral contracts that link incentives to actual energy savings are possible. The incremental step to this type of program is the funding of projects related to process and facility automation and control. These control systems will provide the detailed and timely reporting that will simplify program evaluator measurement and verification efforts for conventional programs and pave the way for pay-for-performance programs.

As program administrators contemplate how to take advantage of smart manufacturing to meet energy efficiency resource needs, the following program design issues should be considered:

- Not all process-automation projects save a lot of energy. Planners must identify manufacturing processes with the greatest opportunity for system savings through improved control.
- Not all control systems will save energy. Programs can increase their value by helping customers determine the validity of vendor claims.
- Lead times for project implementation can be long: it can take more than a year to design and prepare for an automation project, and then another year to install and optimize.
- Energy savings will change over time: it may take several months before energy savings can be documented. As a control system is optimized, so is the productivity of a facility. Associated energy savings will also increase over time.
- Projects can be very complex: customers need program flexibility to accommodate projects with multiple investments and multiple benefits.
- Determination of energy-use baselines will be challenging: the output of manufacturing facilities change over time. Product mix and volume vary, hours of operation change, and equipment upgrades are frequent. All of these variable affect energy consumption. Therefore it is important to have a robust method for determining energy savings and program attribution.

- Control systems can augment and improve the collection of energy performance data and the evaluation, measurement, and verification of savings.
- Attribution of savings to a control system will be challenging: system savings come from optimizing multiple devices toward a common goal. Smart control systems and associated sensors and communication devices are enabling components that make savings possible.

The payoff for programmatic support of smart manufacturing will be the following:

- Potential for automated reporting of savings and lower administrative costs
- Greater savings per customer
- Greater interest in programs
- More cost-effective programs
- Verification of savings persistence

Given that national potential for energy savings is in the tens of billions of dollars, and given that the cost of acquiring these savings will be low compared with alternatives, energy efficiency program administrators should consider targeting smart manufacturing technologies in programs. Doing so will help programs achieve near- and long-term goals for acquisition of energy efficiency resources.

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Chapter 18. Conservation Voltage Reduction

Author: Steven Nadel

MEASURE DESCRIPTION

In the United States, about 6% of electricity generated is lost in the transmission and distribution system due to line and other system losses, although this is lower in some areas and higher in others, including most rural areas.[68] Distribution systems account for roughly two-thirds of these losses.[69] One of the leading ways to reduce power losses is conservation voltage reduction (CVR). CVR heavily overlaps with Volt/VAR control, which addresses control of reactive power.[70]

In the United States, electricity is supplied to residential and small commercial users at 120 volts nominal. However, under American National Standards Institute (ANSI) standards, voltage at the meter can range between 114 and 126 volts at all times and between 106 and 127 volts for brief periods (see Figure 1). The minimum ANSI voltage for some industrial uses is slightly higher: 117 volts (R. W. Beck 2008). Figure 18-1 shows ANSI voltage ranges.

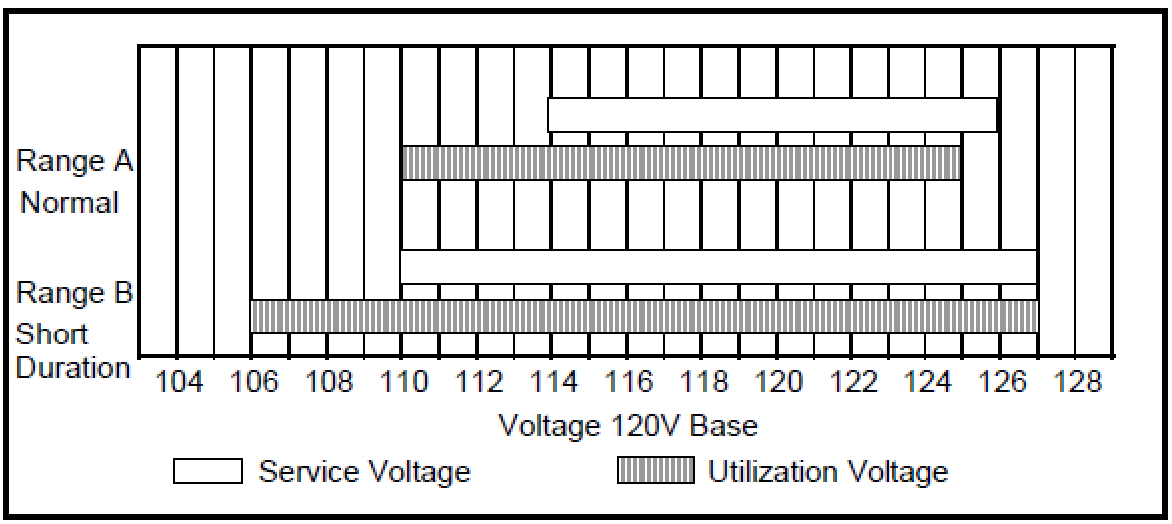

Figure 18-1. ANSI voltage ranges. *Source:* ANSI C84.1 standard as excerpted in R. W. Beck 2008.

CVR involves measuring and analyzing voltages on distribution feeders in order to find ways to reduce voltages while still maintaining service requirements (including voltage levels and phase balance) at levels that allow equipment to operate without problems. Lower voltages can improve end-use equipment efficiency and reduce line losses on both the customer and the utility side of the meter. Voltage optimization can also improve the

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68 See www.eia.gov/tools/faqs/faq.cfm?id=105&t=3. Losses during critical times, such as on hot days when systems peak, can be twice the average; such losses are directly related to voltage and the amount of electric current flowing through the wires.

69 ACEEE estimate based on a review of data at www.ercot.com/mktinfo/metering/dlfmethodology/.

70 Reactive power increases losses on the system and is caused by some loads such as electric motors and other equipment with a low power factor.

effective capacity (kW) and help with reactive power management (NWPCC 2009). Voltage can be regulated using either voltage regulators or load tap changers at the substation. Less common methods include controlling the distribution voltage level from the transmission system or using switched capacitors. Voltage control needs to be automatic and can be done via line drop compensation settings, switched capacitor banks, excitation on the generator, or voltage feedback signals from the extremities of the distribution system (R. W. Beck 2008). At times, distribution system improvements will be needed on some circuits in order to optimize voltages across the circuit. Best methods for voltage control will often vary from circuit to circuit—there is no one-size-fits-all approach. For more information on voltage control, see a report by the Regulatory Assistance Project (Schwartz 2010).

Several recent technology developments can contribute to distribution system efficiency. First, there are improved ways to optimize voltage. For example, several companies (General Electric, Cooper, Utilidata) are now marketing integrated volt/VAR controls (IVVC) that provide automated adjustment of substation-level voltage based on end-of-line voltage and predictive algorithms. And some of these products can also control switchable capacitor banks to regulate reactive power compensation.

Second, smart meters with two-way communication being installed in many areas can provide utilities with a way to measure service voltage for each customer. These data can aid in voltage control. For example, Dominion Voltage (a subsidiary of the utility Dominion Energy) has a set of three software products that use this smart meter data for customer voltage control as well as grid planning and energy savings validation.[71]

EXPERIENCE TO DATE

CVR has been in use since the 1970s in the US, before modern grid technologies were widely available. Such technologies are not necessary for CVR implementation. However the use of advanced smart grid systems can help with CVR implementation by automating processes for managing voltage and enabling finer control (quicker and more localized).

Recent work on CVR began in the Pacific Northwest with a major project by the Northwest Energy Efficiency Alliance (NEEA). The NEEA project involved pilot demonstrations involving 6 utilities, 10 substations and 31 feeders (NWPCC 2009). Voltage was controlled one day, off the next day, controlled the following day, and so on, for periods of several months. In this way the impacts of voltage control could be separated from non-control under a wide range of operating conditions. The NEEA project found average energy savings from voltage control of 2.07% of the consumption on the circuit, with savings higher in summer and lower in winter (seasonal variation is discussed further below) (NWPCC 2009). As long as voltage is carefully controlled to be above minimum thresholds, pilot programs have found that most customers will not notice any difference.

Based on the results of the NEEA pilot project, BPA, a wholesale power provider, decided to go to larger-scale implementation of voltage optimization and supporting system improvements. Utilities that purchase power from BPA can receive incentives for CVR projects. BPA requires that each participant conduct a study estimating savings, and it then

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[71] See www.dom.com/business/dominion-voltage/edge-overview.jsp.

pays incentives based on the savings achieved. Details can be found in BPA's Implementation Manual (BPA 2012). As of February 2015, six of the utilities BPA supplies power to are pursuing CVR (S. Brooks, industrial program specialist, BPA, pers. comm., February 11, 2015).

The Northwest Regional Technical Forum, a regional group of technical and program evaluation experts, has adopted two measurement and verification protocols for savings verification—one for simple approaches, one for sophisticated systems.[72]

PacifiCorp serves portions of six states and has begun to pursue voltage optimization in three of these. Of particular note, in Utah, the utility commission asked the utility to incorporate voltage optimization as part of its normal transmission and distribution business. PacifiCorp conducts a planning exercise on each circuit every five years, with about 20% of circuits reviewed each year. Voltage optimization is now being incorporated into this process (J. Jones, T&D standards manager, PacifiCorp, pers. comm., July 2012).

The Electric Power Research Institute (EPRI) sponsored a major project, called Green Circuits, which worked with 22 utilities to characterize 66 circuits across many states, with a concentration in the Southeast. The project also included field trials on nine circuits (EPRI 2011). Results of the project in terms of savings and costs are discussed below in sections on these topics. Among the nine circuits in the field test, there were almost no complaints about circuits operating at reduced voltage. There were initial complaints on two circuits, but these were resolved by less aggressive voltage reduction.

Dominion Energy, the dominant utility in Virginia, has installed more than 250,000 smart meters in its service area and has used a subset of the information provided by these meters to implement CVR in these areas.[73] Dominion has software that measures the energy savings from CVR, and the utility is now achieving an average of 2.9% savings year-round. It is gradually rolling out smart meters to keep costs down and implement CVR as these meters are installed on specific circuits. So far the smart meters represent about 10% of the utility's total. As noted above, Dominion Voltage has also been actively marketing voltage optimization services to other utilities. It now has contracts with Pacific Gas & Electric (PG&E), Hawaiian Electric Company (HECo), Nevada Power, Hydro Ottawa, and several municipal utilities. The company has a methodology it uses to estimate savings on a circuit by alternately raising voltage and then restoring the voltage to normal and seeing how loads change in response to these changes. Savings vary from utility to utility and have ranged from 2-4%, with savings toward the lower end of the range for circuits in the moderate climates along the Pacific Coast and savings higher in East Coast applications. Dominion also notes that in Hawaii and California, CVR helps to stabilize the voltage in circuits with above-average saturations of photovoltaic systems (P. Powell, director, grid innovations,

[72] See www.nwcouncil.org/energy/rtf/protocols/Default.asp.

[73] Smart meters are not needed to implement CVR, but if smart meters are installed, they can be used to provide feedback on voltage at very local levels.

Dominion Voltage, pers. comm., February 6, 2015; T. Headlee, director, Dominion Voltage, pers. comm., February 11, 2015).

Another substantial program is being operated by Oklahoma Gas & Electric (OG&E). OG&E is in the middle of an eight-year project to use volt/VAR control on 400 circuits to reduce peak load by 75 MW. The project includes capacitor control equipment and retrofit tap charger controllers. The 75 MW goal was chosen to defer a new peaking power plant. They estimate that this project will cost about one-third as much as the peaking power plant. The 400 circuits are primarily in the Oklahoma City metropolitan area and represent about one-third of their circuits. As of January 2015 they have implemented the project on 200 circuits. In terms of lessons learned, they emphasize the importance of working with vendors to make sure the software is working well and also the need to take the time needed to explain the project and get everyone on board. They will consider next steps after the current project is completed (IEI 2013; C. Killian, manager, product and service implementation, Oklahoma Gas & Electric, pers. comm., Jan. 29, 2015).

Finally, there are a number of other utilities that are actively implementing voltage optimization. For example, Baltimore Gas & Electric (BG&E) has estimated that full deployment of CVR on its system could lower peak demand by 85 MW and reduce electricity consumption by 251 million kWh annually (IEI 2014). Implementation began in 2014, and results are not yet available. The utility recently filed plans for 2015–2017 to use CVR to reduce peak demand by 72 MW and annual electricity use by 208 million (kWh) (BG&E 2014). And case studies of projects at American Electric Power (AEP) and Avista are included in a compendium published by the Institute for Electric Innovation (2013). This compendium notes that AEP did volt/VAR optimization on 17 circuits and as a result reduced customer energy use by 2–3%. These savings count toward its energy saving targets. In a follow-up conversation, AEP noted that it is gradually rolling out CVR in Indiana, where the public service commission has approved a program including cost recovery, lost revenue recovery, and credit toward energy saving goals. A similar proposal is pending before regulators in Ohio. So far, work has begun on less than 10% of AEP's total circuits in Indiana. And the company is looking at CVR in Texas as a potential demand response strategy for peak days (T. Weaver, manager, distribution system planning, American Electric Power, pers. comm., February 11, 2015). Avista is implementing CVR on 72 of its 350 feeders and anticipates load reductions (kW) averaging 1.86%.

ENERGY SAVINGS

In our midrange case, we estimate that CVR programs can reduce US 2030 electricity consumption by 2.1%, assuming average savings of 2.3% but with some adjustments noted in table 18-3 below. The 2.3% figure is based on the 2.34% average savings estimated by EPRI for the 66 circuits examined in its Green Circuits program (EPRI 2011) and also on the simple average of seven estimates as summarized in table 18-1.

Table 18-1. Summary of published savings estimates

Project	Average savings (%)	Source
EPRI Green Circuits modeling	2.34	EPRI 2011
EPRI Green Circuits field test	2.01	EPRI 2011
PNNL all circuits*	3.04	Schneider et al. 2010
PNNL 40% best circuits	2.40	Schneider et al. 2010
NEEA	2.07	NWPPC 2009
AEP Ohio	2–3	IEI 2014
Avista	1.83	IEI 2014
Simple average	2.31	

* PNNL is Pacific Northwest National Laboratory.

While 2.34% is an average in the EPRI analysis, savings on individual circuits can vary from less than 1% to more than 3%, as shown in figure 18-2. Our midrange estimate of 2.3% average savings is also very similar to the 2.4% average savings estimated by PNNL for a nationwide program that optimized the 40% of circuits where CVR has the highest value (Schneider et al. 2010). For this reason we apply the 2.3% average savings to all electricity put into the US electricity grid. For the low savings case we estimate average savings of 1.8%, based on the lowest savings estimate in table 1. In the high savings case we estimate 2.9% average savings, based on a PNNL estimate that 3.04% can be saved on average if all circuits are optimized, but then multiply by 95% because PNNL estimates there will be very little savings in the 25% of circuits that provide the least benefit (see figure 18-3) (Schneider et al. 2010). This is very similar to the average savings Dominion Energy is achieving in Virginia, as discussed above. Based on these estimates, total US savings are 1.6% of US 2030 electricity consumption in the low saving case and 2.6% in the high savings case. Figure 18-2 shows the modeled savings from voltage optimization of 66 circuits.

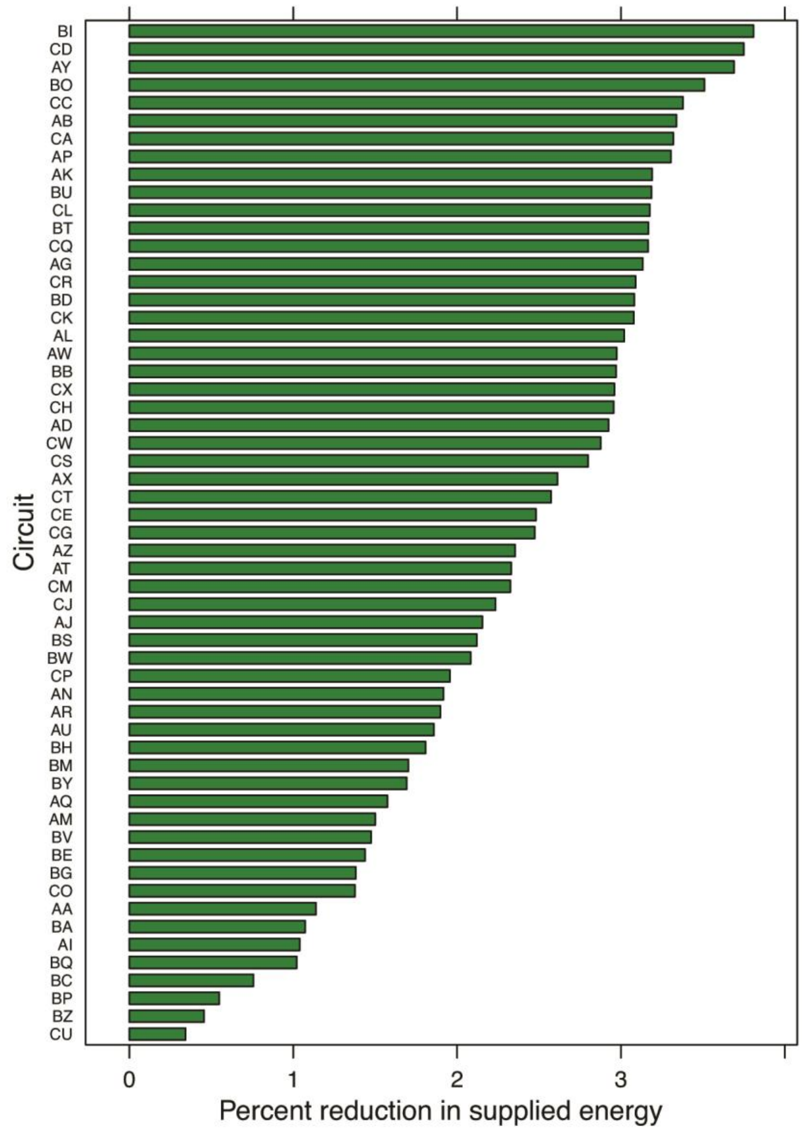

Figure 18-2. Modeled savings from voltage optimization of 66 circuits. *Source:* Arritt, Short, and Brooks 2012.

Figure 18-3 shows the relationship between the percentage of total feeders and the percentage of total benefit in the United States. The total benefit is the total energy savings available nationwide. Half the circuits account for about 85% of the total savings available.

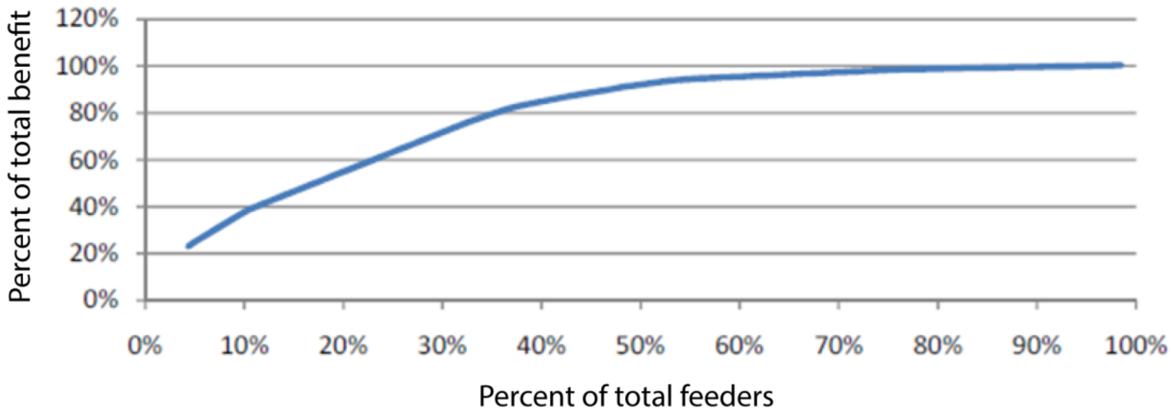

Figure 18-3. Percentage of total benefit versus percentage of total feeders in the United States. ***Source:*** **Schneider et al. 2010.**

A few other points regarding energy savings are worth noting. First, the vast majority of savings from CVR are on the customer side of the meter. Based on its detailed modeling on 24 prototypical feeders, PNNL estimates that 98–99% of the energy savings are on the customer side of the meter (Schneider et al. 2010). EPRI (2010) found that that overall, 95.6% of the kWh savings were at the end-use level. An earlier analysis based on computer modeling estimated that 60–90% of the savings are on the customer side of the meter (Leidos 2007).[74]

Second, it appears that energy savings and peak load reductions, on a percentage basis, are similar. For example, PNNL's results indicated 0.5–3% reductions in both peak load and annual energy use, depending on the feeder, with results for these two metrics nearly the same in percentage terms (Schneider et al. 2010).

Third, it will take many years to achieve all of these savings because optimizing a circuit requires either smart meters (the Dominion approach) or significant engineering work.[75] Of our examples, no utility has yet done more than 10% of its circuits; several companies are proceeding at the rate of about 25 circuits per year, and large utilities can have more than 1,000 circuits each.

Fourth, Tom Short of the EPRI Green Circuits team reports that achieving savings is generally easier and more cost effective on shorter circuits. On long circuits, voltage drops over the entire length of the line are greater, and therefore, to avoid violating voltage limits, voltage can be reduced less or more monitoring points and regulator banks must be

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[74] A calculation approach to estimate this split for specific circuits can be found at distributionhandbook.com/calculators/mdpad.html?cvr.md.

[75] There is also a quick-and-dirty approach: It is possible to find some circuits where voltage can be lowered by reducing the set point at voltage regulators. Such an approach results in less savings and can be done only on some circuits.

installed, which increases costs (T. Short, senior technical executive, Electric Power Research Institute, pers. comm., July 2012).

Fifth, savings tend to be higher in the summer when air conditioners are running and lower in the winter on circuits with substantial electric resistance heat. With electric resistance heat, when voltage is reduced, the amount of heat is also reduced and equipment needs to run a little longer. This is illustrated in figure 18-4, which shows results from the NEEA study. CVRf is the conservation voltage reduction factor. It is the percentage reduction in energy use divided by the percentage reduction in voltage.

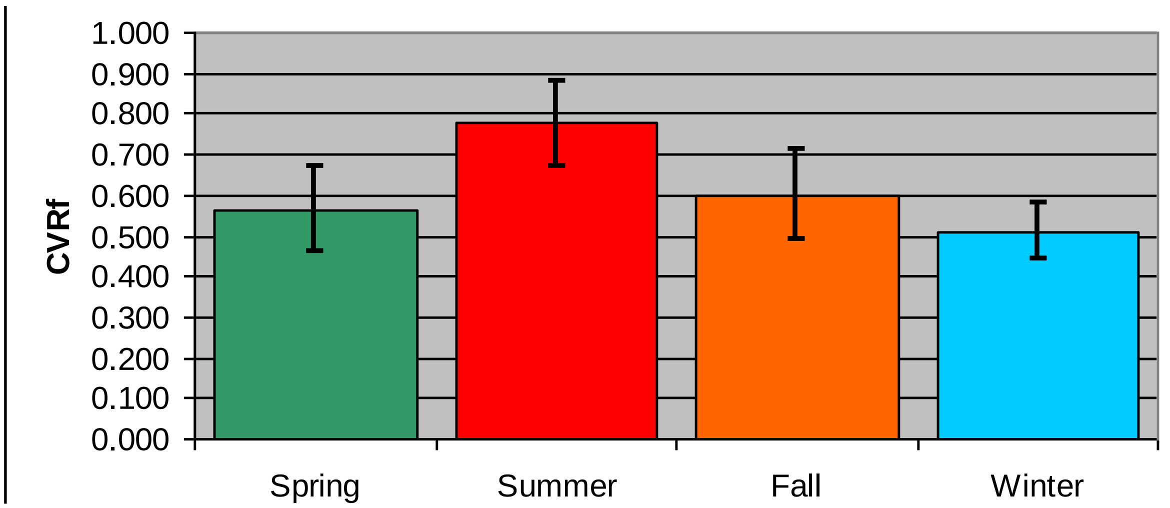

Figure 18-4. Energy savings per percentage voltage reduction by season in Northwest pilot. *Source:* NWPCC 2009.

Work has been done primarily on circuits that are residential and secondarily on circuits with significant commercial loads. But little work has been done on circuits with large commercial and industrial customers, although the PNNL study did look at these circuits. Experts we consulted expect lower savings on these circuits. While not clear, the low savings shown in figure 18-3 from 75–100% of circuits could reflect this factor.

In addition to reducing energy use and peak loads, CVR can reduce reactive power requirements. In the EPRI Green Circuits field test, reactive power was measured on two circuits and very positive improvements in reactive power were obtained. Schwartz (2010), based on her review of data available as of 2010, estimates that voltage optimization can reduce reactive power requirements by 5–10%.

Returning to the midrange case, savings are calculated as shown in table 18-2.

Table 18-2. Electricity savings in 2030 from CVR

	Value	Unit	Comments
	4,526	TWh	2030 electricity available to grid from EIA 2014
x	2.3%	average savings	Discussed in text
x	90%	participation rate	Among utilities. Small ones may not participate.
x	95%	net-to-gross ratio	Standard assumption for this report
=	89	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	2.1%	of US electricity use	

COSTS AND COST EFFECTIVENESS

Costs vary widely depending on the circuit and the upgrades being made. For example, as part of the Green Circuits program, EPRI looked at a wide variety of costs, including a variety of specific upgrade options for six circuits. Table 18-3 summarizes the costs EPRI used.

Table 18-3. Construction and cost estimates

Element	Cost
Voltage reduction	
Regulator control modifications plus related	$63,600.00
Single-phase tap movement/phasing	
Overhead	$1,400.00
Underground	$2,800.00
Capacitors	
300 kvar fixed	$3,000.00
600 kvar fixed	$5,175.75
900 kvar fixed	$8,000.00
1,200 kvar fixed	$7,597.00
300 kvar switched	$4,500.00
600 kvar switched	$12,573.33
900 kvar switched	$12,000.00
1,200 kvar switched	$23,084.50
Salvage value from bank removal	20% of list price
Reconductoring	
Conductor	
477 kcmil AA	$2,000.80/kft
556 kcmil AA	$2,328.64/kft

Element	Cost
795 kcmil AA	$3,481.60/kft
Conductor installation	1.8x cost of conductor
New poles with installation at 12 kV	3.3x cost of conductor
New poles with installation at 34 kV	7.6x cost of conductor
Voltage regulators	
Single-phase 100 A	$15,000.00
Three-phase 100 A	$22,000.00
Three-phase 219 A	$42,600.00
Three-phase 328 A	$50,650.00
Three-phase 548 A	$62,000.00

Source: EPRI 2011

Table 18-4 summarizes the costs of saved energy (cents per kWh saved) for specific measures for specific circuits.

Table 18-4. Levelized cost in cents per kWh for the best option in each category

Category	Circuit					
	A	B	C	D	E	F
Base voltage feedback	1.1	0.6	2.2	5.4	2.8	0.3
Phase balancing	0.9	0.6	2.3	4.4	2.9	0.4
VAR optimization	0.9	0.6	2.5	2.3	3.0	0.3
Reconductoring	2.0	4.1	47.3	24.1	14.0	0.6
Voltage regulators					3.2	0.4
Combinations	0.8	0.9	2.4	2.1	4.6	1.7

Source: EPRI 2011

Across the six circuits, the cost of saved energy ranged from 0.8–4.6 cents per kWh saved, with a simple average of 2.1 cents (median of 1.9 cents). These calculations assume a 15-year life for energy savings, a 35-year life for capital equipment, and a 6% discount rate for the investments (EPRI 2011).

UNCERTAINTIES

Available data indicate that overall average savings of 1.8–3% are available from voltage optimization, with the savings for individual utilities varying within this band. This is a fairly large range, and further evaluation of actual projects over time should help to both narrow the range and clarify what level of savings might be possible in different types of situations. Some circuits are not good candidates for voltage optimization, but this is somewhat factored into the savings range referred to above. Still, a better understanding of these situations will allow better targeting of voltage optimization efforts.

RECOMMENDATIONS AND NEXT STEPS

Based on these findings, we recommend that utilities conduct CVR studies on their circuits, beginning primarily with residential and light commercial circuits and proceeding over time to circuits with substantial industrial loads. Such studies can be done in blocks, as PacifiCorp is doing in Washington, or included as part of regular planning processes, as PacifiCorp is doing in Utah. To optimize all the attractive circuits will take a decade or more and significant capital investment. For utilities that are installing smart meters or undergoing other grid modernization projects, CVR can be undertaken as part of these projects. Since most of the savings are on the customer side of the meter, we recommend that utilities receive credit for the savings as part of efforts to reach savings goals and to earn incentives if they meet their goals.

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Chapter 19. Combined Heat and Power Systems

Author: Meegan Kelly

MEASURE DESCRIPTION

Combined heat and power (CHP) is an energy-efficient method of generating both electricity and useful thermal energy in a single, integrated system capable of recovering thermal energy that would otherwise be wasted. Without CHP, industrial, commercial, and institutional users access heat and power services separately, typically purchasing electricity from their local utility and burning fuel onsite in a conventional thermal conversion unit such as a boiler or furnace. A CHP system allows operators to generate both energy outputs from a single fuel source in one onsite system, requiring less fuel overall to provide the same amount of useful energy.

In typical applications, the CHP customer remains connected to the electric utility grid and meets its energy needs with a balance of CHP generation and conventional supply. Given all the times throughout the year when a customer's need for electricity and thermal energy do not instantaneously and simultaneously overlap, a typical site fulfills about half of its needs with CHP and half with conventional supplies.

The average efficiency of a fossil-fueled power plant in the US is currently about 35%, meaning approximately two-thirds of the energy contained in the fuel input is lost as wasted heat (EIA 2015a). As a result, the conventional scenario (with separate heat and power) is typically about 50% efficient, as depicted in figure 19-1 below. By contrast, a CHP system has the ability to recover heat that would otherwise be wasted and to use this energy onsite. Further, by avoiding the purchase of electricity from the grid, energy losses that normally occur in transmission and distribution across the grid are eliminated. Such losses are typically 6% and can be higher during periods of peak load (EIA 2015b). With these savings, CHP systems regularly achieve energy efficiencies of 65–80%, which is significantly better than producing heat and power separately.

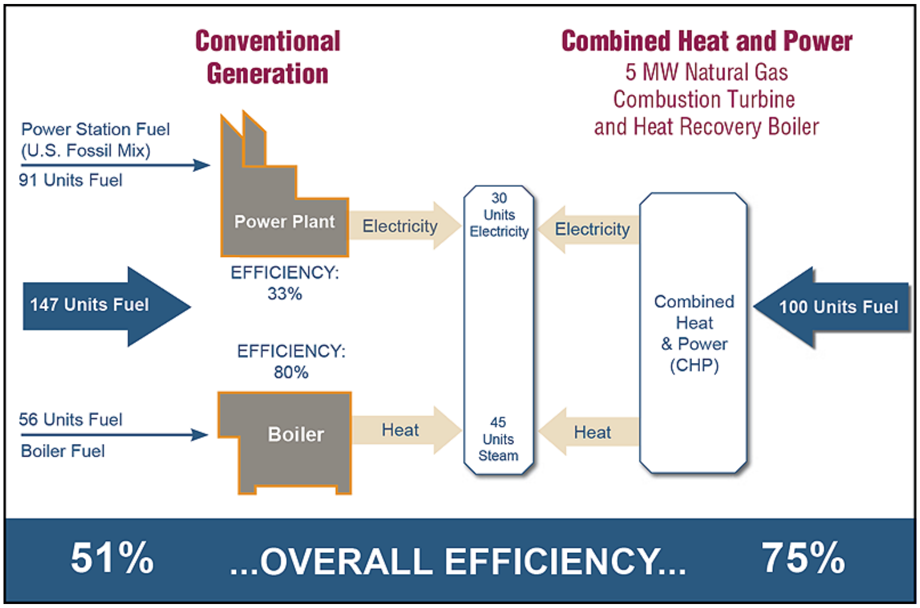

Figure 19-1. Comparison of conventional generation and CHP. Using the representative system depicted here, the CHP system uses 32% less ((0.51–0.75)/0.75) fuel per unit of energy (electricity and thermal) than conventional generation. *Source:* EPA 2015a.

CHP systems are most often used in the commercial and industrial sectors at facilities with large or round-the-clock power needs. About 80% of the 82.7 GW of currently installed CHP capacity is in the industrial sector, with the most CHP capacity in the chemicals, refining, and paper industries.[76] The remaining CHP applications are located at other industrial sites such as food processing, textile, auto manufacturing, metal casting, and other manufacturing facilities; and at commercial and institutional sites such as hospitals, universities, hotels, and commercial and multifamily buildings.

The higher efficiency of CHP results in a range of benefits for the system owner, utilities, and society at large. The system owner benefits from lower energy bills, increased productivity, and greater power reliability. Some CHP systems can run every day in parallel with the utility grid to save money and can also run independently during a grid outage to provide enhanced reliability at the site. CHP can also benefit utilities by reducing grid congestion, deferring the need for infrastructure investments, and improving overall grid reliability. Investments in CHP also provide a range of benefits for society, such as reduced overall fuel consumption, energy infrastructure resiliency, and greenhouse gas emissions reductions when compared with conventional power plants.

EXPERIENCE TO DATE

CHP is a well-established technology with a long history of use in every state of the nation. Today there are installations at more than 4,300 facilities in the United States. The installed base of 82.7 GW of CHP currently represents 8% of US electric generating capacity producing more than 12% of total electricity generated (DOE and EPA 2012). But CHP has

[76] See the DOE/ICF CHP Installation Database for more information: doe.icfwebservices.com/chpdb/.

the potential to achieve much more and remains a largely untapped resource. Recent estimates indicate an additional 130 GW of capacity is technically feasible at existing industrial, commercial, and institutional facilities (ICF International 2013).

To capture these potential energy savings, efforts have been developed across the country to increase deployment of CHP. President Obama established a national goal of 40 GW of new CHP capacity by 2020 (Executive Order No. 13,624, 2012), and the Department of Energy is providing regional and state technical assistance to help achieve this goal (DOE 2015). States have also developed innovative approaches to encourage energy savings and emissions reductions with CHP. A handful of states including New York, California, Massachusetts, and Maryland have led the way in developing innovative approaches to increase deployment of CHP for its energy savings and additional benefits. The following section describes some of the design elements of these successful approaches that could serve as good models for other states and program administrators to consider.

New York

The New York State Energy Research and Development Authority (NYSERDA) has some of the most extensive experience implementing programs to encourage CHP. It launched one of the first CHP programs in the country—the DG-CHP Demonstration Program—in 2001. NYSERDA used a competitive review process to select and fund demonstration projects that would provide the best lessons for deploying CHP throughout the market (Navigant 2011). By the time the program ended, in 2012, annual savings attributable to CHP had reached a reported 576,689 MWh (NYSERDA 2013). Midway through the term of the DG-CHP Demonstration Program, NYSERDA launched a companion program, the CHP Performance Program, and these two programs ran concurrently to provide support to trailblazing projects and projects following proven examples, respectively.

After a brief hiatus in 2012, NYSERDA launched its two current incentive programs: a revival of the CHP Performance Program for larger systems (now focused on customized CHP systems greater than 1.3 MW) and the CHP Acceleration Program for smaller, pre-engineered systems (less than 1.3 MW). The Performance Program emphasizes customization and provides incentive payments based on energy generation ($0.10/kWh) and summer peak demand reduction ($600– 750/kW). It also offers bonus incentives for some projects, including those that operate at higher overall efficiency. The Acceleration Program emphasizes simplicity and standardization and uses an innovative catalog model, which allows customers to choose from a selection of preapproved CHP systems and prequalified vendors that are directly eligible for incentives. NYSERDA assigns incentives ($/kWh) to each CHP system in the catalog based on the size of the system and the site location. Both programs prioritize increasing the resiliency of buildings and infrastructure in the state and require systems to be able to operate during grid outages.

NYSERDA's programs are expected to provide incentives for the next several years, after which the state will shift toward a long-term approach that establishes a self-sustaining market in the absence of public subsidies.

California

Two state policies set targets for CHP deployment in California. One is Assembly Bill 32, the California Global Warming Solutions Act of 2006, which includes a reduction target of 6.7 million metric tons of CO_2 to be achieved specifically from CHP resources. The second is the Governor's Clean Energy Jobs Program, which calls for the addition of 6,500 MW of CHP by 2030 (CEC 2015). Several policy mechanisms help meet these goals in California.

The California Public Utility Commission's (CPUC) Self-Generation Incentive Program (SGIP) is one of the longest-running distributed generation incentive programs in the country. SGIP is a ratepayer-funded program that offers a rebate of $0.48/watt for CHP technologies to customers of four utilities in the state. CHP systems of any size may qualify, although the incentive payment is capped at 3 MW. Half of the incentive is provided to customers up front, and the other half is provided based on actual kWh production over the first five years.

CHP systems in California also have access to a feed-in tariff (FIT), which establishes a price and approved standard-offer contracts for the purchase of excess electricity from eligible CHP generators. CPUC established the feed-in tariff for CHP systems that are smaller than 20 MW and operate above a 62% total efficiency.

California was also one of the first states to establish a standard interconnection policy for distributed generation, including CHP. Technical standards that reflect best practices for connecting to the distribution and transmission networks simplify the path to interconnection with the grid and support CHP deployment. California's interconnection standard, Rule 21, applies to CHP systems up to 10 MW. It includes a fast-track application process for systems that meet certain size standards and offers several detailed study options for larger facilities.

Massachusetts

A variety of policies encourage CHP deployment in Massachusetts, including an Energy Efficiency Resource Standard (EERS) that recognizes CHP as an eligible technology and two CHP programs designed to acquire CHP energy resources. A ratepayer-funded rebate program is administered by Massachusetts's electric and gas utilities, and an alternative energy portfolio standard (APS) is administered by the Massachusetts Department of Energy Resources (DOER).

The Green Communities Act of 2008 requires Massachusetts's electric and gas utilities to procure all cost-effective energy efficiency before more expensive supply resources, and it sets some of the most ambitious energy savings targets in the country. Annual savings targets began at 1.4% in 2010 and ramped up to 2.6% by 2015. The Act specifies CHP as an eligible resource for meeting these targets, and all the electricity generated by CHP systems that meet minimum efficiency requirements is credited to each utility's energy savings goals.

The ratepayer-funded CHP program is implemented through the Mass Save initiative to help utilities meet their savings targets. Launched in 2010, the program provides incentives per kW depending on system size and the level of efficiency measures in place or planned at the user's site. Three tiers of incentives are available to utility customers—basic, moderate, and advanced—and each tier provides a greater reward to systems that are sized and designed to achieve ideal performance and cost effectiveness. This emphasis on right sizing and optimal performance is one of the most innovative aspects of this program. One of the participating utility administrators, Eversource Energy, reported 54,024 MWh of annual energy savings from CHP systems in its service territory during the 2013 program year, with nearly $4.8 million in CHP program spending (Nowak, Kushler, and Witte 2014).[77]

The second program, the APS, is a complementary initiative that prioritizes CHP systems as part of the state's renewable portfolio standard (RPS) to achieve 20% of electricity from renewable energy and 5% from alternative sources. As an eligible alternative source, CHP systems earn a performance incentive (per kWh) in the form of alternative energy credits (AECs). One of the main innovations of this program design is its use of a clearly defined methodology for quantifying energy savings from CHP. An AEC Estimator tool is available online that allows prospective CHP owners or vendors to estimate the amount of AECs their project can expect to earn, which helps applicants incorporate this income into budgets and move projects forward.[78] Compliance with the APS is being met almost entirely using efficient CHP technology, which earned 99.4% of AECs in 2013 (DOER 2014). In 2013, 81 CHP projects representing 329 MW of capacity earned credits through the APS program for generating 531,781 MWh of net source fuel energy savings (Ballam 2015).[79]

The combination of these two programs significantly improves the economics of installing CHP, and savings through the program are expected to increase (EEAC 2015). In addition to the financial assistance made available by these programs, Massachusetts has established interconnection standards for distributed generation that utilities are implementing statewide.

Maryland

The EmPOWER Maryland Efficiency Act of 2008, which set electricity savings goals in the state, resulted in several new incentives for CHP that are being offered by electric utilities and by the Maryland Energy Administration (MEA). Maryland also adopted statewide rules in 2008 that specifically allow for the interconnection of CHP.

[77] Eversource Energy was known as NSTAR in 2013.

[78] See www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/rps-aps-sqa/aps-statement-of-qualification-applications.html.

[79] "Net source fuel energy savings" compares the fuel energy required for a given amount of electricity generated and recovered heat transferred to a facility thermal load produced by a CHP unit with the amount of fuel energy that would be required to obtain the same amount of electricity from the ISO-NE grid and heat from a conventional onsite thermal conversion system such as a boiler or furnace. The formula is: Net Source Fuel Energy Savings (MWh) = MWh Elec CHP/0.33 + MWh Heat CHP/0.80 – MWh Fuel CHP.

In 2012 the Maryland Public Service Commission approved a CHP pilot incentive program to be implemented by electric utilities to help achieve the goals of the EmPOWER Maryland Act. Although each program differs slightly, we use the one offered by Baltimore Gas & Electric (BGE) as an example. BGE's Smart Energy Savers CHP program provides financial incentives to commercial and industrial customers that employ CHP to reduce their energy consumption and demand usage. Qualified projects are eligible to receive incentives up to $2.5 million during several phases of CHP project development. Projects receive a design incentive ($75/kW) after they have committed to the program and an installation incentive ($175/kW or $275/kW, depending on size) after the system has been commissioned and the installation has been inspected by BGE. Projects also receive a production incentive ($0.07/kWh) during the first 18 months of operation.

The first phase of BGE's program (2012–2014) resulted in five implemented projects that generated more than 25,000 MWh of annualized energy savings and $1,762,540 in incentive spending (BGE 2015). Due to the popularity of the first phase, BGE requested and the Maryland Public Service Commission granted an increase in the incentive cap in the second phase (2015–2017) to $2.5 million, providing an even greater benefit to BGE's CHP program participants (MPSC 2014). Currently, 13 projects ranging in size from 60 kW to 8 MW and totaling over 16.5 MW of installed capacity have been approved to participate in the program.

In addition to the utility programs, in 2014 the Maryland Energy Administration launched the EmPOWER Maryland CHP Grant Program, which targets health care and wastewater treatment facilities. The goal of the program is increase the energy resiliency of these facilities while also contributing to the state's energy savings targets. The incentives range from $425/kW to $575/kW per project, based on the size of the system and funding availability. Grants are disbursed in two installments, with 30% as a ground-breaking incentive and 70% as an installation incentive upon final commissioning (MEA 2015).

ENERGY SAVINGS

CHP can be a major contributor of energy savings across the country. Compared with average fossil-based electricity generation, the entire existing base of CHP saves 1.8 quadrillion Btus of energy annually, which is about 2% of US energy use (DOE and EPA 2012). With the amount of CHP currently installed remaining far below its estimated potential, CHP is a readily available, proven option for achieving large energy savings in the future.

CHP does not result in direct electricity end-use savings. Instead, CHP shifts electric load away from centralized power plants to the CHP unit (typically located near the point of use) while moderately increasing onsite fuel consumption. Due to the avoided transmission and distribution losses and overall efficiency of cogenerating heat and power, CHP results in primary fuel savings. We account for net energy savings by finding the fuel saved at a centralized power plant due to CHP, less the increased on-site fuel consumption to power the CHP system. Then we calculate the amount of end-use electricity savings it would take to achieve the same amount of primary fuel savings at a centralized power plant.

In a recent report, ACEEE found that more than 68 million MWh of US energy could be saved in the year 2030 from installing CHP, which represents 18 GW of avoided capacity (Hayes et al. 2014). This report first estimated the cost-effective potential for new CHP in each state for both the commercial and industrial sectors. Then we calculated the effective electricity savings resulting from the expected installation of cost-effective potential in each state and sector.

Our estimate resulted in the expected installation of about 8.7 gigawatts (GW) of commercial CHP and 9.4 GW of industrial CHP nationwide by 2030. All of the CHP potential considered was technically feasible in the year 2013, based on publicly available data from ICF International (2013). ACEEE adapted ICF's technical potential data to determine how much CHP potential could be considered cost effective in each state, sector, and installation year. We did this by applying a simple payback acceptance analysis and a cost-effectiveness test that considered forecast electricity and natural gas prices.

Using our estimate of cost-effective CHP installations that could take place in each year, we calculated effective electricity savings from CHP: approximately 34.6 million MWh of commercial savings and 33.7 million MWh of industrial savings nationwide in 2030. This represents about 1.3% of US 2030 electricity consumption, as shown in table 19-1.

It is important to note that this analysis represents a constrained estimate of the potential for CHP. Only natural-gas–fueled CHP units sized less than 100 MW were considered, and the impact of state-level policies and programs to encourage CHP deployment was not included. Additional policies could result in a higher level of CHP implementation. Assumptions are also limited by the use of state average electricity and gas rates, which do not reflect local variations in economic potential in some states.

Table 19-1. Electricity savings in 2030 from CHP

	Value	Unit	Comments
	68	TWh	Energy savings in 2030 estimated from Hayes et al. 2014
x	90%	participation rate	
x	95%	net-to-gross ratio	Standard assumption of this report
=	58	TWh	
/	4,327	TWh	Projected 2030 US electricity consumption from EIA 2014
=	1.3%	of US electricity use	

We also developed low and high cases with lower and higher participation rates. In the low case, the participation rate is 75% of the potential from the Hayes et al. analysis, and in the high case it is 100%. As a result, CHP would represent 1.1% of 2030 US consumption in the low case and 1.5% in the high case.

COSTS AND COST EFFECTIVENESS

The cost of CHP varies widely depending on the system size, application, and state within which it is installed. The economic benefits of any given project are determined mostly by the system's operating characteristics, such as how efficiently it performs, its costs, and the magnitude of the avoided utility costs. CHP generally entails three types of costs: capital/installation, non-fuel operations and maintenance (O&M), and fuel. Project economics may be most sensitive to fuel costs, which will fluctuate significantly depending on the price of fuel to generate energy with CHP relative to the cost of purchasing delivered electricity from the local utility.[80] Economics are also impacted by the availability of financial incentives and the state's regulatory context.

Electricity savings from CHP are the amount of electricity generated by the system that no longer must be acquired from the central power plant. We can approximate the cost of electricity savings by calculating the cost per kWh of CHP electric generation using a representative CHP system and assuming typical operating characteristics and costs. In table 19-2, the cost per kWh is calculated based on the installation of a 10 MW gas turbine CHP system with operating assumptions using EPA's *Catalog of CHP Technologies*.[81]

Table 19-2. Cost of electricity for a representative CHP system

Characteristic	Assumption
Technology	Gas turbine
Capacity (kW)	10,000
Availability	93%
Effective electric heat rate (Btu/kWh)	5,905
Economic life (years)	20
Capital cost ($/kW)	$1,976
O&M cost ($/kWh)	$0.012

Source: EPA 2015b

EPA assumes systems of this size and technology are available for operation 93–96% of the time (EPA 2015b). Average capital costs are assumed to be $1,976/kW, and average operations and maintenance (O&M) costs are assumed to be $0.012/kWh. Fuel costs depend on how efficiently the CHP system generates electricity, current fuel prices, the amount of useful CHP thermal output, and the efficiency of the boiler that is partially displaced by the CHP system. For the sample system, EPA estimates the effective electric heat rate, which describes how much fuel input is used to generate electric output, is 5,905 Btu/kWh. We

[80] In some localities, utility-supplied electricity is dependent on the price of pipeline natural gas and the price of electricity rises and falls with the fluctuating price of natural gas. In these areas, a relatively constant delta between the price of gas and the price of electricity (the so-called spark spread) is maintained regardless of the variability of fuel pricing, and this minimizes the sensitivity of project economics to fuel costs.

[81] EPA offers a detailed comparison of different CHP technology sizes, costs, and performance parameters in its *Catalog of CHP Technologies* (EPA 2015a). We use cost and performance characteristics of System 3 described in table 3-2 from the catalog, "Typical Performance for Gas Turbines in CHP Operation."

calculate costs for fuel based on a current fuel price for natural gas of $4 and a long-term forecast fuel price of $6.50 in 2030, expressed in real 2012 dollars per million Btus.[82]

As shown in table 19-3, we estimate that electricity savings from a representative 10 MW natural gas CHP system cost approximately 5.3 cents per kWh based on an estimated natural gas price of $4/MMBtu.[83]

Table 19-3. Cost of energy saved through CHP

	Value	Unit	Comments
	87,600	MWh	Annual generation capacity from 10 MW gas turbine
x	93%	availability	EPA CHP catalog estimates 93–96% availability.
x	100%	average savings	
=	81,468	MWh savings	Annual electricity savings from 10 MW gas turbine
	$19,760	current cost	From EPA CHP catalog, based on 10 MW gas turbine with $1,976/kW in capital cost
	$19,760	long-term cost	Same capital cost, but high natural gas price scenario
	0%	of costs assigned to other benefits	
	20	year measure life	Estimate for 10 MW gas turbine
	$0.054	CSE based on current fuel cost	Includes $0.012/kWh in O&M costs; fuel cost is based on effective electric heat rate of 0.006 MMBtu/kWh and current natural gas price of $4/MMBtu, based on NYMEX and including delivery charges
	$0.069	CSE based on long-term fuel cost	Includes $0.012/kWh in O&M costs; fuel cost is based on effective electric heat rate of 0.006 MMBtu/kWh and forecast long-term natural gas price of $6.49 (in 2012 dollars) for electric power sector in 2030 from EIA 2014

UNCERTAINTIES

A number of uncertainties affect the market for CHP deployment, making it difficult to forecast the true potential for CHP to contribute energy savings. While technical potential estimates reasonably interpret how much CHP may be technologically feasible in a given state, it is more difficult to estimate how much CHP will be economically feasible, and what fraction thereof would actually be installed.[84] The actual participation level in the CHP market is uncertain. ACEEE's estimate that CHP could provide 68 million MWh of energy

[82] Current natural gas price estimate of $4/MMBtu is based on NYMEX and includes delivery charges. We assume a forecast long-term natural gas price of $6.49 (in 2012 dollars) for the electric power sector in 2030 based on EIA 2014.

[83] This analysis does not account for the financial benefits of incentive funds, revenue from providing ancillary services, tax implications via accelerated depreciation, reductions in premiums for business continuity insurance policies, and so forth, all of which further improve the economics of CHP.

[84] For example, lack of available space at a given site would preclude installation of an otherwise technologically and economically feasible project.

savings in the year 2030 reflects a set of assumptions that somewhat constrain the scope of savings CHP can provide. Future state policy commitments or changes to regulatory models could result in substantially higher levels of energy savings and cost-effective CHP implementation.

Uncertainties surrounding the price of energy also strongly impact the level of CHP implementation that is realized in the marketplace. Because the majority of CHP systems are fueled by natural gas, availability issues and volatility in gas prices can create significant uncertainties in the future cost of CHP projects. According to an article in *The Wall Street Journal*, natural gas markets experienced greater volatility and greater price swings in 2014 than in recent years (Puko 2015). Current low-cost natural gas has created more economically favorable conditions for many potential installers, but this may not always be the case.

Several other possible factors could favorably impact the economics for CHP deployment. First, greater interest in reducing greenhouse gas emissions could result in new revenue streams for CHP. CHP is a proven emissions reductions strategy that could provide significant savings for compliance with future air regulations, such as EPA's Clean Power Plan. Second, greater interest in improving grid resiliency or improving a site's reliability in the event of a natural or man-made disaster could also improve the economics for CHP. Initiatives to protect communities from losses that occur during extreme weather events are emerging across the country, and CHP systems can continue to supply power even after a loss of grid-supplied electricity.[85] If these additional benefits from CHP were monetized, markets would respond with greater deployment. However this is not easy due to the current lack of a generally accepted accounting principle (GAAP) for determining the amount by which to monetize the enhanced reliability attributable to CHP. In the absence of a GAAP, project financiers often ascribe a default value of zero.[86]

RECOMMENDATIONS AND NEXT STEPS

A number of barriers impede the full capture of CHP potential in the industrial and commercial sectors, and a variety of policy and regulatory measures could facilitate wider adoption. Perhaps one of the strongest opportunities for capturing significant energy savings from CHP comes when states define CHP as an eligible technology for meeting state energy efficiency or renewable energy savings goals. Massachusetts and Maryland have successfully driven investment in CHP by allowing it to qualify as an eligible measure within clean energy portfolio standards—energy efficiency resource standards (EERS), alternative portfolio standards (APS), or renewable portfolio standards (RPS). State

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[85] Several states, including New York, New Jersey, and Connecticut, have recognized CHP's role in critical infrastructure resiliency and emergency preparedness by providing incentives for CHP systems that are able to operate when the grid is down.

[86] In 2014, with funding from NYSERDA, ACEEE launched an effort to work with the accounting and insurance sectors to discern a process and willing partners to develop a GAAP for monetizing the enhanced resiliency of CHP. Once a process is discerned, a broader coalition will be assembled to execute that process.

policymakers should consider setting portfolio standards with CHP potential in mind and consider appropriate methods for accounting for energy savings from CHP. Another option is to set a distinct target for annual CHP generation that is separate from the target outlined in the portfolio standards.

As utility-sector energy efficiency programs are developed to meet state savings goals, states and program administrators should consider developing complementary programs that are designed to acquire cost-effective energy resources from CHP. Customers demonstrate a strong interest in programs that provide financial assistance including incentives, grants, and loan programs, whenever they are available. In addition to financing options, programs may provide technical assistance including engineering or feasibility studies that help reduce expenses and overcome the high up-front costs of installing a CHP system.

State regulators may also consider streamlining certain procedures in order to reduce barriers to CHP deployment and capture significant energy savings. Environmental permitting processes can be streamlined, and states can establish fast-track air permitting for qualified systems. States also can deploy output-based emissions standards that more fairly calculate the emissions savings and the full energy efficiency benefit of CHP.[87] States could also streamline procedures for interconnecting CHP systems with the electric grid by adopting statewide, simplified procedures for systems that meet certain qualifications. While interconnection raises somewhat less of a barrier today than it has in years past, several states are yet to address the issue.

Changes in state policy and regulations will also help utilities begin to view CHP as being in their economic interest. The states that have seen greater CHP deployment have typically engaged directly with local utilities to identify program structures that can bring utilities in as dedicated partners (Hayes et al. 2014). States should assess the impact of backup, stand-by, and supplemental power rates on the CHP market and work with utilities to develop fair and equitable rates that allow adequate cost recovery for the utility but do not discriminate against the CHP system owner.

Utilities could also play an important role in CHP deployment by investing in direct ownership of CHP. In a 2013 report, ACEEE described the many direct and indirect benefits CHP is capable of providing to utilities (Chittum and Farley 2013). CHP provides utilities with a low-cost capacity resource that improves overall system reliability and has lower infrastructure costs. Utilities are also well suited to making the kind of long-term capital investment that CHP requires and well positioned to strategically site systems so that they provide the greatest benefit to the overall grid. Only about 3% of installed CHP capacity is currently owned by utilities, but CHP could become an increasingly attractive generation option in markets where utility ownership of CHP is allowed (Hampson and Rackley 2014;

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[87] Several states including Connecticut, New Jersey, and Texas have introduced streamlined permitting procedures for certain types of CHP systems in order to simplify and speed up the permitting process. For more information, see: http://www.epa.gov/chp/documents/PBRFactsheet-10162014.pdf.

Chittum and Farley 2013). The potential benefit to utilities is significant, and state-level policies to encourage this activity will help the US reach the full potential for CHP.

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Chapter 20. The Way Forward

NEW AND EXPANDED OPPORTUNITIES FOR ENERGY EFFICIENCY

Our analysis highlights a number of trends and developments in energy efficiency technologies, markets, and customer programs. These clear drivers of change are the foundations for new models and approaches to energy efficiency. Some industry analysts refer to these transformations collectively as Energy Efficiency 2.0. They include:

- Technological innovation
- Systems solutions
- Behavior change

These are not exclusive categories; many changes under way encompass all three drivers. In fact, some of the greatest possible energy efficiency improvements come from all three trends coming together in a given application, whether in a home, business, or factory.

Technological Innovation and Change

Energy efficiency is embracing and building upon leading-edge technologies in many areas—from end-use equipment and devices to the smart systems that are able to monitor, communicate, and control building and manufacturing systems by automatic and even learned responses. Energy-efficient technologies are becoming smarter and more attractive to customers than their often stodgy predecessors. LED lighting, smart thermostats, and mobile device apps are generating genuine consumer excitement not generally associated with energy efficiency technology. Coincident with such innovations, big data capabilities are creating a wealth of new opportunities to understand, manage, and optimize energy system use.

New devices and technologies have burst into markets previously characterized by a general lack of significant change. The Nest and other learning thermostats are one clear example. LED lighting is another, for both residential and commercial applications. Other new devices and technologies included in our analysis that show strong potential for achieving significant savings include

- Heat pump clothes dryers
- Heat pump water heaters
- Advanced lighting controls
- High-efficiency unitary air conditioners (residential and commercial)
- Smart commercial buildings
- Smart manufacturing

Two types of technological innovation and change are evident. The first is energy efficiency improvement of the component or technology deployed for a given application, such as space cooling, clothes drying, or room lighting. In some cases there are significant energy efficiency improvements in existing, conventional technologies, such as unitary air conditioners. In other cases technologies are being applied in new, unconventional ways, such as using heat pumps within clothes dryers. LEDs are a revolutionary lighting technology and are poised for rapid and sustained market growth as they offer performance and attributes superior to the technologies they replace, incandescent and fluorescent lamps.

While there are clear examples of rapid technological and associated market change, there also are more gradual, evolutionary changes occurring within building design and operations. Such changes are evident in the continued evolution of both residential and commercial building codes that address energy efficiency. Such improvements are possible through advances in building design, construction practices, materials, and operations that are capable of yielding higher building energy performance. Continued updating of building codes requiring higher energy performance ensures that the baseline energy efficiency of buildings will continue to increase while locking in the associated savings.

Toward Systems Solutions

Historically, customer-funded energy efficiency programs generally have targeted single energy efficiency technologies and devices, such as refrigerators, air conditioners, and motors. While it has long been understood that such one-off replacements or new applications are often cost effective alone and clearly are worth doing, it is often possible to achieve greater savings through improvements in entire systems and their operations, not single devices or equipment. For example, high-efficiency fluorescent lamps have been a long-standing and proven technology to reduce commercial lighting energy use. However, through the design and operation of advanced commercial lighting systems that not only make light efficiently but also control how much light is delivered to specific areas at specific times, much higher savings are possible. Such design emphasizes lighting quality and occupant needs by matching and optimizing lighting systems to those needs through application of suitable lighting technologies and advanced control systems. Customers able to make such comprehensive changes to building systems can realize significant savings.

System solutions are at the heart of several of the broad measures we analyzed that show significant operational savings opportunities. In addition to advanced commercial lighting, systems approaches are central to comprehensive building retrofits (both residential and commercial), strategic energy management, and energy performance labels for commercial and industrial equipment. For systems opportunities to be realized, efficiency program administrators will need to revisit their program and evaluation approaches and the way they view operational savings. Operational savings need to include automation savings. Innovation in program evaluation also will be needed, given that measurement and verification of system and automation savings often require going beyond conventional engineering calculations and employing other evaluation approaches, such as quasi-experimental designs.

The operation of systems is being greatly transformed and improved by the use of information and communications technologies (ICT). Such technologies—sometimes referred to as "smart" technologies—enable system optimization. ICT is capable of monitoring, communicating, and responding to real-time energy use and related data—even learning usage patterns of building occupants in order to optimize and economize the operation of key building systems. This results in more efficient operation and associated energy savings. This innovation is "intelligent efficiency," which ACEEE has defined as a systems-based, holistic approach to energy savings, enabled by ICT and user access to real-time information (Elliott et al. 2012). Perhaps the simplest example of this is a commercial lighting system that, rather than lighting an entire floor of an office when a single occupant stays late, instead delivers light only to the area where that occupant is working.

Intelligent efficiency focuses on system improvement and optimization. It is adaptive, anticipatory, and networked. At the residential scale, the primary example is the learning thermostat, such as the Nest. At the commercial scale, there are advanced controls for lighting and HVAC that can work in similar intelligent modes. The result is smart buildings, which can provide both superior performance for occupants and system benefits to utilities by better enabling them to manage and optimize system loads in accordance with demand and supply. ICT also is revolutionizing manufacturing and plant operations. Such technologies track precise, rich, and real-time data for diagnostics and system optimization. Overall, intelligent efficiency has tremendous potential for transforming numerous systems in our homes, businesses, and industries to yield significant energy savings through much higher energy efficiency (Rogers et al. 2013).

Systems approaches clearly show great potential for many types of customers and in many applications. This is not to suggest that a systems approach is always the right choice. For many types of customers, particularly smaller commercial customers with simpler building equipment and systems, single one-off replacements may be the best options in terms of cost effectiveness and practicality. Program portfolios will need to support both types of change. One-off replacements also may be a stepping stone for certain customers not quite ready to take a more strategic, long-term systems approach to managing energy use.

Beyond Technology: Behavior Change

Customer behavior is an area ripe with promise for delivering high savings. The importance of customer behavior in affecting end uses of energy has long been known. However programs historically did not take a behavioral approach beyond simplistic models of customer choice and decision making. One behavioral approach examined in this study is to provide customers with energy data in real time with dynamic pricing (prices varying by time of use). This approach has been shown to be effective in helping customers decrease their energy use and costs. A variety of technologies need to be deployed to provide such data, including smart metering, in-home displays, and mobile device software applications. Program administrators today are using a wide and expanding array of behavioral approaches to increase program participation and customer energy savings; some include pricing options, and others draw on different customer motivations (Mazur-Stommen and Farley 2013). Regulators need to adapt regulatory frameworks and rules, such as program evaluation, to accommodate these changes and other new approaches to program design and delivery.

Non-residential customers also are benefiting from technologies that provide rich, real-time data. With dynamic (time-of-use) rate structures and enabling technologies, commercial and industrial customers can manage and optimize their energy use to yield significant energy and cost savings. Clearly this is integral to many applications of intelligent efficiency. Utilities and other program administrators are establishing new types of relationships with customers, such as strategic energy management, which actively engages customers and creates long-term partnerships so that improving operations and associated energy efficiency becomes an ongoing practice rather than a series of isolated or episodic decisions and investments.

NEXT STEPS TO REACH HIGH SAVINGS

Capturing new energy savings opportunities will be challenging. For one thing, the regulatory frameworks that govern utility and related programs must change. As programs push the frontiers of new technologies and more comprehensive, systemic approaches to energy efficiency, regulators must establish frameworks and rules that support and reward these efforts. New approaches and metrics may be necessary for the evaluation of programs. Utility business models and rate structures also may need to change to support high energy savings goals.

Along with these changes, we recommend the following overarching actions and directions for utilities and energy efficiency program administrators:

- *Research markets.* Better understanding of customer needs, preferences, and behavior will help program administrators design and tailor programs to best reach and serve customers. Market research also is necessary to segment markets.
- *Complement and catalyze markets.* Innovation is advancing and new products are being developed and introduced independently of customer programs. Administrators should closely monitor such market developments to identify new opportunities and develop program approaches that support and expand such markets.
- *Support research, development, and demonstration of new and emerging energy-efficient technologies.* Many such technologies may be significantly different from existing, conventional technologies. Customers will need to gain confidence and understanding of such technologies for these markets to grow.
- *Expand eligible options within programs to include new technologies as appropriate.* Work with program partners to inform customers about new technologies and ensure that their adoption yields positive experiences.
- *Integrate and target behavioral change.* Achieving high, persistent energy savings takes more than advanced technology. Changing the way customers understand and interact with devices, systems, and entire buildings that use energy can yield significant energy savings.
- *Target systems approaches.* While device efficiency is important, in many cases greater savings and higher performance can be achieved through analysis and optimization of entire systems within buildings and factories.
- *Launch pilot programs to test new program models and explore ways to improve the cost effectiveness of some measures.* While there are numerous proven program approaches, innovation will be needed for some markets and technologies in order to increase participation and impacts.

These recommendations also apply to each of the particular measures we analyze. To reach the savings we estimate are possible for each measure, program administrators will need to build on existing programs through research, communications, partnerships, and selected pilot efforts. New program and initiatives also may be needed in some cases. Table 20-1 summarizes the next steps and priorities for each measure discussed in the preceding chapters.

Table 20-1. Key next steps by program area

Program area	Next steps
Residential appliances	1. Promote the most energy-efficient products on the market through programs as identified by the ENERGY STAR Most Efficient and Emerging Technologies designations 2. Target programs to appliance markets that have been largely untapped by energy efficiency programs, such as multifamily building common-area facilities. 3. Develop midstream program approaches to work with retailers on encouraging the sale of more efficient appliances.
Residential LEDs	1. Include, promote, and expand LED products in existing residential lighting programs. 2. Support development of the market by assuring quality and performance of LED products through ENERGY STAR and related labeling and communication initiatives.
Real-time energy use feedback and behavioral response	1. Continue to experiment with innovative programs and technologies that improve feedback to customers as they offer time-varying rates. 2. Broaden programs based on experience gained with pilot programs.
Residential smart thermostats	1. Initiate and complete pilot programs. 2. Expand pilots to full programs as appropriate, drawing on experience gained in the pilots.
Very-high-efficiency unitary air conditioners and heat pumps	Promote high-efficiency AC in hot regions and heat pump efficiency upgrades in all regions; convert electric furnaces to heat pumps. Cooling savings in other regions require local analysis as does installation of ductless heat pumps to replace electric baseboard heating units. Quality installation can result in large energy savings but active experimentation is needed to bring down costs.
Heat pump water heaters (HPWH)	Offer incentive programs for HPWH, learning from the best programs described in this report.
Residential retrofits	1. Leverage meter data to target homes based on energy use. 2. Develop programs that leverage other planned home maintenance and renovation work to incorporate energy upgrades. 3. Measure pre and post energy use data to evaluate and validate retrofit efforts. 4. Give contractors and customers information on the types of improvements that can realize the greatest savings. 5. Explore opportunities to provide financing so homeowners can complete more comprehensive retrofit projects.
New construction programs	1. Adopt current model building codes. 2. Offer programs to promote ultra-low energy use buildings. 3. Grow the state of the art of advanced energy-efficient design and construction techniques such as completing New Building Institute's (NBI) Tier 4 and conducting additional cost studies.

Program area	Next steps
Plug loads	1. Play active role in development of standards and labeling to ensure they include latest technology developments and match program goals. 2. Develop advanced incentives to bring emerging high-efficiency products and components to market and accelerate their adoption. 3. Work with retailers and other partners to address plug-load efficiency opportunities. The ENERGY STAR Retail Products Platform is one model.
Advanced commercial lighting design and controls	1. Support demonstration projects to showcase advanced lighting design and control opportunities and quantify savings in larger number of settings. 2. Pursue pilots of innovative program designs and incentives. Support new approaches to incorporating controls and actual energy performance in codes. Cost reductions may be necessary for programs to meet cost-effectiveness targets.
Advanced commercial rooftop units	Promote Consortium for Energy Efficiency (CEE) efficiency tiers as well as DOE Rooftop Challenge. Include prescriptive criteria beyond just efficiency ratings, such as items in ASHRAE 90.1-2013 and the Rooftop Challenge.
Smart commercial buildings	1. Sponsor demonstration projects for various building types to establish credibility of savings. 2. Focus commercial retrofit programs on whole buildings using systems-based intelligent efficiency applications to provide analytical rigor and technological control. 3. Participate in efforts to develop common communications and EM&V protocols for smart building controls and energy management.
Comprehensive commercial retrofits	1. Increase the number of retrofit projects by modifying programs to focus on comprehensive solutions, deep savings, and streamlined project management. 2. Develop trade allies and create strong business cases for comprehensive retrofits.
Strategic energy management (SEM) for large commercial and industrial facilities	1. Design SEM programs as part of a portfolio to meet the needs of customers in the service territory. 2. For evaluation, look to SEM not to stand on its own but to facilitate greater participation and savings from other programs. 3. Measure program performance over multiple-year periods.
Energy performance labels for C&I equipment	1. Identify equipment types that are common in a service territory and that have the potential for significant energy savings. 2. Work with trade organizations to identify more efficient equipment and collect performance information. 3. Participate in initiatives to develop performance standards and labels, and undertake pilot projects based upon them.
Smart manufacturing	1. Identify processes with the greatest opportunities for energy savings through improved control. 2. Expand programs to include controls, meters, and software as eligible assets for financial assistance. 3. Explore using the data from process control systems to perform EM&V calculations.
Conservation voltage reduction (CVR)	Gradually but steadily conduct CVR studies on each utility circuit and implement cost-effective CVR improvements.

Program area	Next steps
Combined heat and power (CHP) systems	1. States: Specify CHP as an eligible measure within clean energy portfolio standards (EERS, APS, RPS). 2. Policymakers: Consider setting targets that recognize CHP potential, and devise appropriate methods for accounting for energy savings from CHP. 3. Utilities: Develop complementary programs designed to acquire cost-effective CHP energy resources.

As evident in this table, there is much work to be done by program administrators, policy makers, and program stakeholders to achieve the savings potential for these different program areas. Strong foundations are in place in most states and regions for this next push toward high savings.

CONCLUSION

Our analysis shows clearly that the well of energy savings from energy efficiency is not running dry. Instead it is being replenished through advances in technologies and practices, system optimization, and behavioral approaches. Energy Efficiency 2.0 shows great promise to reach more customers and achieve high energy savings. Evolutionary and revolutionary changes are creating opportunities for higher levels of energy efficiency in our homes, businesses, institutions, and factories.

While our analysis reveals a wealth of new and expanded opportunities for energy efficiency, a key conclusion is that no single measure will yield a dominant share of energy savings for utility program portfolios, as have CFL programs in the past. Without a single, dominant energy-efficient technology like the CFL, utilities and other program administrators will have to rely on a wider set of measures and attract greater numbers of participants. This diversification will have many dimensions—not just expanded sets of technologies and devices, but also systems and comprehensive upgrades and applications. Diversification will also include more granular market segmentation in order to tailor programs to traditionally underserved narrow audiences, e.g., small businesses and multifamily buildings.

Diversification is just one of the signs that energy efficiency has entered a new era. High levels of savings from programs and other advances in energy efficiency have helped to dramatically reduce US electricity demand. As this study has shown, the future holds many opportunities for even greater energy savings. The cornucopia of energy efficiency will remain bountiful.

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Appendix A. Adjustment for Overlap of Energy Savings among Measures

To arrive at this figure we looked at overlaps in the residential, commercial, and industrial sectors. In the residential sector there is probably an overlap in savings between smart thermostats and providing consumers with energy use information. The sum of unadjusted savings for these two measures is 1.3% of total 2030 electricity sales. We made an educated guess and reduced the total to 1.0%. Furthermore, these two measures overlap with savings from heating and cooling improvements and home weatherization, so we further reduced the savings from smart thermostats and energy use information by 10%, resulting in 0.9% savings from these two measures.

Likewise, there is overlap in the commercial sector among smart buildings, strategic energy management, comprehensive retrofits, and lighting improvements. Together these measures sum to 4.1% savings. Our educated guess was to reduce the sum to 3.0% savings.

In the industrial sector there is overlap between strategic energy management and smart manufacturing. Savings from these measures total 2.2%, but to address the overlap, we reduced this to 1.8%. Finally, as loads go down, the savings from conservation voltage reduction (CVR) will also go down. Total savings from all measures, after the other adjustments, were 22%. Therefore, we reduced the CVR savings by the same 22% (a reduction of 0.4% of 2030 electricity consumption).

The total adjustment we made is the sum of the individual adjustments (0.3% + 0.1%+ 1.1% + 0.4% + 0.4%).

We made similar adjustments for the low- and high-savings cases, with each of the individual adjustments prorated for the higher and lower savings in these alternative cases.

These adjustments are approximate, but since each of the individual savings estimates is also approximate, our overlap adjustments are at a similar level of detail.