Future Energy Reductions in Residential Lighting

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A Report of BPA's Emerging Technologies Initiative

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A Report for the BPA Emerging Technologies Initiative

The following report was funded by the Bonneville Power Administration (BPA) to assess emerging technology topics that have the potential to increase energy efficiency. BPA is committed to identify, assess and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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Abstract

Energy savings from BPA's residential lighting program currently provide the majority of savings in the residential portfolio, yet their savings' contribution will begin to decrease in 2018 as lighting program baselines increase. Improvements in LED quality and efficacy leading to saturation of energy efficient lamps, an anticipated 2020 national standard requiring greater lumens per watt, and more stringent residential lighting building codes will create fewer savings' opportunities, reducing the amount of savings that residential lighting programs may claim. Reduction in energy use continues to be realized through use of LEDs, while the next breakthrough for greatly reducing energy use with emerging lighting technologies is not expected until at least 2025. Residential energy savings from lighting controls, whether stand alone controls, integrated or part of home automation systems, are hampered by low usage and high efficacy of residential lighting, limiting effectiveness. This paper was commissioned by the BPA to identify new technologies to ensure future residential lighting energy savings for the Pacific Northwest.

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Executive Summary

Lighting energy savings play a key role in BPA's Residential Energy Efficiency Program. Between 2015 and 2017, lighting savings grew from 43% to 72% of the total residential portfolio. This contribution will fall substantially starting in 2018 when changing baselines will cut savings by up to 60%. Anticipating these changes, BPA began evaluating alternatives to replace expected losses from the residential lighting program in 2017. This research supports the resulting strategic planning initiative to redesign the residential lighting program in response to the anticipated changes.

The objectives of this report were to understand the future state of residential lighting including how the continued growth of LEDs would impact future savings, as well as identify new technologies that could potentially replace anticipated saving losses. An extensive literature search, as well as interviews with staff from utilities, manufacturers and subject matter experts provided the content. The report has been divided into two major categories including lamps and controls. Residential lighting energy savings are identified in the Northwest for both new construction and retrofit applications. Energy efficient lighting solutions are presented for both near term savings (1 – 5 years) as well as technologies which require additional research and development for future energy savings (over 5 years).

During the next five years, potential for reductions in total residential lighting energy use will be driven by further penetration of high efficacy lamps, primarily LEDs. During this time frame, the efficacy of LED lighting is expected to continue to improve with the potential for LEDs to become twice as efficient as products currently in the market. The efficacy of LEDs currently available in the Northwest ranges from 80 to 100 lumens/watt. However, state of the art products can be found with efficacies of 200 lumens/watt. The efficacy of all products is anticipated to increase to this level in the near future with DOE targeting 200 lumens per watt by the year 2025 as the standard.

While improving, concerns about cost, light quality, flicker and dimming performance have slowed adoption of LEDs. To address these barriers consumers have purchased familiar looking halogens lamps, resulting in their market share growing from 1% in 2011 to 26% in 2016. However, the upcoming Energy Independence and Security Act (EISA) 2020 will require an efficacy of greater than 45 lumens/watt which eliminates halogens from the lighting mix. As prices continue to fall and halogen lamps are eliminated from the market, customers' expectations will demand LED lamps with good lighting and dimming performance.

The EISA 2020 federal standard, along with advancing energy codes in the Northwest, have the potential to increase the market penetration of higher efficacy lamps. New codes will raise the baseline from and diminish utilities programmatic savings. As a result, utilities may look to promote lighting products with efficacies higher than the EISA minimum. Utility incentive programs could potentially accelerate the adoption of higher efficacy LED lighting, for instance through the use of tiered incentives that provide larger incentives for more efficient products.

Increased use of lighting controls in the residential sector has the potential to increase lighting energy reductions, but energy savings are small compared to the savings potential from the expanded use of high efficacy lamps. Savings from control strategies are minimized as higher and higher efficacy lamps become the norm. DOE estimates 7% of residential lighting savings can come from controls by 2035. According to DOE and CEE, proper control of exterior lighting on homes has higher potential for savings (energy use reduction of as much as 36%) than interior residential controls.

Adding controls that include connectivity to house automation systems and/or the internet increases installation costs but has not been shown to significantly increase energy savings over savings provided by independent lighting control technologies. Connectivity does however provide the potential to create a demand response resource for utilities. Further research is recommended to validate energy savings potential and cost effectiveness.

There are interesting emerging lighting technologies that may impact the residential sector in the long term, many beyond five years. These include Organic LEDs, Laser LEDs and Quantum Dots. Currently, there is limited availability of organic LED (OLED) products for the residential sector, but cost and incompatibility with current fixtures and standard lighting design are significant barriers. Laser LEDs and quantum dots may play a role in the future (beyond ten years), but with no products generally available in the market, their application to lighting remains speculative. In addition, while these new technologies could radically impact how lighting is implemented, they do not appear to offer significant, if any, improvements in efficacy. Future efforts for these new technologies will need to focus on accelerating their development through strategic partnerships to support research and development.

It will be challenging to continue the very successful reductions in residential lighting energy use achieved in the last five years at the same pace. As more sockets are filled with low wattage, high efficacy lamps such as LEDs, opportunities for further energy savings diminish. In addition, incremental savings from reduced operating hours through lighting controls shrink as the source wattage is reduced. Finally, the rated life of the high efficacy, low wattage fluorescent and LED sources are long, resulting in low replacement rates. With these lamps remaining in sockets longer, there is limited opportunity for installation of newer, more efficient lamps.

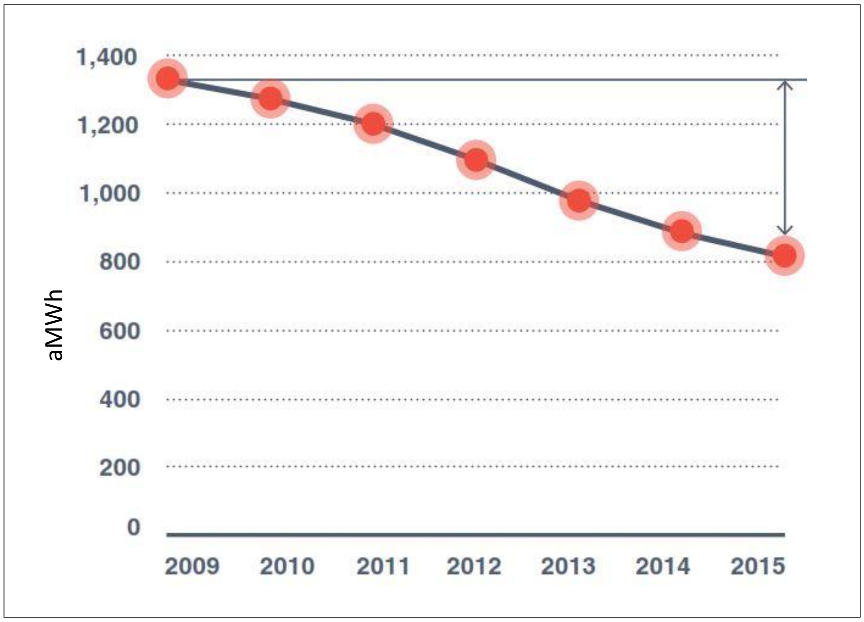
Background

Currently, there are more than 300 million lamps in Northwest homes (Navigant Consulting, Inc. 2017). Lighting is the 3rd largest residential electrical energy end use after space conditioning and domestic hot water and represents 6% of regional consumption (Northwest Power and Conservation Council).

The last ten years has been a unique period in the evolution of lighting as we have seen significant changes in the dominant lighting technologies in our homes. Almost half (46%) of all light bulbs are now either a CFL or LED compared to just 25% (all CFLs) in 2014 (RBSA, 2017). Due to the shift from inefficient incandescent bulbs to these more efficient sources, the lighting power density (watt per sq. ft.) decreased from 1.4 to 1.0 (RBSA, 2017).

These changes have been driven by three key factors: the adoption of the 2007 Energy Independence and Security Act (EISA) prohibiting the manufacture of the most common incandescent lamps between 2012 and 2014; rapid advancement in performance and decline in cost of highly efficacious light emitting diodes (LEDs); and aggressive utility programs promoting efficient lighting technologies. As a result the region has seen a large reduction in total residential lighting energy consumption from 2009 to 2015 of 39% (see Figure 1).

Figure 1. Residential Lighting Consumption Decrease from 2009 to 2015 in aMWh



Navigant Consulting, Inc. (2017). *Residential Lighting Market Characterization Study.* Bonneville Power Administration.

The lower annual residential lighting energy consumption is the direct result of the growing market penetration of higher efficacy lamps, both CFLs and more recently LEDs. Based on all the lamps shipped to the region for the years 2011 through 2015 for all applications and technologies, there was a significant reduction in average wattage and resulting annual energy consumption, as shown with the right two arrows in Figure 2. At the same time, the efficacy and rated life for the average lamp sold increased, as shown with the left two arrows in the figure.

Figure 2. Lighting Market Changes from 2011 to 2015

	EFFICACY (lumens/watt)	RATED LIFE (years/lamp)	WATTAGE (watts/lamp)	CONSUMPTION (kWh/year)
2011	16	3.6	49.7	38
	+41%	+67%	-32%	-31%
2015	22.5	6.1	33.8	27

(Navigant Consulting, Inc)

Continuing to reduce residential lighting energy consumption at the same pace as the last five years will be difficult. As more low wattage, high efficacy lamps are installed in homes, opportunities for further reduction in wattage diminish. In addition, incremental savings from reduced operating hours through lighting controls shrink as the source wattage is reduced. Finally, the rated life of the high efficacy, low wattage fluorescent and LED sources are long, resulting in low replacement rates. With these lamps remaining in sockets longer, there is limited opportunity for installation of newer, even more efficient lamps.

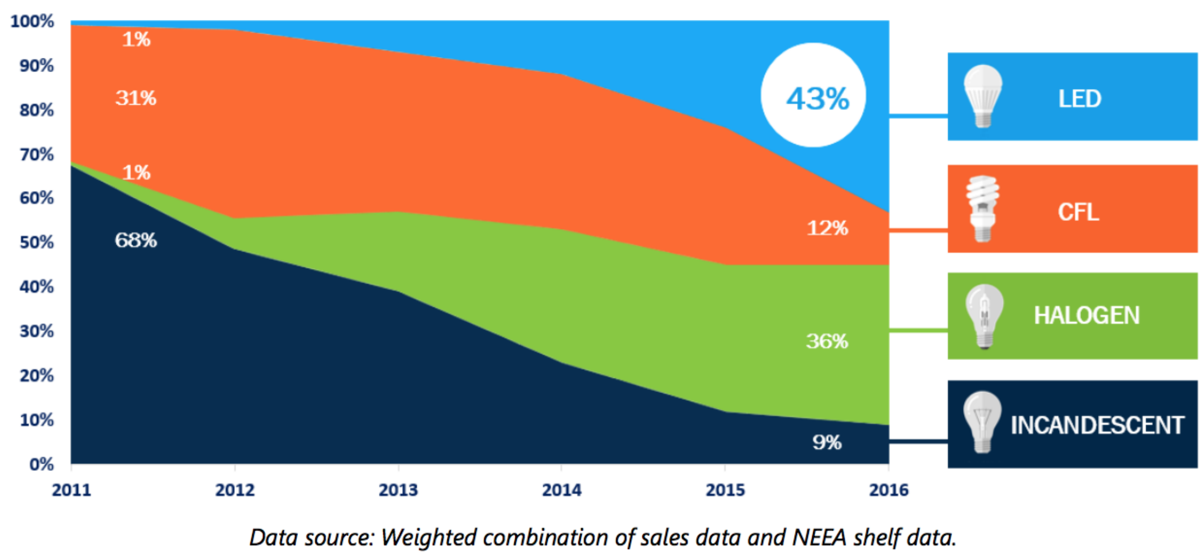
Market Characterization

BPA completed its' most recent Residential Lighting Market Study (Navigant Consulting, Inc) in May 2017. This report documents market conditions and trends in the Northwest and illustrates the magnitude of the LED revolution as these lamps have surged into the high efficacy part of the market displacing CFLs. Similar to LEDs, halogen lamps have surged into the low efficacy market displacing the once dominant standard incandescent lamps but with only minimal improvement in efficiency and no improvement in rated life. These changes have been most pronounced in general service lighting as a result of the EISA 2007 legislation.

Specialty lighting, which includes decorator, reflector, globe, 3-way, appliance and rough duty lamps among others, is currently exempt from EISA 2007 requirements. However, incandescent lamps in this category will be phased out once the 2020 EISA rulemaking goes into effect on January 1, 2020. Until recently, the availability of high efficacy LED and fluorescent lighting options for specialty lighting has been limited. However, in anticipation of the EISA 2020 the technology has advanced and specialty LED lamps are now becoming more readily available.

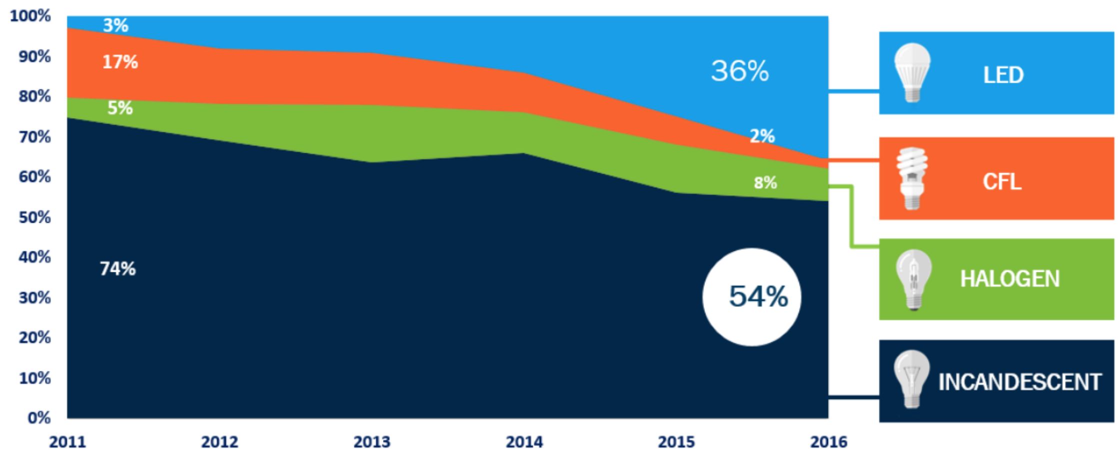
Figures 3 and 4 show the units sold in the Northwest region for general purpose and specialty lamps.

Figure 3. General Purpose Lamps - Technology Shares, 2011-2016



Source: 2016-2017 Northwest Residential Lighting Long-Term Monitoring and Tracking Study, Oct 19, 2017 REPORT #E17-357

Figure 4. Specialty Lamps - Technology Shares, 2011-2016



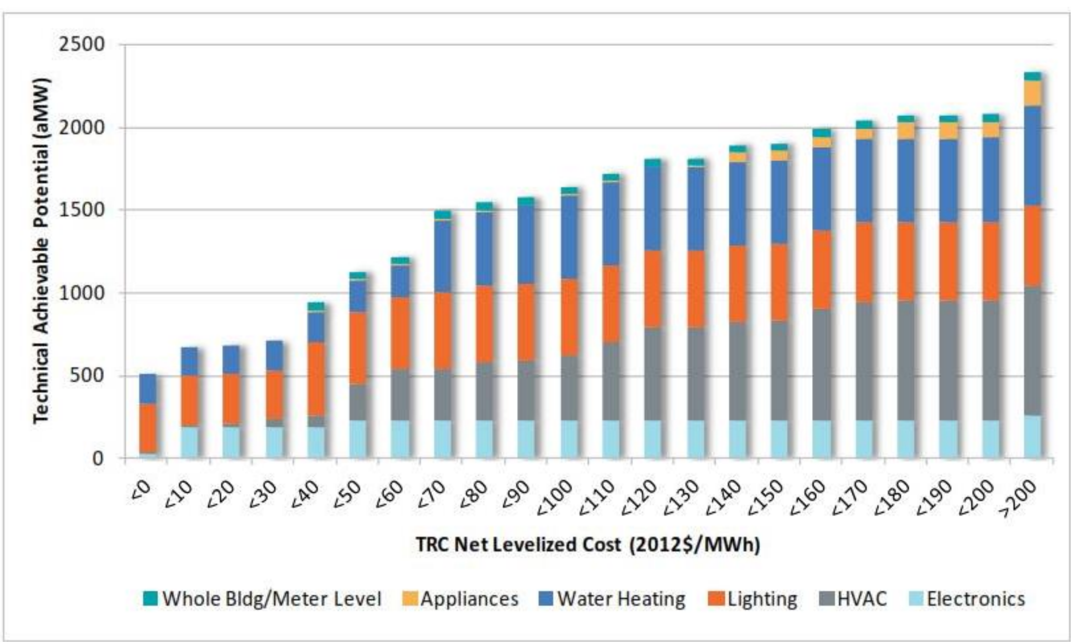
Data source: Weighted combination of sales data and NEEA shelf data.

Source: 2016-2017 Northwest Residential Lighting Long-Term Monitoring and Tracking Study, Oct 19, 2017 REPORT #E17-357

Regional Technical Potential

The 7th Northwest Power Plan (Northwest Power and Conservation Council), adopted February 10, 2016, identifies lighting as providing the second highest potential savings in the residential sector with 484 average megawatts, most of which is available at less than $0.07/kWh. The potential is identified as being driven by the advent of low cost solid state lighting (LEDs) and was based on projections from PNNL (PNNL) completed in October of 2013 and included projected improvements in costs and efficacy of LEDs through 2017 (see Figure 5). This estimate does not include additional potential savings from residential lighting controls.

Figure 5. Residential Potential by End-use and Levelized Cost by 2035



From NWPCC 7th Power Plan

Methods

The objective of this report is to provide an understanding about current and future residential lighting technologies and their impact to the BPA residential lighting program. Profiles have been created for residential lighting technologies (both current and future) using the following characteristics: future technical potential (energy savings); product features; availability; cost; and market, product and program readiness levels. This information has been divided into two categories –lamps and controls. This information will be used by BPA to revise the Residential Lighting Program to deliver future energy savings for the Pacific Northwest.

In order to complete this assignment, WSU performed an extensive literature search, as well as interviews with staff from utilities, manufacturers and subject matter experts. The list of organizations interviewed includes: Lighting Design Lab, Lighting Research Center – Rensselear Polytechnic Institute, Northwest Energy Efficiency Alliance, CLEAResults, Design Lights Consortium, Consortium of Energy Efficiency, Electric Power Research Institute (EPRI) and BPA. The complete list of experts is included in Appendix B. A complete list of reviewed sources is provided in Appendix A.

Findings

Lighting Technologies

Potential Savings

Within the next two to five years, it is anticipated that the largest savings in residential lighting energy will be realized from the continued penetration of higher efficacy lamps, specifically LEDs. The DOE September 2016 publication, Solid State Lighting Report Summary: Energy Savings Forecast of SSL in General Illumination, projects that 93% of future residential lighting sector energy savings through 2035 will be from utilization of higher efficacy lamps. DOE projects that 86% of all residential lighting will be LEDs by 2035 (Building Technologies Office).

In the Northwest, residential demand reduction from high efficacy lamps is estimated at 484 average megawatts based on Northwest Power and Conservation Council (NWPCC) projections in the 7th Power Plan.

Current studies indicate large numbers of inefficient lamps continue to be sold in the Northwest. Through 2016, lower efficacy halogens and incandescent lamps comprised 45% of general service lamp sales in the Northwest (Navigant Consulting, Inc). Halogen and incandescent sources comprised 62% of specialty lamp sales (decorative, reflector, globe, and 3-way) (Navigant Consulting, Inc). Significant energy savings could be achieved through converting these lamps sales to high efficacy sources.

It is also important to note that significant continued improvement in the efficacy of LED lamps of all types is predicted in the next few years. In 2016, the U.S. Department of Energy (DOE) (Building Technologies Office) estimated that the "highest performing LED devices can produce 160-170 lumens/watt; DOE projects that a target of 255 lumens/watt can be achieved". In 2017 Phillips started marketing the "Dubai Lamp" (Philips) in the United Arab Emirates with a reported efficacy of 200 lumens/watt in three lamp sizes (1 W, 2W, 3W) designed to replace 25W, 40W and 60W incandescent lamps respectively. The Dubai Lamp is roughly twice as efficient as the typical LED lamp sold in the US today. Focus on promoting these higher efficacy lamps would maximize potential energy savings.

The expected life of LED sources is ten years or more in residential applications. This suggests currently installed LED lamps will remain in sockets for many years providing persistent savings. Paradoxically, this could potentially slow the replacement of older less efficient LED lamps with future higher efficacy products. Because LED lamps will remain in sockets for many years, utilities should encourage the use of the most efficient products on the market, with program adjustments as the technology advances to always promote the most efficient products available including continued incentives for higher efficacy LEDs.

Barriers to LED Growth

While improving, concerns about cost, light quality, flicker and dimming performance are presumed to have at least in part slowed the adoption of LEDs. Barriers both real and perceived continue to limit LED sales and support the sale of halogen lamps, which do not exhibit the same drawbacks. Key barriers include: competitive products; higher prices; poor light quality; and flicker performance issues.

Competitive Products

Initially, LED sales were limited by high prices and consumers looked for cheaper efficient lighting alternatives. Lower cost halogen lamps which also addressed light quality and flicker performance issues entered the market. The ready availability and appeal of halogen lamps slowed the adoption of LED alternatives. Halogen lamp sales grew from 1% of the general service lamps in 2011 to 36% in 2016 (Navigant Consulting, Inc). For the typical consumer, halogen lamps looked and performed the same as the lower efficacy traditional incandescent lamps and were lower cost than CFL and LED lamps. It is expected that halogens will maintain in this position until January 1, 2020, when new standards calling for 45 lumens per watt, will make it illegal to sell most halogen and incandescent lamps in the U.S.

High Prices

LED lamps and fixtures are typically more expensive than lamps and fixtures using fluorescent and incandescent. However, the cost of LEDs has been dropping rapidly. In particular, the cost of LED general service lamps purchased in multipacks at big box stores are now much more competitive.

Poor Light Quality

Poor light quality as perceived by consumers has long been recognized as a barrier to market acceptance. Light quality is most commonly referenced in terms of CRI (Color Rendering Index). Limitations of CRI as a metric have long been recognized and the industry has struggled to develop more effective standards. In 2015 a new standard IES TM-30 was introduced (Energy Efficiency & Renewable Energy), however this standard has not been widely adopted. To help assure consumer satisfaction with LED products, it will be important to promote products with good color quality.

In addition, minimum requirements for color quality should be considered. For example, Energy Star requires a minimum CRI of 80 for LEDs. Another standard, the California Quality Lighting Specification, requires a CRI of 90.

Flicker

Concern about flicker is another barrier to widespread adoption of LEDs. The most basic definition of flicker is a modulation of light; light levels fluctuate high to low and back to high. Sometimes this modulation of light happens at a slow enough rate that it is visible. Often with LED and fluorescent sources, this modulation happens at a very high frequency, so it can only be detected when there is movement relative to the eye and the light source. This is called stroboscopic flicker. Even though stroboscopic flicker is not directly visible, it may cause people who work under such light to experience more subtle effects of this flicker, including headaches, eye strain, and discomfort.

LED lighting sources require a driver to convert AC current to DC and flicker can result from the use of low quality drivers. . Flicker is more of an issue when LED lamps are dimmed. LED dimming performance is a function of both the quality and capability of the driver and compatibility with the dimmer. The cost of the driver is a significant part of the total cost of an LED lamp and using a quality driver that completely eliminates flicker increases product cost.

Dimming in the real world can be challenging and can be an additional barrier to acceptance. First not all LED lamps are designed to be dimmable. Therefore, it is essential that consumers choose lamps that the manufacturer describes as 'dimmable'. Secondly, there is a wide variation in the characteristics of different LED sources and different dimmers. It is important for consumers to use a dimmer designed for use with LED lighting. Most major lighting manufacturers publish lists of dimmers that are compatible with their products.

The National Electrical Manufacturers Association (NEMA) is initiating a LED Dimming Compatibility Program. This is a voluntary program through which lamp and control manufacturers can label their products as dimming compatible with the logo shown below. When the logo appears on the package, consumers know that the LED bulb or dimmer inside has been designed to be compatible with dimmers or bulbs that have the same logo on their package.

Figure 6. NEMA LED Dimming Compatibility Logo

Technology Overview

The following section of the document provides an overview of various lighting technologies. The technologies are presented across three categories depending on different development phases: currently in the market place; near term emerging technologies expected to enter the market in the next 2 – 5 years; and long term emerging technologies expected after five years.

Current (and continuing) technologies are available in the market today and are expected to continue contributing significant energy savings over the next two years. These include LED general service A-line lamps, LED specialty lamps, linear LEDs, LED exterior lighting, and dedicated fixtures.

Near term lighting technologies may have recently entered the market place, have a small adoption rate and are expected to mature over the next 2 – 5 years. In most cases energy savings and cost effectiveness for these technologies have not been validated. These technologies include OLEDs.

Long term technologies are in the Research and Development Phase of development with expected market entry defined as being five years or more. These technologies are still in the proof of concept stage and include Laser Diodes and Quantum Dots. Expected applications and energy savings are currently unknown.

Information about two additional power distribution technologies that are related to lighting, Power over Ethernet and DC Power Distribution, are provided in Appendix D. While these technologies do not provide direct lighting energy savings, their implementation may provide more efficient means of powering high efficacy lighting systems.

Technologies have been profiled using the characteristics in the following table.

Table 1. Characteristics and definitions used in report

Characteristics	**Definition**
Technical Potential	What are the expected savings if the technology is fully deployed within the Pacific Northwest?
Applications	Where and how are technologies utilized?
Product Features	What are the unique characteristics of the technology?
Availability	Where are the technologies offered?
Energy Savings	How much energy savings are associated with the use of this technology?
Cost	How much do the technologies costs?

The Regional Emerging Technology Advisory Committee (RETAC) made up of public and IOU utilities in the Pacific Northwest facilitates collaborative activities to identify, prioritize and assess emerging technologies. The RETAC has proposed a series of scales to identify readiness across three different levels: market or commercial readiness – how available is the technology; product readiness – has the technology been validated; and program readiness – has the cost effectiveness of the technology been assessed. Each readiness criteria has 1 – 6 different levels as defined as follows.

Table 2. Readiness Level Score Definitions

Market/ Commercial	**LEVEL 1:** Not commercially available or limited, pre-commercial availability **LEVEL 2:** Commercially available outside of NW. Requires special order in NW. **LEVEL 3:** Commercially available in NW from one manufacturer through standard channels. **LEVEL 4:** Commercially available in NW from at least two manufacturers. Stocked throughout region. **LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 1:** Concept not yet validated **LEVEL 2**: Concept validated **LEVEL 3**: Limited Assessment **LEVEL 4:** Extensive Assessment **LEVEL 5:** Comprehensive Analysis **LEVEL 6:** Approved for Implementation
Program	**LEVEL 1:** No program design. No risk assessment. **LEVEL 2:** Not cost effective, but preliminary analysis shows a pathway to CE. Limited program design and risk assessment. **LEVEL 3:** Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots. **LEVEL 4:** Marginally at cost effective levels. Program design complete, larger scale pilots underway. Well-developed risk assessment. **LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

Technical potential estimates for the current and continuing technologies were developed by staff from the NWPPC. As part of their mission, the NWPPC prepares periodic regional power plans that include development of technical potential for energy efficiency technologies. The technical potential estimates provided for this paper are **rough** estimates, and are not intended to represent what will be in the Power Plan. However, having the NWPPC provide technical potential for this paper will provide consistency in the analysis and data sets.

The technical potential estimates account for the impacts of the 2020 EISA standard that will raise the baseline efficacy to 45 L/watt and represent long-term savings potential. For A-lamps and specialty lamps, the near term potential could be up to five times higher. However, this higher level of savings will only be available to utility programs until January 1, 2020 when the new EISA standards go into effect.

In addition, the estimates reflect recent findings from RBSA II (RBSA, 2017) that show the saturation of LED lighting in homes is approximately 20%. The savings per bulb is based on recent work by the Regional Technical Forum that developed a "current practice" bulb for use as the baseline. A current practice bulb is defined as the bulb the customer would have *purchased* in the absence of an energy efficiency program and includes a mix of all bulb types (halogen, CFL, LED).

Finally, it should be noted that the technical potential estimates for individual technologies are not mutually exclusive. For instance, a portion of the technical potential for exterior lamps will come from replacement of general service A-lamps. Therefore, these savings are included in the technical potential for both exterior lighting and general service A-lamps.

Since there is so much uncertainty regarding newly emerging and R&D technologies, no estimates of technical potential were developed for these technologies.

Current and Continuing Lighting Technologies

Efficient LED sources are currently supported in NW efficiency programs and are expected to continue contributing significant energy savings over the next two years. Continued improvement in the efficacy of LED lamps of all types is predicted in the next few years. Potential energy savings could be maximized through a utility focus on promoting these higher efficacy lamps, for instance through tiered incentives.

General Service A-Line Lamps

The most familiar and available LED lamps in the residential market are general service lamps configured to replace standard Edison base lamps. Currently available LED lamps are significantly more efficient than incandescent lamps, providing energy savings of up to 80%. LED lamps are about 25% more efficient than CFL lamps and provide superior light quality. In addition, LED lamp life can range from 10,000 to 25,000 hours, as compared to 1,200 hours for incandescent lamps and 8,000 hours for CFL lamps.

There is a variation in quality of LED lamps. Costs are higher for lamps that provide good color quality, good dimming performance and long lamp life. Filament LED lamps are a type of general service A-line lamp that are typically used in decorative settings. These lamps are becoming widely available with high efficacy and lower costs and consumer interest is strong driven by the unique look and style.

Technical Potential: 35 aMW

Applications: Residential fixtures that have an Edison base suitable for screw in lamps.

Product Features: Lamps are available with various lumen outputs and in various color temperatures. Dimming and non-dimming versions are available.

Availability: Readily available through all consumer channels: big box stores, hardware stores, online.

Energy Savings: LED lamps use about 80% less energy than standard incandescent lamps; about 30% less than CFLs.

Cost: LED lamps cost somewhat more than standard incandescent halogen lamps, but costs continue to decline and can be competitive when purchased in multi-packs. Costs are higher for LED lamps that provide good color quality, good dimming performance and long lamp life.

Readiness Levels:

Category	Scores
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 6:** Approved for Implementation
Program	**LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

LED Specialty Lamps

Specialty lamps is a broad category that generally refers to lamp types other than standard A-line Edison screw base lamps and include reflector, globe and candelabra light bulbs. Because standard A-line lamps represent the largest market share, manufacturers of LED lamps originally focused attention on development of these lamps and LED specialty lamps were not commonly available. As the A-line lamps have become readily available with good quality and low price, manufacturers have shifted attention to the introduction of LED specialty lamps. LED versions of numerous specialty lamp types are now becoming readily available and the number of Energy Star approved products is growing rapidly.   As with A-line LED lamps, the efficiency of the LED specialty lamps is far superior to the efficiency of the incandescent versions, providing the opportunity for significant energy savings.

Technical Potential: 51 aMW

Applications: Residential fixtures that use replaceable lamps with other than an Edison base. These include fixtures that use reflector, globe and candelabra light bulbs with various screw base sizes, such as candelabra (E11) and medium screw (E26) and with pin bases such as GU4 and GU10.

Product Features: Lamps are available in a large variety of sizes and shapes to fit a variety of applications. Lamps come with various lumen outputs and in various color temperatures. Dimming and non-dimming versions are available.

Availability: LED specialty lamps are becoming readily available through most consumer channels: big box stores, hardware stores, online.

Energy Savings: LED lamps use about 80% less energy than standard incandescent lamps; about 30% less than CFLs.

Cost: The cost of LED specialty lamps is typically higher than the equivalent standard incandescent and halogen lamps. Costs are higher for LED lamps that provide good color quality, good dimming performance and long lamp life

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 6:** Approved for Implementation
Program	**LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

LED Linear Lamps

Based on the Residential Building Stock Assessment (RBSA) developed by NEEA, 11% of lamps in single family homes in the Northwest are in linear fluorescent fixtures typically located in shops, garages, basements and kitchens (David Baylon). Linear fluorescent lamps are also found in multifamily facilities in common areas and garages. The majority of these linear fluorescent lamps are T8/T12 fluorescent lamps drawing 32 W to 40 W. LED linear replacement lamps currently in the market can provide energy savings of 40 – 45% at competitive prices. Current data on market penetration of linear LED replacement lamps has not been found.

However, for these it is important to confirm the compatibility of the existing T8 fluorescent ballast and the new linear LED T8 replacement lamp. LED tube replacement lamps come in a variety of configurations. Some require rewiring fixtures and installation should be done by a qualified electrician. Others are plug and play and can be installed without rewiring. Attention needs to be paid in retrofit applications to ensure proper and safe installation.

Technical Potential: 2.7 aMW

Applications: Residential fixtures that use linear fluorescent lamps. These are most often found in garages, closets and utility rooms.

Product Features: LED linear replacement lamps are available in a variety lumen outputs and in various color temperatures. Dimming and non-dimming versions are available. Lamps have different installation configurations with some requiring rewiring of fixtures and others being are plug and play.

Availability: LED linear replacement lamps are becoming readily available through most consumer channels: big box stores, hardware stores, online.

Energy Savings: LED linear replacement lamps currently in the market can provide energy savings of 40 – 45%

Cost: The cost of LED linear replacement lamps is typically higher than fluorescent versions. Costs are higher for LED lamps that provide good color quality, good dimming performance and long lamp life**.**

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 6:** Approved for Implementation
Program	**LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

LED Exterior Lighting

Based on 2012 findings, the average exterior lighting power in a Northwest home is 227 W (Poppy Storm). Based on the RTF Residential Building Stock Assessment (2014 RBSA) metering the average hours of use for exterior lighting in Northwest homes was 3.7 hours per day (Ecotope). This is the highest average hours of use for lighting in any location in a typical home.

LED replacement lamps with built in photo sensors are readily available and are an easy upgrade for existing homes. Alternatively, outdoor lights can be replaced with new fixtures with a built in photo sensor control.

Technical Potential: 19 aMW

Applications: Exterior porch and security lighting.

Product Features: New fixtures with integrated LED sources are available in a wide variety of styles, mounting types, lumen outputs, and color temperatures. These are available with integrated photo sensors and motion sensors. Alternatively, LED replacement lamps with integrated photo sensors can be used in existing fixtures.

Availability: Readily available through all consumer channels: big box stores, hardware stores, online.

Energy Savings: Exterior fixtures with LED sources use about 80% less energy than fixtures with standard incandescent lamps; about 30% less than fixtures with CFLs.

Cost: The cost of exterior fixtures with LED lamps is comparable to the cost of exterior fixtures using incandescent and fluorescent sources. Cost varies widely and is more a function of style and housing material, rather than light source.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 6:** Approved for Implementation
Program	**LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

Dedicated Fixtures

Dedicated fixtures that use integrated LED sources are widely available. Well-designed dedicated LED fixtures, those that have been designed from the ground up to incorporate LED sources, can provide benefits over the use of LED replacement lamps in fixtures that were designed for incandescent and fluorescent sources. For instance, dedicated LED fixtures can more effectively accommodate the directionality of LED emitters, provide improved thermal management, include higher quality drivers and incorporate integrated controls.

Dedicated LED fixtures are sometimes more expensive than fixtures using traditional sources, although this cost premium is not large and is dropping as the cost of LEDs continues to decline. In existing homes, it is still typically much less expensive to replace a lamp with an LED lamp than to replace the entire fixture. The incremental cost of dedicated LED fixtures is small, making them more suitable for new construction applications.

Technical Potential: 89 aMW

Applications: All residential lighting applications.

Product Features: New fixtures with integrated LED sources are available in a wide variety of styles, mounting types, lumen outputs, and color temperatures.

Availability: Readily available through all consumer channels: big box stores, hardware stores, online.

Energy Savings: New fixtures with LED sources use about 80% less energy than fixtures with standard incandescent lamps; about 30% less than fixtures with CFLs.

Cost: The cost of dedicated LED fixtures is sometimes higher, but often comparable to, the cost of new fixtures using incandescent and fluorescent sources. Cost varies widely and is more a function of style and materials, rather than light source.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 6**: Approved for Implementation
Program	**LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

Future Lighting Technologies

In addition to the efficient lighting technologies that are established and available today, research and development of other efficient lighting technologies continues. These technologies are in various states of development, with technical viability and widespread availability at competitive costs not expected for at least 5 to 10 years.

Due to the anticipated initial high cost of market-available products, initial adoption will likely take place in commercial applications. If and when costs decline, these technologies may find applications in the residential market. It is recommended that utilities monitor these technologies and reassess viability for the residential market as the technologies advance. Future efforts for these new technologies will need to focus on accelerating their development through strategic partnerships to support research and development.

Near Term Two – Five Years

OLEDs

OLEDs are light emitting diodes in which the emissive electroluminescent layer is a film of organic compound that emits light when excited by an electric current. OLED lighting panels were first mass produced in 2011 and OLED lighting panels are now available from a number of manufacturers however, production volumes are small. They are a growing part of the TV and display market and a major area of research in the development of white OLED devices for use in general illumination applications.

Advantages: OLEDs offer advantages over regular LEDs primarily in relation to lighting quality and new alternatives for lighting design. They can uniquely produce large area panels as light sources.

Potential Barriers: Current efficacies (50 lumens/watt) are comparable to CFLs far behind current LEDs. In addition, OLEDs require dedicated fixtures and don't provide a one for one screw-in replacement that can be used in existing fixtures.

Outlook: With the current high cost, it is likely that OLEDs will first be adopted in commercial applications, with early residential applications limited to high-end residential new construction. The potential to drive significant near term energy savings in the residential sector seems low.

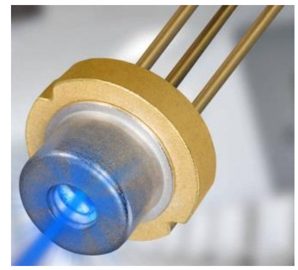
Readiness Levels:

Category	**Scores**
Market/Commercial	**Level 1:** Not commercially available or limited, pre-commercial availability
Product	**Level 2:** Concept validated
Program	**Level 1:** No program design. No risk assessment.

Long Term Over Five Years

Lighting technologies with significant uncertainty regarding technical viability and application in the residential market include laser diodes and quantum dots. Widespread availability is not expected for at least 5 to 10 years.

Laser Diodes



Shuji Nakamura, Nobel Laureate for his contributions to the invention of blue LEDs, says, "The laser, we believe, is the next generation of lighting, even for general applications such as homes, businesses, and a variety of displays". Laser diodes do not fit a marketing model of a transition to a new replacement A-Lamp but rather offer a powerful, high density, efficient light source that could revolutionize lighting design. Laser diodes are currently the most common type of laser with wide applications in telecommunications, measuring devices, scanners and many other applications. Lighting applications have been very limited to specialty applications.

Advantages: The best laser diodes have similar efficiencies to current LEDs. The advantage of the laser diode is that it can function with much higher power inputs literally producing a 1000 times as much light from a single diode. Steven DenBaars, a research scientist at UC Santa Barbara, envisions using small numbers of powerful lasers and redirecting the light into fiber optic cables and other waveguides that would evenly distribute the light as a warm diffuse glow. A single intense source of light could be used in this way to create a diffuse glow that could appear to emanate from entire surfaces of rooms or light fixtures of any conceivable shape (Mims).

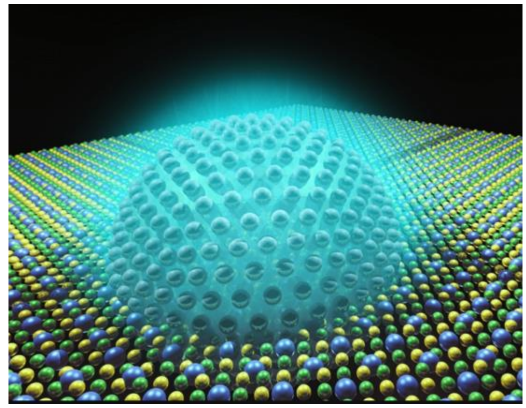
Potential Barriers: Barriers to market introduction are high and utilization would almost certainly begin with commercial application before residential. Efficiency is high but on a lumen to lumen basis only comparable to existing LEDs and the potential for additional reductions in residential lighting energy use probably low.

Outlook: Competitive products appear to be at least 5-10 years in the future and their acceptance will be based on possible advantages to lighting quality and design.

Readiness Levels:

Category	**Scores**
Market/Commercial	**Level 1:** Not commercially available or limited, pre-commercial availability
Product	**Level 1:** Concept not yet validated
Program	**Level 1:** No program design. No risk assessment.

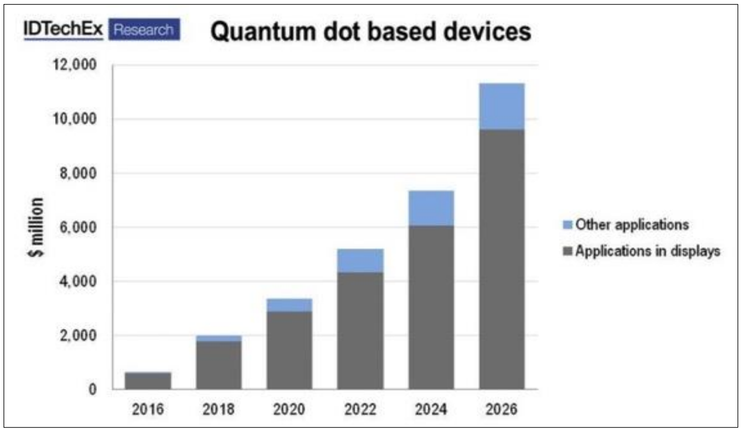
Quantum Dots



Quantum dots are very small (typically 2-10 nanometers) semiconductor particles many of which will emit light of specific frequencies if electricity or light is applied to them. They are a central component in the expanding world of nanotechnology first identified in 1986. Research underway is exploring applications in quantum computing, studying intercellular biological processes, improved photovoltaic devices, photodetectors, photo catalysts, and light emitting devices.

Advantages: Potential advantages to using quantum dots in lighting systems are unclear at this point in the technology development**.**

Figure 7. Projected sales of different quantum dot based devices



Potential Barriers: Potential barriers to using quantum dots in lighting systems are unclear at this point in the technology development**.**

Outlook: Quantum dots represent the newest of emerging technology but could produce improvements in LEDs and/or laser diodes in the next 5-10 years. The potential impact on general lighting remains undetermined but should be monitored.

Readiness Levels:

Category	**Scores**
Market/Commercial	**Level 1:** Not commercially available or limited, pre-commercial availability
Product	**Level 1:** Concept not yet validated
Program	**Level 1:** No program design. No risk assessment.

Residential Lighting Controls

Lighting savings from the use of controls comes from either a reduction in the hours of use or a reduction in power. Lighting controls generally fall into two categories: traditional stand alone controls and connected controls. Savings for residential lighting controls have traditionally been provided by stand-alone controls, such as vacancy/occupancy sensors, dimmers, timers and photo sensors.

With the introduction of the Internet of Things (IoT), consumers have new capabilities to control their environment and access conveniences considered unimaginable just a decade ago. Connected lighting controls offer solutions for improved security, convenience and comfort. Today consumers can turn lights on and off, dim them and change the color of the lighting all through smart phones or tablets. With technology advancements, connected "smart" lighting controls are becoming more widely available including being incorporated into Home Energy Management Systems (HEMS) that provide users with information, feedback and/or control of household energy usage.

For the purpose of this paper, the market for residential lighting controls and the rapidly evolving connected control technologies has been broken down into two categories:

1. Traditional standalone controls including vacancy and occupancy sensors, dimmers, timers, and photo sensors
2. Connected controls both
    a. lighting specific for lamps, fixtures and switches; and
    b. implemented as part of a complete HEMS as part of the larger Internet of Things.

Potential Savings

In September 2016, DOE estimated 7% of future savings in the residential sector would come from controls through 2035 (Building Technologies Office). While the study identified much larger savings from controls in the commercial, outdoor and industrial sectors, savings from lighting controls in the residential sector is limited because of the relatively low baseline average hours of use.

As with the lamp technologies, staff at the NWPCC developed a technical potential estimate for residential lighting controls. Given the lack of specific data for the NW, the estimate was developed using the DOE estimate of 7% savings from controls, which results in a technical potential of 18.5 aMW for all residential controls combined.

Average residential hours of use by lamp location shown in Table 3 were documented in the Northwest Regional Technical Forum's Residential Building Stock Assessment (RBSA 2014). Interior residential lighting averages less than two hours of use per lamp per day while exterior residential lighting averages 3.7 average hours of use per lamp per day.

Increased penetration of high efficacy, low wattage lamps further reduces the potential energy savings from lighting controls that reduce hours of use.

Table 3. Residential Lighting Hours of Use (HOU) by Room Type

Room	Hours/day
Bedroom	1.4
Master Bedroom	1.1
Bathroom	1.2
Closet	0.08
Dining Room	1.9
Exterior	3.7
Family Room	3.3
Garage	1.1
Hall	2.0
Kitchen	3.6
Laundry Room	1.5
Living Room	2.8
Office	1.8

Barriers to Adoption of Controls

While traditional standalone and connected lighting controls have the potential to provide energy savings, issues such as cost, compatibility and complexity, and standby loads are barriers to widespread adoption.

Cost

The cost of traditional standalone controls, such as occupancy sensors and dimmers, is relatively low. However, if a homeowner is not comfortable installing these devices on their own, hiring an electrician could add significant cost.

The cost of connected lighting controls is currently high. Even the simpler smart devices, such as smart lamps and smart switches, cost significantly more than similar devices that do not include connectivity. When considering a larger, whole home energy management system to control lighting, costs can range from several hundred to several thousand dollars.

Compatibility and Complexity of Connected Controls

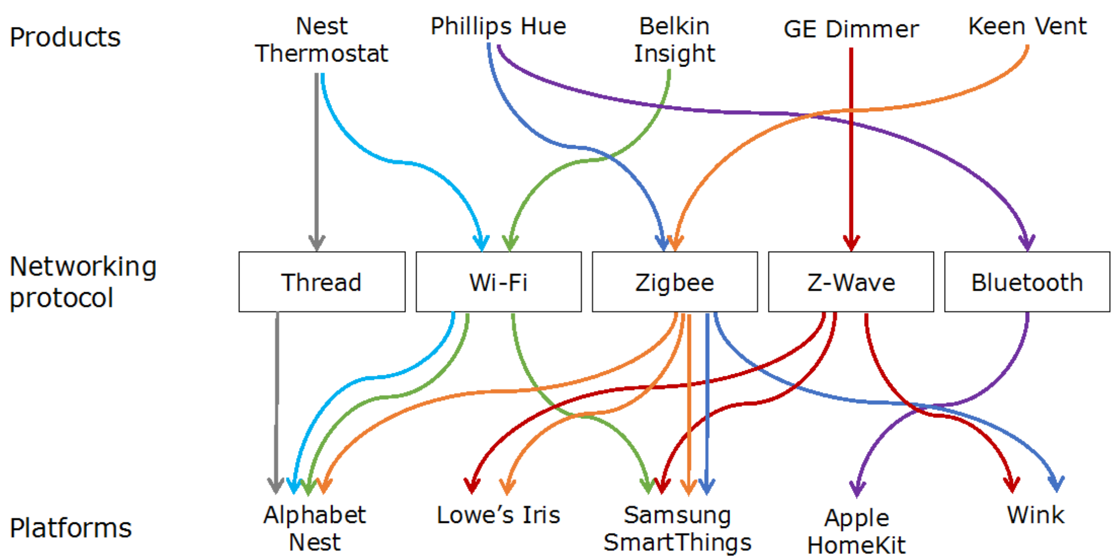
A recent report completed by PG&E's Emerging Technologies Program (Ford, 2016) provided a comprehensive review of home energy management systems (HEMS), including a discussion of compatibility and complexity issues. A brief excerpt from the report is provided here, and readers are encouraged to read the full report for more detail.

Understanding which products work together, how exactly they can work together is a moving target as the HEMS, smart home, and IoT industries are rapidly evolving. For example, is their interaction limited to simply being accessed via the same energy portal? Or are users able to set integrated schedules or rule-based control so events or data from one Home Energy Management (HEM) technology can be used to control another? Compatibility and complexity of connected controls are challenges to be resolved over the next five years.

Further confusion arises due to the lack of standardization of smart home network protocols (e.g., ZigBee vs. Z-Wave vs. Wi-Fi). Also, consumer media often confuses protocols (e.g., Bluetooth) with smart home platforms (e.g., Wink). The former strictly describes the type of network protocol the device uses, whereas multiple network protocols can still be integrated into a smart home platform, either using a hub to translate between them or via a system than can communicate across all of these protocols.

At the same time, two HEM technologies that speak the same network protocol could still be non-interoperable because the higher software layers are not compatible. This is illustrated in Figure 8, showing how HEM technologies (on top) use different wireless protocols (the middle) and are compatible with different smart home platforms (bottom).

Figure 8. Integration and Interoperability within HEMS Technologies



Standby Loads of Connected Controls

Another potential barrier is the "hidden" energy cost to provide connectivity generally referred to as standby loads. In order to respond to remote control, smart devices must remain powered in standby mode and are never completely off, increasing the total energy usage of the lamp. The stand-by load can significantly impact the potential energy savings provided by the control functions of a connected smart lamp. This is because the standby load is consumed 24 hr/day, while average lighting operation in residential applications is around two hr/day.

For Energy Star certification of Smart Lamps, the maximum allowable standby power is 0.5 W. There are products in the market that easily meet this requirement with standby power draws as low as 0.1 W. However, when additional sensors are included to sense motion or light levels the standby loads increase and many products have standby loads closer to the 0.5 W level. For example, consider the case of a typical 10 W LED residential lamp operating two hours/day, compared to a smart lamp with 0.5 W standby load and total 10.5 W consumption when on. The total energy use for three situations is calculated below with the results shown graphically in Figure 9 below.

<u>Baseline Energy Use</u>

10 W/hr * 2 hr/dy = **20 W-hr/dy**

<u>Smart Lamp with No Reduction in Hours of Use</u>

10.5 W/hr* 2 hr/dy + 0.5 W/hr * 22 hr/dy = **32 W-hr/dy**

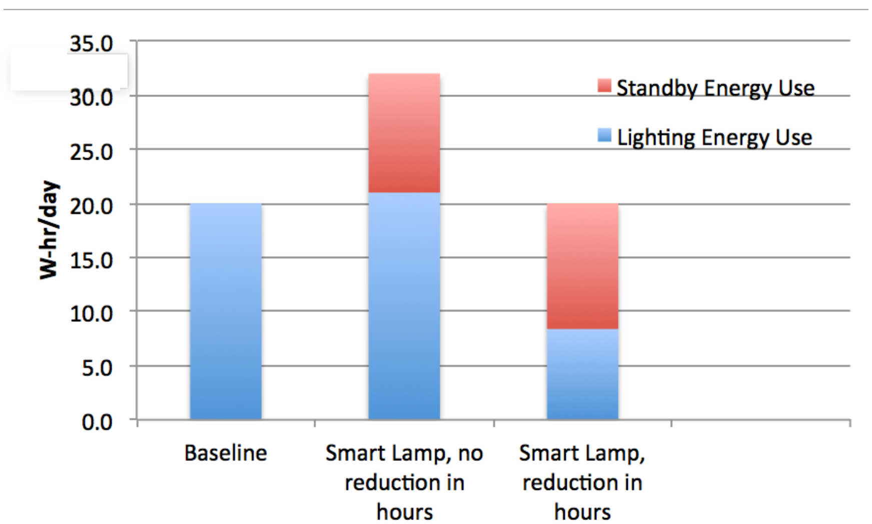
<u>Smart Lamp with Reduction in Hours of Use</u>

Assume lighting hours of operation are reduced to 48 min/day (0.8 hr/day)

10.5 W/hr* 0.8 hr/dy + 0.5 W/hr * 23.2 hr/dy = **20 W-hr/dy**

For the smart lamp to consume the same energy as the standard LED, the hours of operation would have to be reduced by 60% to 0.8 hr/day. To deliver savings, the hours would have to be reduced even further.

Figure 9. Standard LED compared to Smart LED

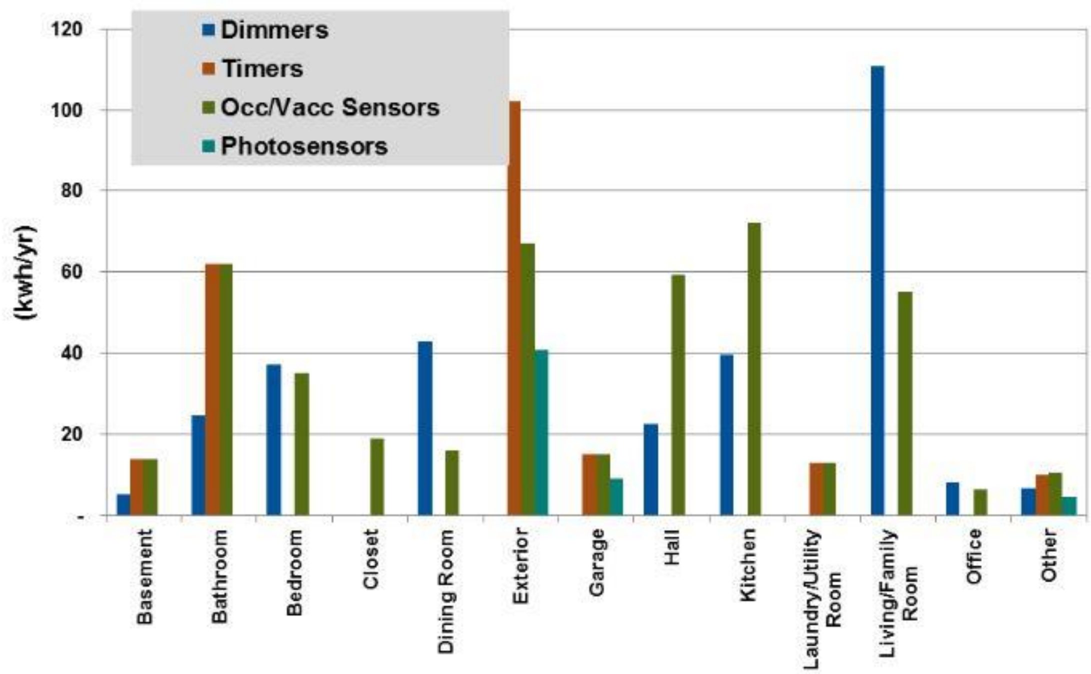


Traditional Lighting Controls

In January of 2014, CEE published *Residential Lighting Controls Market Characterization* (CEE), which was found to be the most up to date and thorough characterization of residential lighting controls available. The data represents a national characterization although at the time of this report, most of the data is more than five years old. Changes in product costs over time (LED prices have fallen significantly) and regional differences in electrical rates (Northwest rates are below national averages) will certainly effect the reported payback times but the overall trends should remain significant.

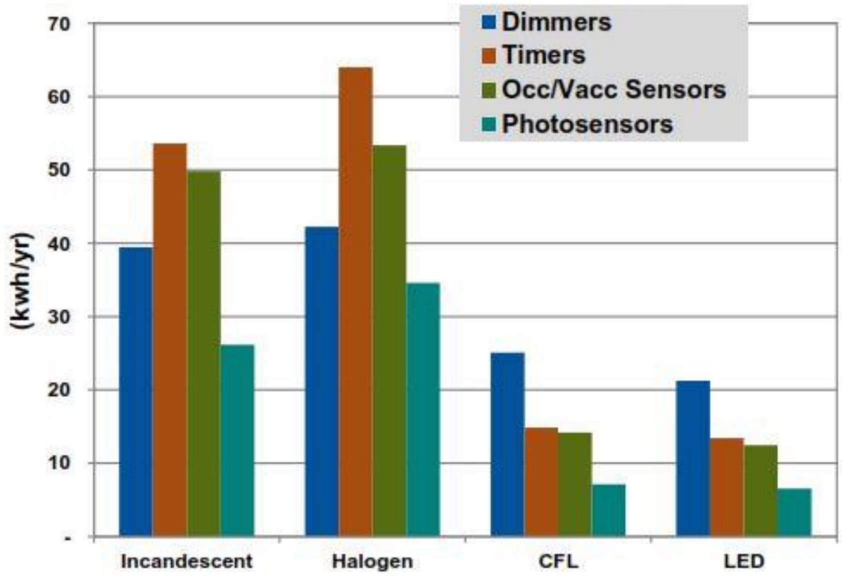
The report focuses on vacancy/occupancy sensors, dimmers, timers, and photo sensors characterizing their use, energy savings and simple payback period by location in the home (room type) and lamp type (incandescent, halogen, CFL or LED). Figure 10 and Figure 11 show estimated savings for each type of control by room type and by lamp type, respectively.

Figure 10. Average Annual Energy Savings per Control, by Room Type



CEE, Navigant Consulting

Figure 11. Average Annual Energy Savings per Control, by Lamp Type



CEE, Navigant Consulting

When controls are coupled with less efficient incandescent and halogen sources, the simple payback period in some room types is less than 2-3 years while the average payback period across all room types is about six years. The simple payback period for controls used with efficient CFL and LED sources is typically longer than ten years.

Dimming controls have the best overall cost to benefit ratio for all lamp types. Dimming control of an LED source in living rooms has a simple payback period of 4.3 years, while the average payback period for dimming control in all room types is 12 years. With low baseline operating hours and high efficacy, the annual average energy savings from dimming control of residential LED sources is low, about 20 kWh/year. Other controls on average save much less.

The CEE report provides information for retrofit situations, where the cost includes the entire cost of new controls and installation labor cost.[1] Given the limited energy savings predicted from lighting controls, they are likely to be much more appropriate for new construction where incremental equipment cost is minimal and there is no incremental labor cost.

Demand for advanced lighting controls in the residential market has been low but Navigant Research projects that total revenue associated with the installation of residential lighting controls will grow at a compound annual growth rate of 4.6% between 2016 and 2025. (Navigant Research)

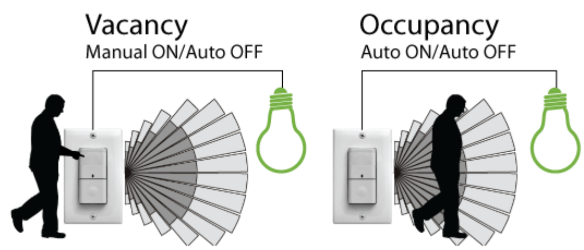
An extensive list of available products for three major manufacturers (Legrand, Leviton and Lutron) is contained in Appendix C of the CEE report.

[1] The CEE report calculates an average installation cost for each type of control assuming some percentage is installed by an electrician and the rest by the homeowner.

Vacancy/Occupancy Sensors

These sensors save energy by turning lights off when they sense that the room is no longer occupied. They can be sensitive to motion or heat (infrared) or both. Both types are limited to the occupant being within line of site of the sensor. Motion sensors may leave you in the dark if you are inactive for an extended period. Vacancy sensors are generally used more indoors and require a manual on. Occupancy sensors are used more outdoors and automatically turn the light on as well as off.

Figure 12. Comparison of Vacancy and Occupancy Sensors



Outdoor applications have greater potential savings because of the generally longer run times. Where security is a primary concern for using exterior lighting, homeowners often resist the idea of motion or infrared control preferring to leave lights on all night. An alternative, bi-level control is now available in the market where the sensor switches the lighting to 30-50% rather than completely off. Significant savings are achieved with bi-level systems (50% or more) while gaining broader market acceptance by addressing security concerns.

The costs of vacancy/occupancy sensors are relatively low. A quick internet search has product starting at $13.25 for a line voltage wall mounted sensor. In new construction, controls will be more cost effective, as the incremental cost of an occupancy/vacancy sensor compared to a standard wall switch is low. (David Douglass-Jaimes) A CEE Residential Lighting Controls Market Characterization study indicates an average payback period for occupancy sensors is 8.6 years, with the shortest payback period of 4.3 years when used with kitchen lights. (CEE) Additional details from the CEE study are provided in Appendix C.

Applications: Any residential light in a home, but most often used in rooms where lights may be left on when unoccupied, such as bedrooms and bathrooms.

Product Features: Typically installed as a wall control and turn lights off when the room is vacant. Can be used with both indoor and outdoor lights.

Availability: Readily available through all consumer outlets: big box stores, hardware stores, online.

Energy Savings: Savings can vary depending on occupancy patterns with studies showing estimated savings from 25% - 60%.

Cost: Occupancy sensor wall controls typically cost slightly more than a standard wall switch.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 6:** Approved for Implementation
Program	**LEVEL 5:** Cost effective. Ready for full-scale programs. Periodic risk assessment process in place.

Dimmers

Currently, approximately 5% of residential lighting in Northwest homes has a dimmer control (David Baylon). A recent small study (less than 15 sites) by Efficiency Vermont reported that occupants dimmed 38% of the lighting fixtures in the home operated by dimmer switches. Also in another small study, PG&E reported that lights with dimmers were dimmed 18.5% of the time. If confirmed with a statistically significant sample, this suggests potential saving from a wider use of controls consistent with DOE estimates for the residential sector.

With the increased use of CFLs and LEDs, compatibility between dimmers and lamps is a potential issue. Even CFLs and LEDs designed to be dimmable will not work with all dimmers. Dimming LEDs and CFLs may also result in flicker depending on the lamp and the dimmer. This is more of an issue in existing homes than in new construction where approved dimmers can be pared with high efficacy lamps.

Compatibility issues between dimmers and LEDs is addressed by NEMA standard SSL 7A and 7B. Part A addresses interoperability and basic compatibility and product labeling for compliance will go into effect in 2018. Part B is designed to set performance standards establishing minimum acceptable functionality but has been delayed because of a lack of industry consensus about what should be required and how it should be tested. Establishing standards of functionality for SSL dimmers remains a barrier to wider deployment of dimmer controls.

As with occupancy/vacancy sensors, the costs of dimming switches are relatively low. A quick internet search has product starting at $12.00 with numerous options below $25.00. In new construction, dimmers will be more cost effective, as the incremental cost of a dimmer compared to a standard wall switch is low. (David Douglass-Jaimes). A CEE Residential Lighting Controls Market Characterization indicates an average payback period for dimmers is 7.7 years, with the shortest payback period of 2.3 years when used with living rooms lights. (CEE) Additional details from the CEE study are provided in Appendix C.

Applications: Any residential light in a home, but most often used in rooms that are frequently occupied and adjustable light levels are desired, such as kitchens, living rooms, bedrooms and bathrooms.

Product Features: Typically installed as a wall control to allow occupants to dim lights as desired. Dimmers specifically designed to be compatible with LED and CFL lamps should be used with these sources.

Availability: Readily available through all consumer outlets: big box stores, hardware stores, online.

Energy Savings: Savings can vary depending on occupancy patterns with studies showing estimated savings from 25% - 60%.

Cost: Dimming wall controls typically cost slightly more than a standard wall switch.

Dimmers - Readiness Levels:

Category	Scores
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 3:** Limited Assessment
Program	**LEVEL 4:** Marginally at cost effective levels. Program design complete, larger scale pilots underway. Well-developed risk assessment.

Timers

Residential timers are found most often on exterior lighting; however the CEE report also found them in garages, basement, laundry/utility rooms and bathrooms where they may be used to control lights that are installed in ventilation fan units. A CEE Residential Lighting Controls Market Characterization indicates an average payback period for timers is 10.2 years, with the shortest payback period of 3.9 years when used with exterior lights. (CEE) Additional details from the CEE study are provided in Appendix C.

Applications: Most often used with exterior lighting, but also in garages, basement, laundry/utility rooms and bathrooms.

Product Features: Typically installed as a wall control to allow occupants to turn lights on for a specified period of time.

Availability: Readily available through all consumer outlets: big box stores, hardware stores, online.

Energy Savings: Savings can vary depending on occupancy patterns with studies showing estimated savings from 25% - 60%.

Cost: Timer wall controls typically cost slightly more than a standard wall switch.

Readiness Levels:

Category	Scores
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 3:** Limited Assessment
Program	**LEVEL 4:** Marginally at cost effective levels. Program design complete, larger scale pilots underway. Well-developed risk assessment.

Photo sensors

Photo sensors are most commonly used to control exterior lighting. The photo sensor is typically an integral part of the fixture and controls operation to only nighttime hours. The photo sensor will turn on the light at dusk and turn off the light at dawn. Where outdoor lights need to operate all night for security reasons, photo sensors can ensure that lights are not left on during the day.

Since photo sensors are typically an integral part of the fixture, replacement of the entire existing fixture is most common in retrofit situations. Most Northwest Codes require photo sensors on exterior residential lighting on new homes. A CEE Residential Lighting Controls Market Characterization indicates an average payback period for photo sensors is 17.2 years, with the shortest payback period of 7.6 years when used with exterior lights. (CEE) Additional details from the CEE study are provided in Appendix C.

Applications: Residential exterior fixtures.

Product Features: Typically included as an integral part of the fixture and controls operation to only nighttime hours.

Availability: Readily available through all consumer outlets: big box stores, hardware stores, online.

Energy Savings: Savings can vary depending on the baseline operation of the fixture. For fixtures consistently left on during the day, converting to photo control can reduce operating hours by about 50%, with the same level of energy savings. For fixtures only intermittently left on during the day, savings will be lower.

Cost: Exterior fixtures with integral photo controls typically cost somewhat more than a similar fixture without photo control.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 3:** Limited Assessment
Program	**LEVEL 4:** Marginally at cost effective levels. Program design complete, larger scale pilots underway. Well-developed risk assessment.

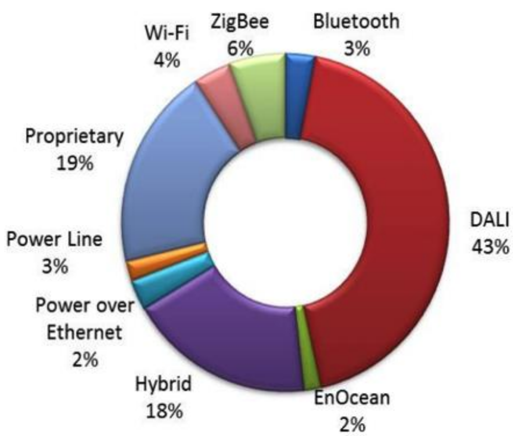
Connected Controls

Connected controls refer to lighting equipment that has an element of intelligence or connectivity. According to DOE's LED Adoption Report: "Realizing the greatest possible benefit from LED lighting will depend on connected lighting controls that respond dynamically to changing conditions and demands" (LED Adoption Report). Controls connect multiple lamps, fixtures, and switches to allow intelligent operation. Connected lighting controls can operate independently within a home without an internet connection; however, most will be connected to the internet through a bridge with control through an app.

Options for implementing connected lighting controls include "smart" lamps, switches, plugs and in-wall dimmers. These can all include various sensors to determine occupancy, lighting levels, timing etc. integrated into a platform that allows remote control and possible monitoring.

As shown in Figure 13 below, the market is segmented, ranging from plug and play smart lamps with built in Wi-Fi (4% of market) that can talk directly to your smart phone to complete automation systems from a couple of dozen manufacturers using both open and proprietary (19% of market) communications protocols (Smallwood).

Figure 13. 2014 Connected Indoor Lighting Market



(Smallwood)

According to DOE, connected controls were installed in less than 0.1% of both commercial and residential lighting systems in 2016 (Building Technologies Office). In the residential sector, the anticipated potential savings for lighting controls is low, given low baseline operating hours and continued penetration of high efficacy sources.

While it has been suggested that this new level of connectivity could provide enhanced control to drive additional savings in the residential lighting sector beyond the savings associated with traditional (unconnected) controls, this remains substantially unproven for wide application. With the current high cost of connected lighting controls, these systems are not likely to be cost effective based on energy savings alone and are dependent on non-energy benefits to drive their market acceptance.

Connectivity could provide a pathway for utilities to acquire a demand response (DR) resource but the fragmentation of the market and lack of standards for compatibility pose significant barriers.

Connected controls fall into two categories,

a) lighting specific for lamps, fixtures and switches; and
b) implemented as part of a complete HEMS as part of the larger Internet of Things.

Both of these options are explored in the next sections.

Smart Lamps

Smart lamps provide a relative low cost path to connected lighting control. These lamps pair LED lighting sources with the ability for remote dimming, color changing, color tuning (CCT) and on/off control. There is a broad range of lighting options (color temp, color tuning, dimming) as well as access to voice control and audio speakers with appropriate hardware. The features of some of the best rated "smart" lamps as reviewed by http://smarthome.reviewed.com are located in Appendix B.

In retrofit applications, installation of a smart lamp with or without a gateway is basically "plug and play" and shouldn't require professional installation. Because the homeowner can generally install these lamps, their cost will be lower than hard-wired controls installed by a contracted professional. However, smart lamps are not cost effective based on energy savings alone. Non-energy related benefits, such as color changing capability, integrated audio speakers and other control features are driving early adoption versus cost effectiveness.

Smart lamps fall into 2 categories: lamps that require a hub or gateway to communicate with other devices and lamps that can communicate directly by WIFI, Bluetooth or proprietary protocols. ZigBee is currently the dominant communication protocol for smart lamps that require a hub or gateway. Gateways are an added cost that becomes less significant if a large number of lamps are being installed. There is a wide variation in the approach used for connecting lamps and devices and some set-up and programing features are awkward especially across different platforms. The PG&E Market Analysis for HEMS published in November of 2016 (B. K. Rebecca Ford) found the following for smart lamps:

> "The main difference between the products is around how they connect to the home area network. Of the 15 manufacturers, whose products were reviewed, four distinct communication approaches emerged. Most developed proprietary hubs (5); others produced bulbs that were compatible with a slew of platforms developed by other manufacturers (4). Two manufacturers produced bulbs that connect to the Wi-Fi router directly. Nine additional products did not need a hub and were directly controlled via Bluetooth using smartphones and tablets, but can only communicate in close proximity, prohibiting remote control from outside the home."

Also, a word of caution, in a small PG&E study in 2014 looking at smart lamps, the hours of use per lamp actually increased for smart lamps compared to standard lamps partially offsetting savings gained from added control. (Price)

Applications: Residential fixtures that have an Edison base suitable for screw in lamps.

Product Features: Remote control for dimming, on/off, color changing, color tuning, audio typically through smart phone apps.

Availability: Becoming more readily available through major consumer outlets, mainly big box stores and online.

Energy Savings: Given the early stage of technology development and adoption, energy savings are generally unproven and anticipated to be low, given low baseline operating hours and the high efficacy of the lamp.

Cost: Smart lamps typically cost significantly more than an LED lamp without integrated control functionality.

Readiness Levels:

Category	Scores
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 2:** Concept validated
Program	**LEVEL 3:** Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.

Smart switches

Like smart lamps, smart switches provide connected lighting control. Smart switches replace the normal wall switches in a house and provide connectivity which enables the ability to turn lights on and off, dim regular bulbs, and provide connected control of switched devices other than lighting. Another feature of the smart wall switch, as compared to the standard wall dimmer, is the remote control capability. An advantage for smart switches is that standard LED bulbs can be controlled. This can be especially useful if the application requires a particular size, shape or style that isn't available as a smart bulb.

However, these switches do not provide the additional features, such as color changing, available with smart lamps unless the bulbs are also replaced.

Most smart switches use either WIFI or ZigBee. WIFI models like the Belkin WeBo Light Switch can pair directly with your home network or smart phone while models that use ZigBee will require some sort of hub or control device. Lutron has an extensive line of higher-end lighting controls for smart lighting based on their own proprietary signal.

Installation is more complicated than a smart lamp, requiring wall switches to be replaced at an average cost, around $50, which is fairly high impacting the cost effectiveness of smart switches. Like smart lamps, market adoption is currently driven by non-energy benefits.

While smart lamps can lose connectivity if they are turned off by a regular wall or fixture switch, smart switches are always connected directly to house power and remain connected as long as the power is on. Because smart switches are always powered even when they are turned off, this results in standby energy use similar to a smart lamp.

Applications: Any residential lighting controlled by a wall switch.

Product Features: Remote control typically through phone apps for dimming, on/off.

Availability: Becoming more readily available through major consumer outlets, mainly big box stores and online.

Energy Savings: Given the early stage of technology development and adoption, energy savings are generally unproven and anticipated to be low, given low baseline operating hours and the continued penetration of high efficacy lamps.

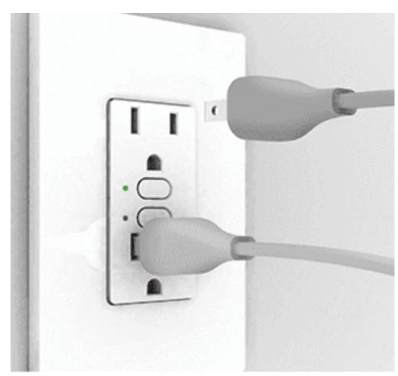
Cost: Smart switches typically cost significantly more than a standard wall switch.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 2:** Concept validated
Program	**LEVEL 3:** Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.

Smart plug-in and hardwired outlets

Smart outlets provide connected intelligent control to any device. Most, smart outlets are designed to work with whatever is plugged into them to turn devices on and off and for lamps provide dimming controls. However, some outlets are lamp specific, with built in dimming control. Many devices now have or are developing compatibility with various platforms such as Apple HomeKit for iOS, Amazon Echo or Google Home. With the right hardware you can have voice control of your lighting and other devices.



These devices can either be plug-in or hard wired. Plug-in options are basically plug and play and adapt an existing outlet they can automate other devices including small applications and provide connectivity for fixtures using standard bulbs. Smart plug-in outlets are simple to set up and like smart lamps can be easily relocated. Other smart outlets are hard wired and offer a more seamless and fully integrated feel for a fully automated home but require more labor to install.

Many smart outlets also provide data on power consumption, which could become a valuable resource in tracking use and verifying potential savings.

Similar to smart switches, unless the smart outlet is turned off, it will have standby energy consumption in order to maintain connectivity even when not in use.

Applications: Any residential lighting plugged into an electrical outlet.

Product Features: Remote control typically through phone apps for dimming, on/off.

Availability: Becoming more readily available through major consumer outlets, mainly big box stores and online.

Energy Savings: Given the early stage of technology development and adoption, energy savings are generally unproven and anticipated to be low, given low baseline operating hours and the continued penetration of high efficacy lamps.

Cost: Smart outlets typically cost significantly more than a standard electrical outlet.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 5:** Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available.
Product	**LEVEL 2:** Concept validated
Program	**LEVEL 3:** Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.

Connected Homes

Home automation systems have been on the horizon for decades but applications have generally been found in higher end residences. With a growing "internet of things" and dropping prices for connectivity, the last five years have seen increased adoption for these systems. Home energy management systems provide a host of services including: home security; controls for lighting levels, color and/or daylighting; controls for HVAC using artificial Intelligence algorithms; and smart appliances including refrigerators that send shopping lists to smart phones or ones that have cameras which show the contents. The landscape of possibilities appears to be limitless.

While connected homes offer the potential for delivery of energy savings, energy management is typically not a feature highlighted in marketing these systems. Rather, the connected home is offered to the public as a path to convenience, control, security and information. In addition, the integration of a Home Energy Management System (HEMS) or stand-alone connected lighting systems into this larger Internet of things (IoT) is expensive relative to the savings potential. However, these costs may be mitigated by non-energy benefits and the service supplier's interest in gaining access to data about homeowners for additional marketing purposes.

As part of home automation, Home Energy Management Systems (HEMS) have been in the market for a number of years. Significant market characterizations and assessments have been published by NEEP (2015), PG&E (2016) and others. Energy savings associated with the use of HEMS are attributed to both changes in behavior of occupants and the growing ability of systems to interact with automated home controls and directly modify operational characteristics that have the potential to reduce overall energy use while maintaining or even enhancing comfort and performance.

Studies designed to quantify energy savings for HEM systems has been limited. Two sources which did develop these estimates are highlighted here. A 2010 ACEEE report began to quantify the potential savings from HEMS technologies reporting 4% to 12% average reduced household electrical consumption (Ehrhardt-Martinez). A Northeast Energy Efficiency Partnership (NEEP) study in 2015 estimated potential savings that is achievable with HEMS for all combined end uses as shown by percentage in Figure 14. As shown in this chart, lighting provides only a small part (11%) of the potential energy savings anticipated from using a HEMS.

NEEP also estimated potential savings by end use for both control-based systems (Table 4) and information-based (feedback only) systems (Table 5). Savings are shown as a percentage of whole home energy use. Again, these tables show relatively low potential savings for control of lighting energy use through a HEMS.

Details about lighting controls via HEM systems are on the next page.

Figure 14. Estimated HEMS Savings Potential by major end use categories

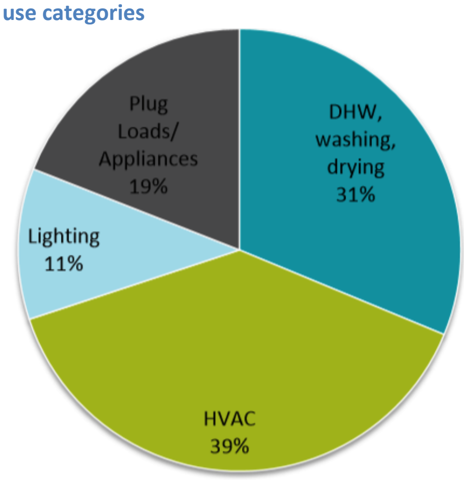


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Table 4. Whole Home Savings Estimates for Control-Based HEMS

Control-Based HEMS Savings Estimates by End-Use							
Products	End-Use	Savings Range (whole home energy usage as baseline)			Cost Range		
		Low	Avg.	High	Low	Avg.	High
Smart Hardware / Smart Home Platforms	Space Heating	1%	7%	13%	$46.00	$247.13	$615.00
	Space Cooling	1%	9%	17%	$46.00	$247.13	$615.00
	Water Heating	1%	8%	15%	$799.99	$1350.00	$1,900.00
	Appliances	<1%	3%	6%	$54.00	$1,503.50	$4,000.00
	Plug Loads	<1%	3%	5%	$11.00	$208.41	$1,300.00
	Lighting	1%	2%	3%	$15.00	$46.89	$150.00

Table 5. Whole Home Savings Estimates for Information-Based HEMS

Information-Based HEMS Savings Estimates by End-Use							
Products	End-Use	Savings Range (whole home energy usage as baseline)			Cost Range		
		Low	Avg.	High	Low	Avg.	High
Customer-Facing Energy Portal / In-home Display / Load Monitor	Space Heating	1%	8%	15%	$20.00	$197.00	$4000.00
	Space Cooling	1%	5%	9%			
	Water Heating	1%	8%	15%			
	Appliances	<1%	1%	1%			
	Plug Loads	<1%	2%	3%			
	Lighting	<1%	2%	3%			

Applications: Theoretically any home, but given cost and complexity will most likely be adopted first in high-end homes.

Product Features: Remote control of lighting and other home appliances typically through phone apps. Can provide additional non-energy benefits such as security, entertainment, usage tracking, and other information.

Availability: Becoming more readily from major manufacturers.

Energy Savings: Given the early stage of technology development and adoption, energy savings are generally unproven. Energy savings for lighting controlled through HEMS are anticipated to be low, given low baseline operating hours and the continued penetration of high efficacy lamps.

Cost: Installing a home energy management system is costly, ranging from several hundred to several thousand dollars, if new smart appliances are included.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 4:** Commercially available in NW from at least two manufacturers. Stocked throughout region.
Product	**LEVEL 2:** Concept validated
Program	**LEVEL 3:** Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.

Codes and Standards

Codes and Standards have been instrumental in the evolution of energy efficient residential lighting. The Energy Independence and Security Act (EISA) of 2007 raised efficacy standards for general service lighting, effectively phasing out incandescent lighting from the market and accelerating the transition to efficient light sources. In addition, current building codes, particularly in California and the Northwest, require widespread use of high efficacy lighting in residential applications and address lighting controls. Lamp quality certification programs, such as Energy Star, have also helped expand the market for efficient lighting.

EISA 2020 rule making

Over the years since its passage in 2007, EISA standards have been implemented through a periodic rule making process. The latest rule making, scheduled to take effect January 1, 2020, requires a minimum 45 lumens/watt for almost all general service lamps (GSL) and previously exempt specialty lighting. This will effectively make only LED and CFL lamps available in the market, since no currently available halogen or incandescent lamps are able to meet the efficacy requirement.

From the article Impacts of the 2020 Federal Light Bulb Efficiency Standard By Chris Granda, February 2018 issue of Strategies:

"While the federal standard is technology neutral and allows the sale of any kind of General Service Lamp (GSL) that can meet the 45 LPW efficiency requirement, most light bulbs of all types for sale in the U.S. will probably be LEDs after the standard comes into effect. LEDs mostly run above 70 LPW, consumers like the technology and LED market share has recently increased rapidly. Halogen bulbs for sale today only run at about 20 LPW and several years ago manufacturers abandoned efforts to commercialize a new generation of more efficient halogens. Most compact fluorescent lamps (CFL) can meet the 45 LPW requirement, but are losing market share to LEDs based on light quality, reliability and price. CFLs dropped from 50 percent of all A-line light bulb sales in 2014 to less than 10 percent today and some manufacturers are discontinuing their CFL product lines. The federal backstop GSL standard does not cover linear fluorescent lamps, which are subject to their own federal standards.

This transition will eventually make most residential lighting efficiency programs no longer cost-effective. A couple of factors point to a closing window for residential lighting efficiency programs. Since 2010, first CFLs and then LEDs have claimed significant shares of the U.S. light bulb market. As a result, the energy efficiency of the average new light bulb sold in the U.S. has increased significantly. That means the savings that energy efficiency programs can claim for helping to install an efficient LED has decreased, compared to the average new light bulb that consumers would have installed anyway. Because LEDs and CFLs last much longer than halogen light bulbs, consumers also need to buy replacement bulbs less frequently and annual sales of light bulbs in the U.S. are dropping."

Energy Star

The EPA Energy Star program maintains quality and efficiency standards for light bulbs. The standard is technology neutral and applies to any lighting technology. Light bulbs that earn an Energy Star label meet these efficiency standards and are tested by accredited labs. The standards require light bulbs to use about 70-90% less energy than traditional incandescent bulb and last at least 15 times longer. Many utility programs provide incentives for only Energy Star certified lamps in order to ensure quality products are offered to consumers. Energy Star also provides educational materials to inform consumers about LED lighting in general, and how choosing an Energy Star lamp can provide assurance of quality in various lamp characteristics.

California Quality LED Lamp Specification

California has developed a separate standard for LED lamps. This specification is intended to set a high performance standard to create a positive public perception of LED lamps, especially in residential applications. California investor owned utilities can only provide rebates for screw-based LEDs products that meet the quality specification. The specification includes enhanced criteria for numerous customer metrics related to customer satisfaction. These include color rendering (CRI), light distribution, dimming performance and flicker. The specification also includes a minimum efficacy requirement of 80 lumens/watt, well above the federal minimum standard of 45 lumens/watt.

Building Codes

California's Title 24 Building Energy Code, effective January 1, 2017, includes comprehensive requirements for energy efficient lighting and controls, including the following

- All lighting must be high-efficacy. Screw-based high-efficacy lighting is allowed, except in recessed ceiling downlights.
- A vacancy sensor must be installed to control lights in bathrooms, garages, laundry rooms, and utility rooms.
- A dimmer or vacancy sensor must be used to control all permanently installed indoor recessed ceiling downlights, screw-based light fixtures, and LED light fixtures.
- Outdoor lighting connected to a building must be controlled with a manual on/off switch plus an astronomical timeclock, or photocell and motion sensor, or photocell and time switch.

Northwest lighting codes vary based on jurisdiction. For example,

- Washington State lighting codes are based on the 2015 IECC with amendments.
- Montana State lighting codes are based on the 2012 IECC.
- Oregon has developed its own set of lighting codes that are mainly prescriptive.
- Idaho State lighting codes are based on the 2012 IECC with amendments.

Conclusions

Increased adoption of LED light sources will continue to be the dominant driver of residential lighting energy savings for at least the next decade. While LED products currently in the market are very efficient, with efficacies of 80 – 110 lumens/watt, continued improvement in the efficacy of LED lamps and luminaires is predicted in the next few years. The DOE estimates that the highest performing LED devices currently have efficacies of 160-170 lumens/watt and 255 lumens/watt is possible.

Stringent federal standards for lighting source efficacy and building codes with requirements for widespread use of high efficacy lighting in residential applications will negatively impact utility residential lighting programs. As these codes and standards go into effect, the baseline for calculating energy savings will be more efficient, reducing the rate of savings efficiency programs can claim. In addition, dropping prices will impact the cost effectiveness impacting the ability to provide incentives.

EISA 2020 will bring significant changes to the residential lighting market when it imposes a 45 lumens per watt standard for lamps including most specialty lamps which are currently exempt. This new standard will eliminate all options currently in the market except for LEDs. Utility lighting programs have a limited amount of time to incent specialty lamps for lighting energy savings before the January 1, 2020 implementation date.

Controls could provide additional incremental energy savings. However, potential savings from residential controls are limited by the successful penetration of the general market by both high efficacy lights and low baseline hours of operation of residential lighting. DOE estimates that residential lighting controls will drive 7% savings by 2035. Traditional controls with the greatest potential savings are dimmers followed by vacancy sensors.

Savings and cost effectiveness for connected controls have not been validated. With higher penetrations of high efficacy lamps and low hours of usage justification to include these technologies in utility lighting programs may be limited. Additional research will be needed to explore if and how to incorporate these technologies into future lighting programs.

Home automation in its various forms will help increase the penetration of lighting controls into more homes. While these technologies offer the potential for lighting energy savings, energy savings are not typically the main driver for adoption. Currently, consumers cite non-energy benefits of these systems, such as safety and security, convenience and entertainment, as higher priorities than energy savings for adoption of home automation.

As more houses become “connected”, home automation offers an opportunity to support demand side management. However, currently most products do not focus on this potential or provide a way to integrate utility signals such as time-of-use or critical-peak pricing into lighting solutions.

Emerging technologies are not expected to impact the residential lighting programs before 2025. These technologies should be monitored and opportunities to accelerate research and adoption with strategic partnerships should be explored.

Overview of Technologies

Table 6. Summary of Report Findings for Lamp Technologies

Lamps	Technical Potential	Energy Savings	Applications	Readiness Scores
Currently Available				
LED General Service A-Line Lamps are available with various lumen outputs and in various color temperatures. Dimming and non-dimming available.	35 aMWs	LED lamps use about 80% less energy than standard incandescent lamps; about 30% less than CFLs	Residential Fixtures	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.
LED Specialty Lamps Lamps are available in a large variety of sizes and shapes to fit a variety of applications. Available in various lumen outputs and color temperatures. Dimming and non-dimming available	51 aMWs	LED lamps use about 80% less energy than standard incandescent lamps; about 30% less than CFLs	Residential fixtures other than an Edison base including reflector, globe, and candelabra light bulbs with various screw base sizes and pin bases	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.
LED Linear LED Linear lamps are available in a variety of lumen outputs and color temperatures. Dimming and non-dimming available. Lamps have different configurations with some requiring rewiring and others plug and play	2.7 aMWs	LED Linear replacement lamps currently in the market can provide energy savings of 40 - 45%	Residential fixtures that use linear fluorescent lamps. Most often found in Single Family in garages, closets, and utility rooms; and in Multifamily common areas and parking garages.	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.

Lamps	Technical Potential	Energy Savings	Applications	Readiness Scores
LED Exterior Lighting New fixtures with integrated LED sources are available in wide variety of styles, mounting types, lumen outputs, and color temperatures. Available with integrated photo and motion sensors.	19 aMWs	Exterior fixtures with LED sources use about 80% less energy than fixtures with standard incandescent lamps; and 30% less than CFLs	Exterior porch and security lighting	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.
Dedicated Fixtures New fixtures with integrated LED sources are available in a wide variety of styles, mounting types, lumen outputs and color temperatures	89 aMWs	Exterior fixtures with LED sources use about 80% less energy than fixtures with standard incandescent lamps; and 30% less than CFLs	All residential lighting applications	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.

Emerging Technologies Near Term				
Organic LEDs (OLEDS) Light emitting diodes in which emissive electroluminescent layer is a film of organic compound.	TBD	Current efficacies (50 lumens/watt) are comparable to CFLS.	OLED panels are growing part of TV and display market and research is underway for general illumination applications	**Market Readiness:** Level 1: Not commercially available or limited, pre-commercial availability **Product Readiness:** Level 2: Concept validated **Program Readiness:** Level 1: No program design. No risk assessment.
Lamps	**Technical Potential**	**Energy Savings**	**Applications**	**Readiness Scores**
Future Technology Over 5 years				
Laser Diodes May offer a powerful, high density, efficient light source that could revolutionize lighting design.	TBD	Similar efficiencies to current LEDs in the market now.	Currently commonly used in telecommunications, measuring devices, scanners and other applications. Limited to specialty applications	**Market Readiness:** Level 1: Not commercially available or limited, pre-commercial availability **Product Readiness:** Level 1: Concept not yet validated **Program Readiness:** Level 1: No program design. No risk assessment.
Quantum Dots Very small , typically 2-10 nanometers, semiconductor particles which will emit light if electricity is applied to them. First identified in 1986, these are anticipated to be a central component in the expanding world of nanotechnology.	TBD	Potential savings would come from possible improvements in efficacy through the use of quantum dots in LEDs.	Research is underway exploring applications in quantum computing; studying intercellular biological processes; improved photovoltaic devices; photodetectors; photo catalysts and light emitting diodes (LEDs)	**Market Readiness:** Level 1: Not commercially available or limited, pre-commercial availability **Product Readiness:** Level 1: Concept not yet validated **Program Readiness:** Level 1: No program design. No risk assessment.

Table 7. Summary of Report Findings for Lighting Controls Technologies

Lighting Controls	Technical Potential	Energy Savings	Applications	Readiness Scores
Currently Available Standalone Controls including sensors, timers, dimmers and photo sensors				
Vacancy/Occupancy Sensors Sensors save energy in indoor and outdoor applications by turning lights off after a period of time with no activity. They can be sensitive to motion or heat (infrared) or both.		Savings can vary depending on occupancy patterns with studies showing estimated savings from 25 – 60%. Outdoor applications provide more savings because of longer hours of use.	Can be used with lamps or fixtures. Typically installed as a wall control and turn lights off when the room is vacant. Can be used with indoor and outdoor lamps.	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.
Dimmers Wall controls that allow light levels to be lowered to save energy and/or create ambiance. Approximately 5% of NW homes have dimmer controls. Compatibility between dimmers and lamps is a potential issue.		Savings can vary depending on occupancy patterns with studies showing estimated savings from 25 – 60%. Establishing standards functionality for SSL remains a barrier to adoption.	Any residential lights but are most often used in rooms that are frequently occupied where adjustable light levels are desired such as kitchens, living rooms, dining rooms, bedrooms and bathrooms	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.
Timers Typically installed as a wall control to allow occupants to turn lights on for a specified period of time.		Savings can vary depending on occupancy patterns with studies showing estimated savings from 25 – 60%	Most often used with exterior lighting but also found in garages, basements, laundry/utility rooms, and bathrooms	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.

Lighting Controls	Technical Potential	Energy Savings	Applications	Readiness Scores
Currently Available Standalone Controls including sensors, timers, dimmers and photo sensors-Cont'd				
Photo Sensors Typically included as an integral part of exterior fixtures to control operation to only nighttime hours.		Savings can vary depending on the baseline operation of the fixture. For fixtures consistently left on during the day, converting to photo controls can reduce operating hours by about 50% with the same level of energy savings.	Residential exterior fixtures.	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 6 – Approved for implementation **Program Readiness:** Level 5 – Cost Effective. Ready for full-scale programs. Periodic risk assessment in place.

Lighting Controls	Technical Potential	Energy Savings	Applications	Readiness Scores
Connected Controls – Multiple Lamps, Fixtures and Switches				
Smart Lamps Replacement LED lamps that provide remote control capabilities for dimming; on/off; color changing; color tuning; and audio typically through smart phone apps.		Given low baseline operating hours and the high efficacy of the lamps as well as the early stage of development and adoption, energy savings are generally unproven and anticipated to be low.	Residential fixtures with an Edison base suitable for screw in lamps.	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 2 – Concept validated **Program Readiness:** Level 3 – Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.
Smart Switches Smart switches replace the normal wall switches to provide remote control for dimming and on/off for lighting through phone apps.		Given low baseline operating hours and the high efficacy of the lamps as well as the early stage of development and adoption, energy savings are generally unproven and anticipated to be low. Standby loads may impact savings.	Residential wall switches that control lights.	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 2 – Concept validated **Program Readiness:** Level 3 – Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.
Smart Plug-in and Hardwired Outlets Provides connected intelligent control to any device plugged into the outlet. Controls support dimming and on/off capability.		Given low baseline operating hours and the high efficacy of the lamps as well as the early stage of development and adoption, energy savings are generally unproven and anticipated to be low. Standby loads may impact savings.	Residential lighting plugged into the electrical outlet.	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 2 – Concept validated **Program Readiness:** Level 3 – Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.

Lighting Controls	Technical Potential	Energy Savings	Applications	Readiness Scores
Connected controls integrated into a complete Home Energy Management System (HEMS)				
Connected Homes Offer the potential to deliver energy savings through energy management systems by providing remote control of lighting and other home appliances typically through phone apps. Can provide non-energy benefits such as security, entertainment and information.		Given low baseline operating hours and the high efficacy of the lamps as well as the early stage of development and adoption, energy savings are generally unproven. Energy savings for lighting controls through HEMS are anticipated to be low. Other non-energy benefits may drive adoption.	Can be used in any home but will most likely be adopted first in high end homes. **Are we sure about this given Alexa and other products?**	**Market Readiness:** Level 5 – Commercially available from 2+ manufacturers, well developed supply chain. Widely and easily available. **Product Readiness:** Level 2 – Concept validated **Program Readiness:** Level 3 – Not cost effective but shows pathway to CE with higher volumes, more competition, improved technology. Small scale pilots.

Recommendations

Opportunities for utility programs to deliver energy savings in residential lighting are changing as technology and codes and standards evolve. Based on the findings in this paper, the following recommendations for utility residential lighting programs are offered.

Short-term: Next 2 years

- Support adoption of high efficacy, high quality sources.
- Utilities might consider a tiered incentive with higher incentives for higher efficacy lamps to encourage consumers to purchase the most efficient lamps available.
- Continue to require quality metrics, such as Energy Star or the CA Quality LED Lamp specification to ensure customer satisfaction.
- Identify specialty lamps that could be targeted for new incentives before the implementation of EISA 2020 where penetration of high efficacy lamps is currently limited.
- Support retrofit of linear fluorescent fixtures with TLEDs, particularly in multifamily applications where hours of operation are longer. Consider supporting only plug and play type TLEDs to minimize retrofit cost and safety concerns.
- Identify pilots and assessments of residential connected lighting controls in order to quantify energy savings and cost effectiveness. Evaluate customer experience issues and demand control opportunities.
- Support lighting controls for exterior fixtures, both in single family and multifamily applications. Exterior lighting has relatively longer hours of operation providing greater potential for savings through use of lighting controls

Mid-term: 2 – 5 years

- Explore a tiered incentive approach to encourage consumers to purchase the highest efficacy lamps to replace failing lamps including early LEDs which were installed beginning in 2010.
- Continue with pilots and assessments of residential connected lighting controls as the technology advances. Evaluate customer experience issues and demand control opportunities and gather additional data to quantify energy savings and cost effectiveness.
- Identify and develop strategic partnerships to support research and development of future lighting technologies to accelerate their development.

Long-term: Over 5 years

- Monitor advances in future lighting technologies and look for opportunities to accelerate development.

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Appendix B: Interviews

Jessica Aiona: presentation on BPA Residential Lighting Market Study May 2017

Eric Strandberg; Lighting Design Lab

Jeremy Snyder; Lighting Research Center; Director of Energy Programs/Director of Lighting Energy Alliance, Rensselear Polytechnic Institute

Ken Nichols; ACS Professional Staffing, BPA

Mary Matteson Bryan; Consultant

Chris Wolgamott; Senior Project Mgr. Technology & Product Management, NEEA

Heather Gates; Operations Mgr., Clear Results

Levin Nock; Design Lights

Michael Jouaneh; ASHRAE 90.2, Lutron

Eileen Eaton; CEE

Appendix C: Smart Lamps

Table 8. Smart Lamps Available for Purchase, Winter 2017/18

Lamp	HUB	Cost	Max W	Standby W	Efficacy L/W	Dim	Color Change	Color Temp Adjust	Programmable	Compatible
Phillips HUE White & Color Starter Kit (GEN 3)	Y	$160/hub + 3 lamps $50 each extra bulb	10W	0.2 W	80 @ 4000K	Y To 5%	Y 16M Colors	Y 2000K to 6500K	Y	Alexa Google Home Siri
C-Sleep by GE	N	$35 each	11w	?	66	N	N	Y	Sleep cycle	Waiting for smart bridge
TP Link LB 100	N	$20 each	7W	0.5 W	86	Y	N	N 2700K	Y	Android 4.1 iOS 8
Phillips Hue White Ambiance Kit	Y	$100 /hub + 3 lamps $28 each extra bulb	10W	0.1 W	80.6 @4000 k	Y	N	Y 2200K to 6500K	Y	Alexa Google Home Siri
Sengled Element Classic Kit	Y	$40/hub + 3 lamps $9 each extra bulb	9W	?	72	Y	N	N 2700K	N	Alexa only
Ikea Tradfri Gateway kit	Y	$80/hub + 3 lamps $18 Extra Tunable lamps	12W	0.5 W	81.7	Y	N	Y 2200K 2700K 4000K	?	Planned for: Alexa Google Home Siri
LIFX A19	N	$60	13W	0.5 W	84.6	Y To 1%	Y 16M Colors	Y 2500K to 9000K	Y	Alexa Google Home Siri
CREE 60W soft white replacement	Y	$20 Lamp only	11.5 W	?	71	Y	N	2700K	Y	ZigBee hub Wink Smart Things WEMO
OSRAM A19 White Tunable	Y	$24	9.5W	?	85	Y	N	Y 2700K to 6500K	Y	ZigBee hub Alexa Google Home

Appendix D: Annual Energy Savings Per Control Unit

The following tables demonstrate the elative payback of different controls in various rooms controlling various lamp types. This information is from the CEE 2014 Residential Lighting Controls Market Characterization (CEE).

Table 9. Occupancy/Vacancy Sensor Results

	Annual Energy Savings Per Control Unit (kWh/yr)					Payback Period (years)				
Room Type	Inc	Halogen	CFL	LED	Average	Inc	Halogen	CFL	LED	Average
Basement	28.2	22.7	7.6	7	14	11	13.6	40.9	44	22.2
Bathroom	75.9	86.8	21.7	19	62	4.1	3.6	14.3	16.3	5
Bedroom	44.9	50.2	12.9	11.2	35	6.9	6.2	24	27.6	8.8
Closet	28.5	20.7	7.8	7.1	19.2	10.9	15	39.6	43.4	16.1
Dining Room	18.3	19.7	6	4.6	16.1	17	15.7	52	67.9	19.2
Exterior	79.4	111.5	21.8	19.9	67.2	3.9	2.8	14.2	15.6	4.6
Garage*	38.1	48.1	10	9.5	15.1	8.1	6.4	30.8	32.5	20.6
Hall	72.2	78.8	21	18.1	59.4	4.3	3.9	14.7	17.2	5.2
Kitchen	126	100.8	35.7	31.5	72.3	2.5	3.1	8.7	9.8	4.3
Laundry/Utility Room	22.8	21.3	6.1	5.7	13	13.6	14.5	50.4	54.4	23.8
Living/Family Room	72.4	81.9	21.4	18.1	55.1	4.3	3.8	14.5	17.1	5.6
Office	8.8	9.7	2.6	2.2	6.4	35	31.9	120.6	140.1	48.2
Other	16.9	16.4	4.8	4.2	10.8	18.3	18.9	64.1	73.3	28.8
Average	49.8	53.4	14.2	12.5	36	6.2	5.8	21.9	24.9	8.6

Table 10. Timer Results

	Annual Energy Savings Per Control Unit (kWh/yr)					Payback Period (years)				
Room Type	Inc	Halogen	CFL	LED	Average	Inc	Halogen	CFL	LED	Average
Basement	28.2	22.7	7.6	7	14	14.3	17.7	53.2	57.1	28.8
Bathroom	75.9	86.8	21.7	19	62	5.3	4.6	18.6	21.2	6.5
Bedroom	-	-	-	-	-	-	-	-	-	-
Closet	-	-	-	-	-	-	-	-	-	-
Dining Room	-	-	-	-	-	-	-	-	-	-
Exterior	120.6	169.3	33.1	30.2	102	3.3	2.4	12.2	13.3	3.9
Garage*	38.1	48.1	10	9.5	15.1	10.6	8.4	40.1	42.3	26.7
Hall	-	-	-	-	-	-	-	-	-	-
Kitchen	-	-	-	-	-	-	-	-	-	-
Laundry/Utility Room	22.8	21.3	6.1	5.7	13	17.7	18.9	65.5	70.7	30.9
Living/Family Room	-	-	-	-	-	-	-	-	-	-
Office	-	-	-	-	-	-	-	-	-	-
Other	15.7	15.2	4.5	3.9	10	25.7	26.5	89.8	102.7	40.3
Average	53.6	64	14.9	13.4	39.5	7.5	6.3	27.1	30	10.2

Table 11. Dimmer Results

	Annual Energy Savings Per Control Unit (kWh/yr)					Payback Period (years)				
Room Type	Inc	Halogen	CFL	LED	Average	Inc	Halogen	CFL	LED	Average
Basement	8.3	6.7	6.2	5.8	5.3	30.5	37.8	40.9	44.1	47.6
Bathroom	27	30.8	21.4	18.6	24.8	9.4	8.3	11.9	13.6	10.3
Bedroom	43.9	49.1	23.9	20.4	37.4	5.8	5.2	10.6	12.5	6.8
Closet	-	-	-	-	-	-	-	-	-	-
Dining Room	46	49.8	29.9	22.3	42.9	5.5	5.1	8.5	11.4	5.9
Exterior	-	-	-	-	-	-	-	-	-	-
Garage*	-	-	-	-	-	-	-	-	-	-
Hall	24.1	26.3	19.5	16.6	22.5	10.6	9.7	13.1	15.3	11.3
Kitchen	57.3	45.8	45.1	39.6	39.7	4.4	5.6	5.6	6.4	6.4
Laundry/Utility Room	-	-	-	-	-	-	-	-	-	-
Living/Family Room	133.1	150.6	70.8	59.6	110.7	1.9	1.7	3.6	4.3	2.3
Office	9.4	10.3	7.6	6.5	8.2	27	24.7	33.5	39.1	31.2
Other	9.6	9.3	6.6	5.5	6.8	26.6	27.4	38.7	46	37.5
Average	39.4	42.2	25.1	21.2	33.1	6.4	6	10.1	12	7.7

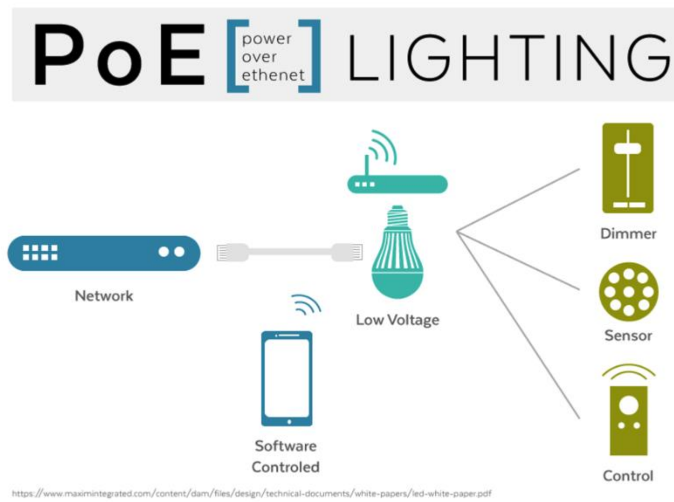
Table 12. Photosensor Results

	Annual Energy Savings Per Control Unit (kWh/yr)					Payback Period (years)				
Room Type	Inc	Halogen	CFL	LED	Average	Inc	Halogen	CFL	LED	Average
Basement	-	-	-	-	-	-	-	-	-	-
Bathroom	-	-	-	-	-	-	-	-	-	-
Bedroom	-	-	-	-	-	-	-	-	-	-
Closet	-	-	-	-	-	-	-	-	-	-
Dining Room	-	-	-	-	-	-	-	-	-	-
Exterior	48.2	67.7	13.2	12.1	40.8	6.5	4.6	23.6	25.9	7.6
Garage*	22.9	28.9	6	5.7	9	13.6	10.8	51.7	54.6	34.5
Hall	-	-	-	-	-	-	-	-	-	-
Kitchen	-	-	-	-	-	-	-	-	-	-
Laundry/Utility Room	-	-	-	-	-	-	-	-	-	-
Living/Family Room	-	-	-	-	-	-	-	-	-	-
Office	-	-	-	-	-	-	-	-	-	-
Other	7.4	7.1	2.1	1.8	4.7	42.4	43.8	148.4	169.6	66.6
Average	26.2	34.6	7.1	6.5	18.2	11.9	9	43.8	47.7	17.2

Appendix E – Power Distribution

Power over Ethernet (PoE)

Technology Description: With the success of LEDs and their extremely low power requirements some vendors have started offering lighting integrated with Ethernet networks which draw their power from the low voltage wiring of the network and are directly controlled on the network. These have been primarily commercial installations.



Advantages: Potential savings comes from increased control and any increased penetration of high efficacy lighting into the market.

Potential Barriers: Wire gauge and potential DC voltage drops over the networks are barriers to more widespread application. Final cost per circuit is high when compared to basic, traditional AC lighting installations.

Outlook: Power over Ethernet systems are not currently applied in the residential sector. Retrofit of existing homes would be cost prohibitive. With the current high cost, it is likely that PoE systems will first be adopted in commercial applications, with early residential applications limited to high-end residential new construction. The potential to drive significant near term energy savings in the residential sector seems low.

Readiness Levels:

Category	**Scores**
Market/Commercial	**LEVEL 1:** Not commercially available or limited, pre-commercial availability
Product	**LEVEL 2:** Concept validated
Program	**LEVEL 1:** No program design. No risk assessment.

DC Power Distribution

Technology Description: Many electrical power uses in the home require direct current (DC) including computers, electronics and LED and fluorescent lighting. Since utilities supply AC power to the home, a driver or ballast is required to convert power from AC to DC. This conversion is not 100% efficient and the additional ballast or driver adds cost to the lighting.

If DC power was available at the outlet, it could reduce the cost to manufacture many types of lamps and fixtures by eliminating ballasts and drivers. As we see an increasing number of homes with photovoltaic (PV) generation of DC power and/or electric vehicles with battery storage for DC power, it may become advantageous to consider at what point the cost of independent distribution of DC power in the home alongside of AC power would be offset by the lower cost of lighting systems without drivers and ballasts.

Advantages: Reduced cost lamps and ballasts without drivers and ballasts.

Potential Barriers: Voltage drop can be an issue with DC distribution. In DC circuits, voltage gradually drops as it travels along through a length of wire. So, with every foot of wire, the available voltage gradually decreases along the length of wire.

Outlook: It will be difficult to change a major infrastructure such as AC distribution systems and retrofit of existing homes would be cost prohibitive. It is likely that DC systems will first be adopted in commercial applications, with early residential applications limited to high-end residential new construction where PV solar is also installed. The potential to drive significant near term energy savings in the residential sector seems low.

Readiness Levels:

Market/Commercial	**LEVEL 1:** Not commercially available or limited, pre-commercial availability
Product	**LEVEL 2:** Concept validated
Program	**LEVEL 2:** Not cost effective, but preliminary analysis shows a pathway to CE. Limited program design and risk assessment.

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