U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Adoption of Light-Emitting Diodes in Common Lighting Applications

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Comments

The Energy Department is interested in feedback or comments on the materials presented in this document. Please write to Brian Walker, Lighting R&D Program Manager:

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List of Acronyms and Abbreviations

AEO	Annual Energy Outlook
BR	Bulged Reflector
BTU	British Thermal Unit
CCT	Correlated Color Temperature
CFL	Compact Fluorescent Lamp
CFR	Code of Federal Regulations
DLC	DesignLights Consortium
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act
EMS	Energy Management Systems
GSFL	General Service Fluorescent Lamp
HID	High Intensity Discharge
HPS	High Pressure Sodium
IRL	Incandescent Reflector Lamp
LED	Light-Emitting Diode
lm	Lumen
LMC	Lighting Market Characterization
LPS	Low Pressure Sodium
MH	Metal Halide
MR	Multifaceted Reflector
MV	Mercury Vapor
PAR	Parabolic Aluminized Reflector
Quad	Quadrillion British Thermal Units
R	Reflector
SSL	Solid-State Lighting
tBtu	Trillion British Thermal Units
TWh	Terawatt-hour
U.S.	United States
W	Watt

Executive Summary

This 2020 report presents the findings for major general illumination lighting applications where light-emitting diode (LED) products are competing with traditional light sources. The lighting applications selected for this study include: A-type, decorative, directional, small directional (MR16), downlighting, linear fixtures, low/high bay, area/parking lot, parking garage, street/roadway, and building exterior.

For each of the above listed applications, this report addresses the following four questions while excluding attributable standby loads for connected lightings:

- In the year 2018, how much energy was consumed by lighting technologies?
- What is the 2018 estimated cumulative installed penetration[1] of LED lamps, retrofit kits, luminaires, and connected lighting systems?
- What are the actual energy savings resulting from the 2018 level of LED and connected lighting penetration?
- What would the theoretical energy savings be if 100% penetration was achieved with LED products that are enabled with connected lighting systems and represented by the top 95th percentile of efficacy of products available in 2018?

To estimate how LED lighting penetration changed in 2018, *U.S. DOE Lighting Market Model* is used as the foundation and analytical engine for this study. The following three scenarios were developed to estimate the cumulative installed penetration[2] of LED technology, the resulting energy savings, and the technical potential for LED and connected lighting systems in 2018.

Reference Case Scenario A comparative scenario modeled based on the level of LED adoption on the market in 2010. This scenario, where the market is dominated by incandescent, halogen, fluorescent, and HID sources, is used as the reference condition from which 2018 LED and connected lighting energy savings are calculated.

2018 LED Adoption The estimated cumulatively installed penetration as of 2018 of LED products and the associated energy savings due to that existing installed stock of LED lamps, retrofit kits and luminaires, and connected lighting systems.

2018 Technical Potential The theoretical energy savings if 100% LED penetration was achieved with LED products that are enabled with connected lighting systems and represent the top 95th percentile of efficacy based on products available in 2018.

The 2018 LED Adoption scenario estimates the U.S. lighting inventory in general illumination applications for 2018, including LED lighting, connected lighting controls and conventional lighting technologies. The 2018 Technical Potential[3] scenario represents the technical potential of LED lighting and connected controls based on 2018 performance levels. The Reference Case scenario, as indicated above, is used as a comparative condition from which SSL energy savings are calculated for both the 2018 LED Adoption and 2018 Technical Potential scenarios. In the Reference Case scenario, LED products are assumed to have their level of

[1] Cumulative installed penetration refers to the installed inventory of LED lighting products relative to the installed inventory of all lighting technologies.
[2] Cumulative installed penetration refers to the installed inventory of LED lighting products relative to the installed inventory of all other lighting technologies.
[3] In previous LED Adoption reports, this scenario was referred to as the Energy Savings Potential scenario.

penetration on the general illumination market in 2010, which is essentially negligible, but all other market conditions, such as energy conservation standards for conventional technologies, are unchanged.

For both the 2018 LED Adoption and 2018 Technical Potential scenarios, connected lighting systems are assumed to be an LED-based lighting system with integrated sensors and controllers that are networked (either wired or wireless), enabling lighting products within the system to communicate with each other and transmit data. The additional potential savings for connected lighting systems are estimated separately and represent additional savings beyond those achieved through LED lighting efficacy improvement alone.

The summary results for the 2018 LED Adoption and 2018 Technical Potential are provided below in Table ES.1.

Table ES.1 2018 LED Lighting Installations and Energy Savings by Application

Application	2016 LED Installed Penetration (%)	2018 LED Installed Penetration (%)	2018 LED Units Installed[1] (Millions)	2018 Energy Savings (tBtu)	2018 Technical Potential (tBtu)[2]
A-Type	15.3%	32.9%	1,144	167.9	486.6
Decorative	7.9%	16.0%	207.0	72.2	321.6
Directional	23.6%	43.0%	228.3	70.4	144.5
Small Directional	28.4%	49.7%	43.7	25.0	35.5
Downlighting	23.9%	44.8%	308.0	148.4	242.2
Linear Fixture	9.4%	20.1%	224.0	73.8	673.7
Low/High Bay	8.9%	17.1%	18.0	199.4	727.6
Total Indoor	**14.6%**	**29.8%**	**2,173**	**757.1**	**2,632**
Street/Roadway	28.0%	48.6%	24.2	93.3	244.9
Parking Garage	37.3%	69.1%	19.0	156.8	276.2
Parking Lot	28.0%	54.0%	27.1	182.5	392.2
Building Exterior	23.2%	45.8%	39.5	103.3	218.2
Total Outdoor	**27.2%**	**51.4%**	**109.7**	**535.9**	**1,131**
Other	7.7%	14.5%	29.2	19.0	189.6
Connected Controls	**<0.1%**	**0.2%**	**13.5**	**15.7**	**1,101**
Total All[3]	**14.9%**	**30.0%**	**2,325**	**1,328**	**5,054**

1. Installations are the total cumulative number of LED lamps and luminaires that have been installed as of 2018.

2. The Estimated Savings Potential is the theoretical energy savings that would result from switching all lighting fixtures "overnight" in the given application to the top 95th percentile of LED products available. It is important to note that these "best of" LED products have efficacies much higher than those most commonly available.

3. Values may not add due to rounding.

The major findings of the analysis include the following:

- From 2016 to 2018, installations of LED products have increased in all applications, roughly doubling to 2,325 million units, increasing LED penetration to 30.0% of all general illumination lighting.

- A-type lamps represent nearly half of all LED lighting installations and have increased to an installed penetration of 32.9% in this application. In 2018, penetration of LED lighting into decorative applications represents the lowest (non-Other) of all general illumination applications; however, it has increased from 7.9% in 2016 to 16.0% in 2018. Penetration of connected lighting controls remains small, with only 0.2% of lighting installed with these systems in 2018.

- In the outdoor sector, parking garages are estimated to have the highest penetration of LED lighting at 69.1% in 2018. In 2018, when comparing indoor versus outdoor applications, LED lighting has a higher penetration in outdoor applications, at 51.4%, compared to indoor applications where LED lighting has a total penetration of 29.8%. Although the total LED units installed in outdoor applications are much lower compared to indoor (5% and 95% of total LED installations, respectively), the energy savings impact in 2018 of outdoor LED lighting is comparable to indoor lighting (536 tBtu and 757 tBtu, respectively) due to the higher LED penetration and high lumen output tendencies in outdoor applications.

- The cumulative installed penetration of LED and connected lighting as of 2018 provided approximately 1,328 trillion British thermal units (tBtu) in source energy savings in 2018, which is equivalent to an annual cost savings of about $14.7 billion.

- Annual source energy savings could approach 3,953 tBtu, about 4 quadrillion Btu (quads), if top tier 2018 LED products instantaneously reach 100% penetration in all applications. If these same top tier products were also configured with connected lighting controls, they would enable an additional 1,101 tBtu of energy savings for a total of 5,054 tBtu or 5 quads. Energy savings of this magnitude would result in an annual energy cost savings of about $56 billion. Linear fixture and low/high bay applications offer the highest technical potential when paired with connected controls, as shown in Figure ES.1.

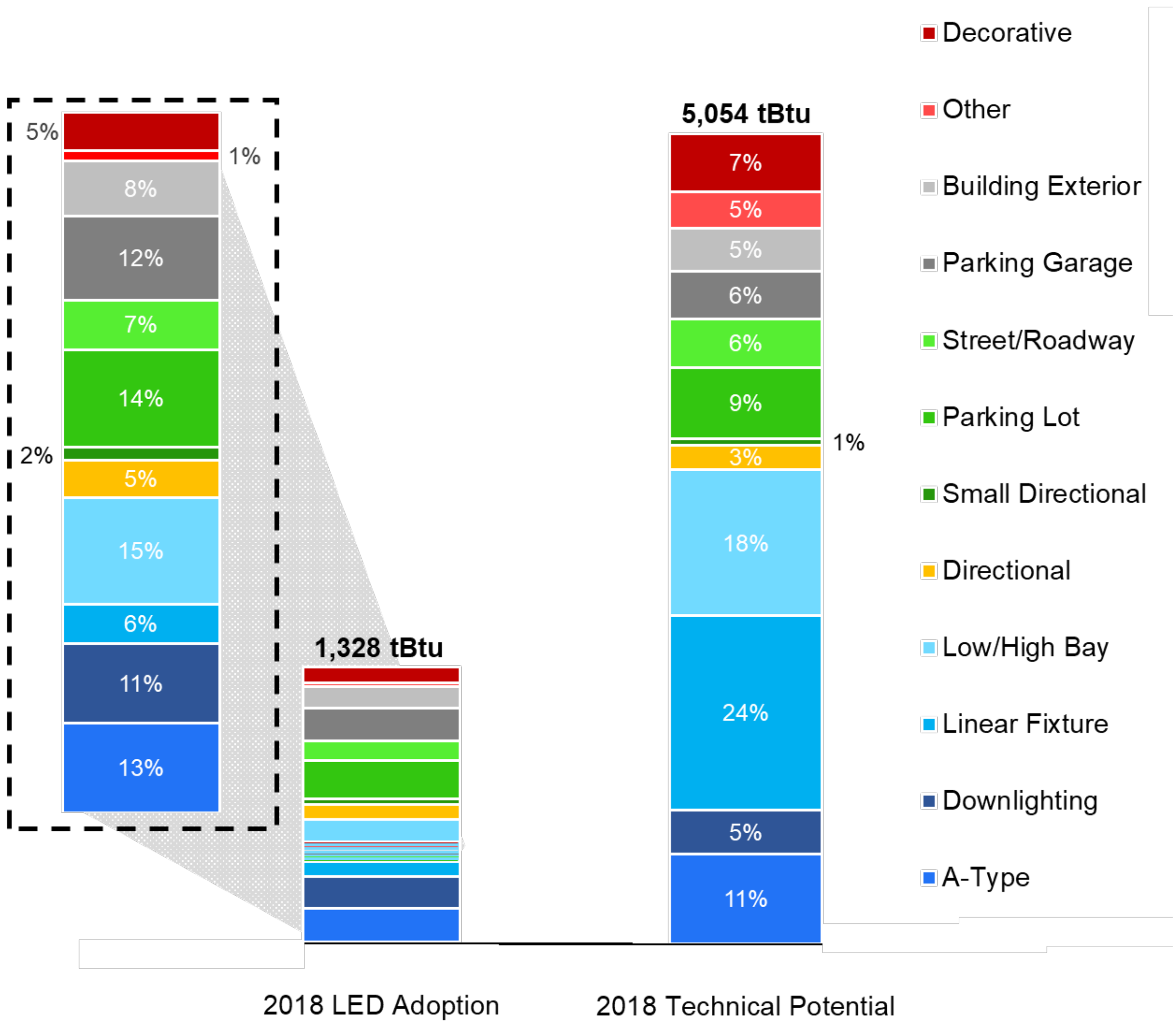

Figure ES.1 Comparison of 2018 Adoption and Technical Potential from LED Lighting. In 2018, LED and connected lighting contributed 1,328 tBtu in source energy savings, but if all lighting installations were converted to top tier LED products (100% LED penetration, 95th percentile efficacy) with connected lighting controls, LED savings could reach 5,054 tBtu.

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1. Introduction

Since 2003, the U.S. Department of Energy (DOE) has evaluated the lighting applications where LED technologies are having the greatest energy savings impact. This assessment provides an update to the *2017 Adoption of LEDs in Common Lighting Applications*[4] report and investigates the 2018 adoption and resulting energy savings of both LED and connected lighting systems in general illumination applications. The lighting applications selected for this study include: A-type, decorative, directional, small directional (MR16), downlighting, linear fixtures, low/high bay, parking lot, parking garage, street/roadway, building exterior, and an "other" category, which includes indoor and outdoor lighting products that account for less common LED products and those that occupy unknown applications.

For each of the above listed applications, this report addresses the following four questions:

- In the year 2018, how much energy was consumed by lighting technologies?
- What is the 2018 estimated cumulative installed penetration[5] of LED lamps, retrofit kits, luminaires, and connected lighting systems?
- What are the actual energy savings resulting from the 2018 level of LED and connected lighting penetration?
- What would the theoretical energy savings be if 100% penetration was achieved with LED products that are enabled with connected lighting systems and represented by the top 95th percentile of efficacy of products available in 2018?

For this report, connected lighting systems are assumed to be LED-based lighting systems with integrated sensors and controllers that are networked (either wired or wireless), enabling lighting products within the system to communicate with each other and transmit data. The energy savings for connected lighting systems are estimated separately and represent additional savings (by reducing operating hours and light output, when applicable) beyond those achieved through LED lighting efficacy improvement alone.

Since the designs of LED lighting products vary significantly, products installed in each of the analyzed applications are classified as LED lamp replacements, retrofit kits, or luminaires. In some applications, LED lamps, retrofit kits, and luminaires are competing for market share, while in some there is only one product type. Typically, LED lamps and retrofit kits are designed to be direct replacements for existing incandescent, halogen, compact fluorescent, and high-intensity discharge (HID) lamps and function using the existing fixture and possibly the ballast. In contrast, LED luminaires represent a complete change-out of the existing lamp, ballast, and fixture system. Table 1.1 indicates which LED product types (lamps, retrofit kits, and/or luminaires) are analyzed within each of the applications, provides a description, and includes example LED product images.

[4] The 2017 report is available at: https://www.energy.gov/sites/prod/files/2017/08/f35/led-adoption-jul2017_0.pdf.

[5] Cumulative installed penetration refers to the installed inventory of LED lighting products relative to the installed inventory of all lighting technologies.

Table 1.1 Summary of LED Product Descriptions for Each Application Evaluated in 2018

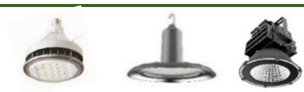
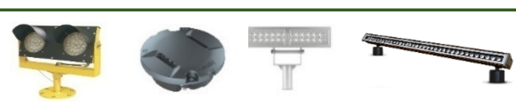
Application	Type	Description	Examples
A-type	Lamp	A-type lamp shapes with a medium-screw base.	
Decorative	Lamp and Luminaire	Bullet, candle, flare, globe, and any other decorative lamp shapes, as well as integrated chandelier, single head pendant, wall sconce, lantern, and cove luminaire products.	
Directional	Lamp and Luminaire	Reflector (R), bulged reflector (BR), and parabolic reflector (PAR) lamps, as well as track heads and integrated track luminaires.	
Small Directional	Lamp	Multifaceted reflector (MR) lamps.	
Downlighting	Lamp, Retrofit Kit and Luminaire	Reflector (R), bulged reflector (BR), and parabolic reflector (PAR) lamps used for downlighting, as well as, retrofit kits and integrated downlight luminaires.	
Linear Fixture	Lamp, Retrofit Kit and Luminaire	Lamp replacements for T12, T8, and T5 fluorescent lamps, as well as retrofit kits and luminaires replacing traditional fluorescent fixtures (i.e., troffers, linear pendants, strip, wrap around, and undercabinet).	
Low/High Bay	Lamp and Luminaire	High wattage lamp replacements as well as low and high bay integrated fixtures.	
Indoor Other	Lamp and Luminaire	Lamps with uncommon base types (e.g.., festoon, mini bi-pin, etc.), luminaires designed for portable, specialty, and emergency applications (white), and rope/tape lights.	
Area/Parking Lot	Lamp and Luminaire	High wattage lamp replacements, as well as luminaires used in parking lot and top deck parking garage illumination.	
Parking Garage	Lamp and Luminaire	Replacement lamps and luminaires for attached and stand-alone covered parking garages.	
Street/ Roadway	Lamp and Luminaire	Replacement lamps and luminaires installed in street and roadway applications.	
Building Exterior	Lamp and Luminaire	Lamps and luminaires installed in façade, spot, architectural, flood, wall pack, bollard, and step/path applications. Not including solar cell products.	
Outdoor Other	Lamp and Luminaire	Lamps and luminaires used in signage, stadium, billboard (white), and airfield lighting.	
Connected	Lamp and Luminaire	Lamps and luminaires that implement the four traditional control strategies (i.e., dimming, daylighting, occupancy sensors, and timers) and enable communication between users and other lamps and luminaires.	

Image Sources: Grainger and Home Depot websites

2. Analytical Approach

The *U.S. DOE Lighting Market Model*, described in the DOE SSL Forecast Report, predicts LED market penetration and energy savings compared to conventional lighting sources – incandescent, halogen, fluorescent, and HID – in general illumination applications from present day through 2035.[6] The *U.S. DOE Lighting Market Model* is used as the foundation and analytical engine for this study. The following three scenarios were developed in the model to estimate the cumulative installed penetration[7] of LED technology, the resulting energy savings, and the technical potential for LED and connected lighting systems in 2018.

Reference Case Scenario A comparative scenario modeled based on the level of LED adoption on the market in 2010. This scenario, where the market is dominated by incandescent, halogen, fluorescent, and HID sources, is used as the reference condition from which 2018 LED and connected lighting energy savings are calculated.

2018 LED Adoption The estimated actual 2018 cumulatively installed penetration of LED products and the associated energy savings due to that existing installed stock of LED lamps, retrofit kits and luminaires, and connected lighting systems.

2018 Technical Potential The theoretical energy savings if 100% LED penetration was achieved with LED products that are enabled with connected lighting systems and represent the top 95th percentile of efficacy based on products available in 2018.

The 2018 LED Adoption scenario estimates the U.S. lighting inventory in general illumination applications for 2018, including LED lighting, connected lighting controls, and conventional lighting technologies. The 2018 Technical Potential[8] scenario represents the technical potential of LED lighting and connected controls based on 2018 performance levels. The Reference Case scenario, as indicated above, is used as a comparative condition from which SSL energy savings are calculated for both the 2018 LED Adoption and 2018 Technical Potential scenarios. In the Reference Case scenario, LED products are assumed to have their level of penetration on the general illumination market in 2010, which is essentially negligible, but all other market conditions, such as energy conservation standards for conventional technologies, are unchanged.

For both the 2018 LED Adoption and 2018 Technical Potential scenarios, connected lighting systems are assumed to be an LED-based lighting system with integrated sensors and controllers that are networked (either wired or wireless), enabling lighting products within the system to communicate with each other and transmit data.

The following sections explain the assumptions and methodology used to determine the resulting energy savings in the 2018 LED Adoption and 2018 Technical Potential scenarios.

2.1. 2018 LED Adoption

To estimate the energy savings for the 2018 LED Adoption, the *U.S. DOE Lighting Market Model* results presented in the DOE SSL Forecast Report are used as a starting place to determine the 2018 lighting inventory. The *U.S. DOE Lighting Market Model* uses assumptions of projected efficacy, retail price, lighting control usage, and operating life to predict trends in lighting technology use – and ultimately provides estimates for the installed base of LED lighting as well as conventional lighting technologies.

[6] U.S. DOE Lighting R&D Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared by Navigant Consulting, Inc., December 2019. The full report can be found at: https://www.energy.gov/sites/prod/files/2019/12/f69/2019_ssl-energy-savings-forecast.pdf
[7] Cumulative installed penetration refers to the installed inventory of LED lighting products relative to the installed inventory of all other lighting technologies.
[8] In previous LED Adoption reports, this scenario was referred to as the Energy Savings Potential scenario.

The 2018 LED lighting outputs from the model are then updated and calibrated using sales and financial reports provided by manufacturers, retailers, industry experts, and utilities, in addition to shipment data from the National Electrical Manufacturers Association (NEMA), retailer point-of-sale (POS) and ENERGY STAR®. As depicted in Figure 2.1, this data collection and interview process serves as the primary source for updating the 2018 outputs. All input provided by the contributing parties is kept confidential and is used to revise and calibrate the 2018 U.S. lighting inventory estimate.

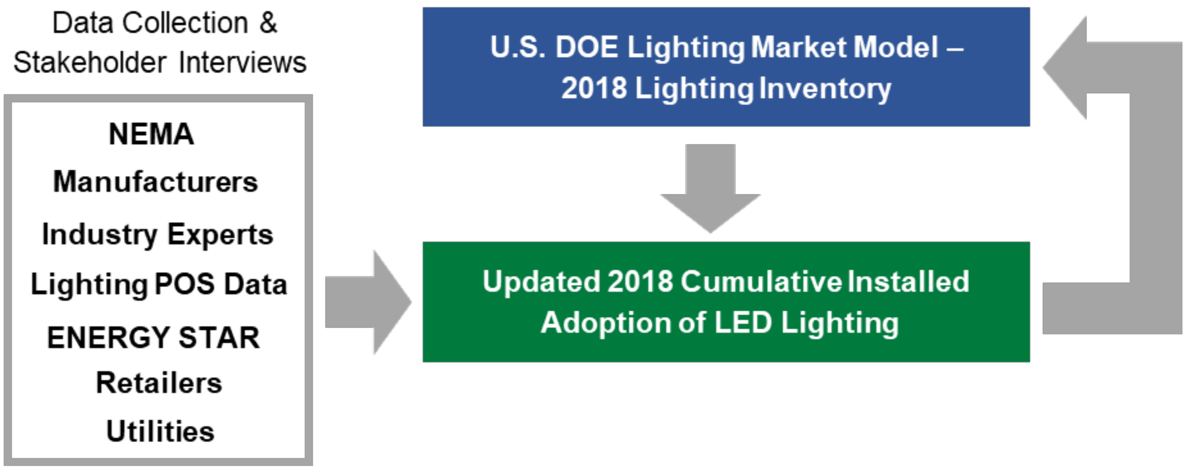


Figure 2.1 2018 LED Adoption Estimation Methodology. The data collection efforts leveraged multiple types of stakeholders, and the 2018 LED sales data were used to update the U.S. DOE Lighting Market Model and determine the cumulative installed inventory as of 2018.

As indicated by Figure 2.1 above, the results discussed in this report are in terms of cumulative installations and not shipments of lighting products. As such, the LED lighting penetration in terms of cumulative installations is lower compared to its market share of unit shipments. The reason for this is twofold: (1) the total number of lighting products installed (i.e., the U.S. inventory of lighting) is significantly larger than the total number shipped each year – this is because the lifetime of lighting products in several applications exceeds one year; (2) the cumulative installed penetration of LED lighting increases as it replaces conventional lighting technologies. Therefore, when an existing LED product installed is replaced by a newer LED product, either due to failure or lighting upgrade, this results in no net gain to the installed penetration of LED lighting. The significance of this phenomenon increases the longer a technology is available on the market and is affecting the cumulative installed stock of LED lighting.

Once the 2018 lighting inventory is determined, the model uses the Reference Case scenario to calculate the resulting LED energy savings. As previously mentioned, in the Reference Case scenario, LED products are assumed to have their level of penetration on the general illumination market in 2010, but all other market conditions, such as energy conservation standards for conventional technologies, are unchanged. Therefore, taking the difference in energy consumption of the Reference Case and 2018 LED Adoption scenarios best represents the resulting energy savings impact of LED lighting technology in general illumination applications.

The energy savings estimates for the 2018 LED Adoption scenario are highly dependent on which conventional technologies are replaced by LED lamps, retrofit kits, and luminaires, as well as the installation and use of lighting controls and connected lighting systems. In addition, wattage within each application also varies for lamps and luminaires in residential, commercial, industrial, and outdoor installations. Assumptions for average wattages and annual operating hours for each lighting type installed in each sector are taken from the *U.S. DOE Lighting Market Model*. LED products are assumed to have the same operating hours as the most energy efficient conventional lighting type within each of the applications. Where available, average wattages for LED lamps, retrofit kits, and luminaires were determined by averaging the performance of products listed in the DOE's LED Lighting Facts®, DesignLight Consortium (DLC), and ENERGY STAR databases as available in 2018 (i.e., products added during 2018 but not archived before December 31, 2018).

In some cases, the data for products entering the market in 2018 were limited, so these product categories were supplemented with 2017 data using the assumption that 2017 products were still sold on the market in 2018. These updated LED product wattages used for each application are provided in Table 2.1.

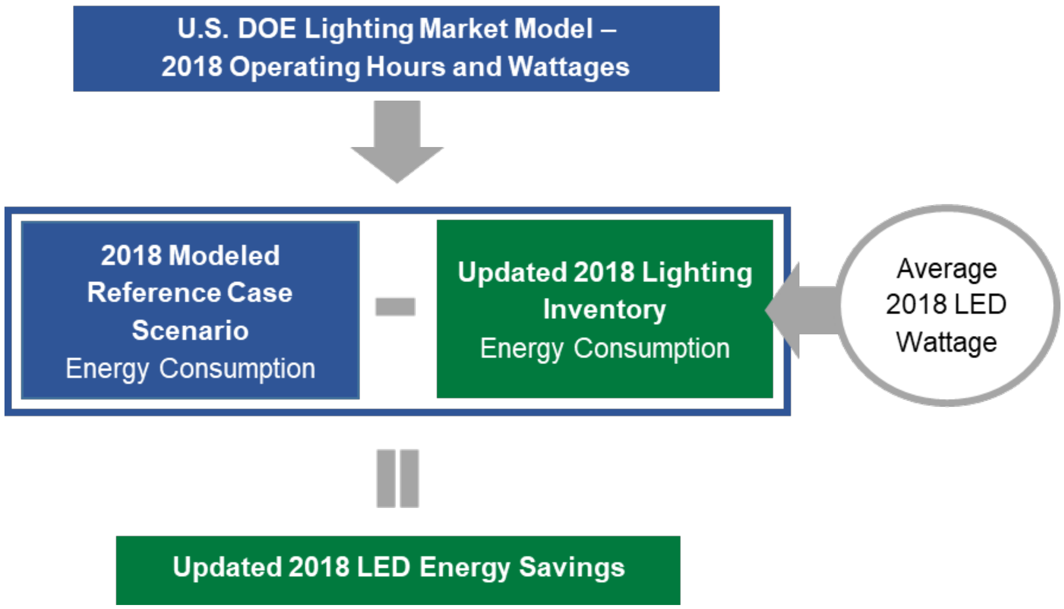


Figure 2.2 2018 LED Energy Savings Methodology. The energy savings attributed to LED lighting in 2018 were based on the energy consumption of a reference scenario with negligible LED penetration and the updated 2018 lighting inventory base.

The *U.S. DOE Lighting Market Model* also calculates the market share of various control systems, including single strategy (i.e., dimming, occupancy sensing, timers, and daylighting), multi-strategy, energy management systems (EMS), and connected lighting[9] for both the Reference Case and the 2018 LED Adoption scenarios. The energy savings per control system are calculated, accounting for the energy saving effect of the control (turning lights off or reducing wattage) and the percent of time that each control strategy is used.

A discussion of how the *U.S. DOE Lighting Market Model* determines energy savings from the penetration of LED lighting installed with connected controls is discussed in the following section.

2.2. 2018 Technical Potential

The methodology used in the 2018 Technical Potential scenario applied the following assumptions:

- LED products instantaneously reach 100% penetration, representing all U.S. lighting installations.[10]
- These installed LED products are enabled with connected controls and represent the top 95th percentile of efficacy performance based on products available in 2018.

As indicated earlier, connected lighting systems represent a substantial opportunity for energy savings. The results presented in the DOE SSL Forecast Report indicate that of the forecasted 4.8 quads in annual energy savings (due to LED adoption at the current pace) by 2035, 12% of those savings is made possible by the

[9] It is assumed that connected controls systems are exclusive to LED lighting and are not available with conventional lighting technologies (i.e., incandescent, halogen, fluorescent, and HID). However, for all other control systems, including single-strategy, multi-strategy, and energy management systems, any lighting technology can be employed.
[10] The theoretical potential savings are based on complete market transformation, which is highly unlikely. Market changes may increase or decrease the potential energy consumption and savings of LEDs per the overall size of the application.

penetration of LED lighting installed with connected controls. Therefore, connected lighting systems provide a large opportunity for energy savings in the U.S. and represent a significant portion of the technical potential.

These additional savings for connected controls are estimated separately and represent the theoretical maximum savings achieved if the top-performing connected lighting systems of 2018 reach 100% penetration.

The “top tier” 2018 efficacy performance is assumed to be characterized by the 95th percentile for each application, and it is determined by averaging the 95th percentile of tested (not rated) efficacy performance of products listed in the DOE’s LED Lighting Facts, DLC, and ENERGY STAR, as available in 2018, as noted in the previous section. Rather than the most efficacious LED product available based on rated performance, the 95th percentile of tested efficacy is used to eliminate outliers and more accurately identify the top tier of 2018 LED performance. It is also important to note that the three databases do not cover the full range of LED applications analyzed in this report. Therefore, as seen below in Table 2.1, the overall average of the three efficacy values (i.e., 5th percentile, average, and 95th percentile) is often an average of fewer than the three possible data points.

To illustrate the wide range of performance in available products within each application, Table 2.1 shows the 5th percentile, average, and 95th percentile of efficacious LED products listed in each of the above-mentioned LED product databases. Overall, LED efficacies have improved from 2016 to 2018. However, in some applications, the top-tier 95th percentile LED efficacy (which are used in the calculation of Technical Potential) may be slightly lower in 2018 relative to 2016. This is primarily due to more manufacturers focusing on producing LED products at a cost competitive performance level (closer to average) as market saturation increases.

Table 2.1 **Range of 2018 Product Efficacies in DesignLight Consortium, DOE LED Lighting Facts®, and ENERGY STAR databases**

Application	Product Type	LED Replacement Description	Overall 2018 LED Efficacy (lm/W)			Design Light Consortium			DOE's LED Lighting Facts®			ENERGY STAR®		
			5th Percentile	Avg.	95th Percentile	5th Percentile	Avg.	95th Percentile	5th Percentile	Avg.	95th Percentile	5th Percentile	Avg.	95th Percentile
A-type	Lamp	A-type replacement lamps.	**80**	**92**	**110**							80	92	110
Decorative	Lamp	B, BA, C, CA, F, and G replacement lamps.	**67**	**86**	**104**							67	86	104
	Luminaire	Integrated chandelier, single head pendant, wall sconce, lantern, and cove luminaires.	**55**	**80**	**109**				41	77	114	69	84	104
Directional	Lamp	PAR, BR, and R lamps.	**69**	**79**	**95**							69	79	95
	Luminaire	Track heads and integrated track luminaires.	**65**	**94**	**119**	65	83	104	65	104	134			
Small Directional	Lamp	MR16 lamps.	**63**	**74**	**83**							63	74	83
Downlighting	Retrofit	Downlight retrofit kits.	**64**	**74**	**85**				67	75	85	60	72	86
	Luminaire	Integrated downlight luminaires.	**59**	**75**	**110**				60	80	131	57	70	90
Linear Fixtures	Lamp	Linear tube replacements.	**107**	**127**	**145**	109	126	145	105	128	146			
	Luminaire	Panels and recessed/surface-mounted troffer luminaires.	**98**	**118**	**138**	99	118	135	97	118	140			
Low/High Bay	Lamp	High wattage lamp replacements.	**100**	**115**	**139**	100	115	139						
	Luminaire	Low and high bay luminaires.	**107**	**129**	**151**	108	128	146	106	130	157			
Street/Roadway	Luminaire	Outdoor area/roadway/decorative luminaires.	**97**	**118**	**138**	100	120	138	94	115	138			
Parking Lot	Luminaire	Outdoor area/roadway luminaires.	**95**	**114**	**135**	95	113	132	94	116	138			
Parking Garage	Lamp	Linear T8 tube replacements.	**109**	**127**	**146**	113	127	146	105	128	146			
	Luminaire	Integrated parking garage luminaires.	**95**	**113**	**132**	92	112	128	98	114	137			
Building Exterior	Luminaire	Spot and flood lights, architectural, wall pack, and step/path luminaires.	**59**	**97**	**122**	95	116	136	22	92	121	60	82	109
Other	Indoor	Lamps and luminaires for portable, specialty, and emergency applications (white) and rope/tape lighting.	**59**	**86**	**126**				51	89	135	66	82	117
	Outdoor	Lamps and luminaires used in signage, stadium, billboard (white) and airfield lighting.	**74**	**95**	**115**	100	105	114	53	97	136	70	82	96

The lighting controls module of the *U.S. DOE Lighting Market Model* was used to determine the impacts of connected lighting in the 2018 Technical Potential scenario. Connected lighting is assumed to be an LED-based lighting system with integrated sensors and controllers that are networked (either wired or wireless), enabling lighting products within the system to communicate with each other and transmit data. Connected lighting standby loads were not included in the calculation of energy savings from connected controls. As shown below in Table 2.2, the analysis assumes that the best available connected lighting systems of 2018 include four traditional control strategies (dimming, daylighting, occupancy sensing, and timing) and thus would have the capability of both reducing wattage and turning the light off.

Table 2.2 Connected Lighting Scope

Control System	Wattage Reduction Effect	On/Off Effect	Lighting Technologies Included	Categories Included
Connected Lighting	✓	✓	LED	Luminaire Level Lighting Controls "Smart" Lamps Advanced Networked

For connected lighting, the savings are calculated by "layering" all four traditional control strategies. Thus, if one control strategy has already turned the light off (e.g., an occupancy sensor), further savings cannot be achieved at that time from using another control strategy (e.g., dimming). An adjustment factor is then applied to account for the additional savings offered by connected systems due to their ability to communicate and the opportunity for use optimization through machine learning. The following equation shows how the energy savings for connected control systems are calculated.

$$Connected\ Control\ Energy\ Savings =$$

$$Baseline\ Load\ Profile - \left(Baseline\ Load\ Profile \times \sum_{Control\ Strategies} (Control\ Effect_{Control\ Strategy}) \right)$$

Where:

$$Control\ Effect_{Control\ Strategy} =$$

$$\sum_{Day\ Types} \sum_{Hours} \Big((Percent\ of\ Time\ Control\ Used \times Energy\ Reduction_{Control\ Strategy}) + (Percent\ of\ Time\ Control\ Not\ Used\ ) \Big)$$

The potential energy savings from connected controls are then calculated assuming all U.S. lighting installations operate with these systems. These savings represent the additional savings beyond those achieved through LED lighting efficacy improvement alone. In addition, this analysis of connected lighting considers 100% penetration in all applications regardless of current product availability. Standby loads attributable to the control systems for connected lighting were not included in the calculation of energy savings from connected controls.

2.3. Lighting Market Model Enhancements

In the recent DOE SSL Forecast Report,[11] several updates were made to the *U.S. DOE Lighting Market Model* to enhance its accuracy and market representation. Input data were updated for most model inputs based on

[11] U.S. DOE Lighting R&D Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared by Navigant Consulting, Inc., December 2019. The full report can be found at: https://www.energy.gov/sites/prod/files/2019/12/f69/2019_ssl-energy-savings-forecast.pdf

increased data availability. In addition to these updated input data, this iteration of the general illumination forecast improves upon the methodology used in past years' iterations in multiple ways. The model enhancements relevant to this report are outlined below:

1. Calibration based on estimated LED market share for years 2010-2018. The last iteration of the *U.S. DOE Lighting Market Model* was calibrated using LED market share data for years 2010 through 2015. With three more years of complete LED market data available *U.S. DOE Lighting Market Model* offers improved calibration to historical data and trends, and thus effectively improves the accuracy of model predictions.

2. Calibration based on 2015 LMC Stock. In the recent DOE SSL Forecast Report and in past years, the *U.S. DOE Lighting Market Model* used the 2010 LMC as its basis for initial stock in 2010. Additionally, for the DOE SSL Forecast Report, the 2015 LMC stock values for all technologies were used during the calibration process to inform growth trends by technology and adjust 2010 stock as needed.

3. Addition of LED luminaires into general purpose submarkets. In past iterations of the DOE SSL Forecast Report, it was assumed that LED luminaires would not be used in general purpose applications. Based on increased data availability from stakeholders, this assumption was updated with the understanding that LED luminaires are viable options for general purpose applications and will penetrate these submarkets.

2.4. Updated 2016 Results

Given the *U.S. DOE Lighting Market Model* updates described in Section 2.3, the results representative of the 2016 installation year that were presented in the 2017 LED Adoption report[12] have been updated for this analysis and republished in this report to enable more accurate comparisons between 2016 and 2018. These updated 2016 results are presented throughout Section 3 alongside the 2018 results.

3. Results

In 2018, the total energy consumption in the U.S. was 100.1 quads of primary energy, according to the U.S. Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2019. Roughly 38 quads, or 38%, of this energy was consumed for electricity use. DOE estimated that in 2018, there were 7.7 billion lighting systems[13] installed in the U.S. and that they consumed approximately 5.6 quads of energy annually. Thus, according to the lighting estimates determined in this analysis, lighting accounted for 5.6% of the total energy and 15% of the total electricity consumed in the U.S. in 2018.[14]

The results of this analysis indicate that by the end of 2018, there were 2,3 billion cumulative LED lighting system installations in the U.S. These LED products are estimated to have saved 1,328 trillion British thermal units (tBtu) of source energy in 2018. As described in Section 2, the following three scenarios were developed using the *U.S. DOE Lighting Market Model* to estimate the cumulative installed penetration of LED technology, the resulting energy savings, and the technical potential for LED and connected lighting systems in 2018.

[12] The 2017 report is available at: https://www.energy.gov/sites/prod/files/2017/08/f35/led-adoption-jul2017_0.pdf.
[13] Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit). For example, a commercial troffer fixture operating two lamps on a single ballast is counted as one lighting system, and hence, one unit.
[14] Based on a total electricity consumption of 38 quads of source energy for residential, commercial, and industrial sectors from EIA's AEO 2019.

Reference Case Scenario A comparative scenario modeled based on the level of LED adoption on the market in 2010. This scenario, where the market is dominated by incandescent, halogen, fluorescent, and HID sources, is used as the reference condition from which 2018 LED and connected lighting energy savings are calculated.

2018 LED Adoption The estimated cumulatively installed penetration as of 2018 of LED products and the associated energy savings due to that existing installed stock of LED lamps, retrofit kits and luminaires, and connected lighting systems.

2018 Technical Potential The theoretical energy savings if 100% LED penetration was achieved with LED products that are enabled with connected lighting systems and represent the top 95th percentile of efficacy based on products available in 2018.

This section considers 12 lighting applications to investigate the results of the 2018 LED Adoption and 2018 Technical Potential scenarios.

The 2018 LED Adoption scenario estimates actual 2018 energy savings due to the existing installed stock of LED lamps, retrofit kits and luminaires, and connected lighting systems. When comparing the 2018 LED lighting stock to that of 2016, installations of LED lighting increased in all applications, roughly doubling from 1,127 million to 2,325 million units. Of the cumulative LED lighting installations at the end of 2018, 95% were in indoor applications, largely led by A-type lamps (roughly 50%) and followed by downlight lamps, retrofit kits and luminaires (roughly 13%). The breakdown of the 2018 LED lighting installed base by application is shown in Figure 3.1.

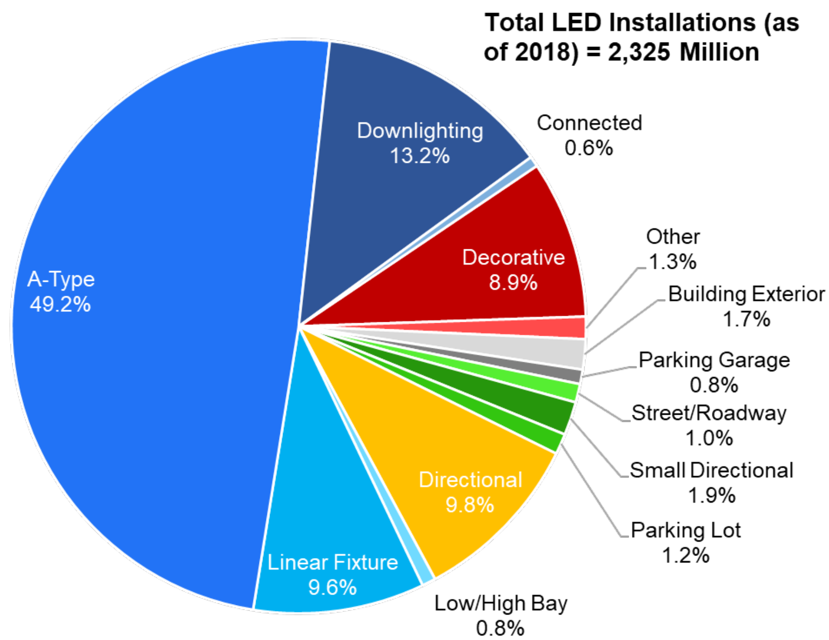


Figure 3.1 Total 2018 LED Unit Installations by Application. Out of the total 2,325 million LED installations as of 2018, nearly 50% are A-Type lamps, followed by downlighting, directional, and linear fixture applications. Indoor and outdoor products represented 95% and 5% of the installed base, respectively.

LED product adoption across all applications increased from 2016 to 2018, with overall adoption growing to 30% in 2018. This is still predominantly driven by the large volume of the A-type applications, the penetration of which has grown dramatically in the past six years, starting at less than 1% in 2012 and increasing to 32.9%

in 2018. Similarly strong increases were seen for decorative, directional, small directional, downlighting, linear fixture, and low/high bay applications, which saw installations rise to 16.0%, 43.0%, 49.7%, 44.8%, 20.1%, and 17.1%, respectively, in 2018. LED products in outdoor applications continue to make significant strides as well. In particular, parking garage and area/parking lot applications reached installed penetrations beyond 50%, while the other outdoor applications approached 50%.

As seen in Figure 3.2, overall, the adoption of LED lighting for general illumination is reaching the majority phase of product adoption, with most of the applications clustered in the "early majority" and "late majority" phases. Of the indoor market, LED products in small directional applications, mainly MR16 lamps, had early success and they continue to have the highest penetration of any indoor application studied in this report, growing from 10% in 2012 to now 49.7% in 2018. LED lighting with connected systems – still residing in the "innovators" phase – have had the least success penetrating the general illumination market due to their more recent market introduction, customer concerns regarding performance claims, defining the value proposition, complexity of installation and use, interoperability between systems and products, as well as high cost. However, connected LED products continue to improve and penetrate the market (now growing from approximately 4.5 million installations in 2016 to 13.5 million in 2018).

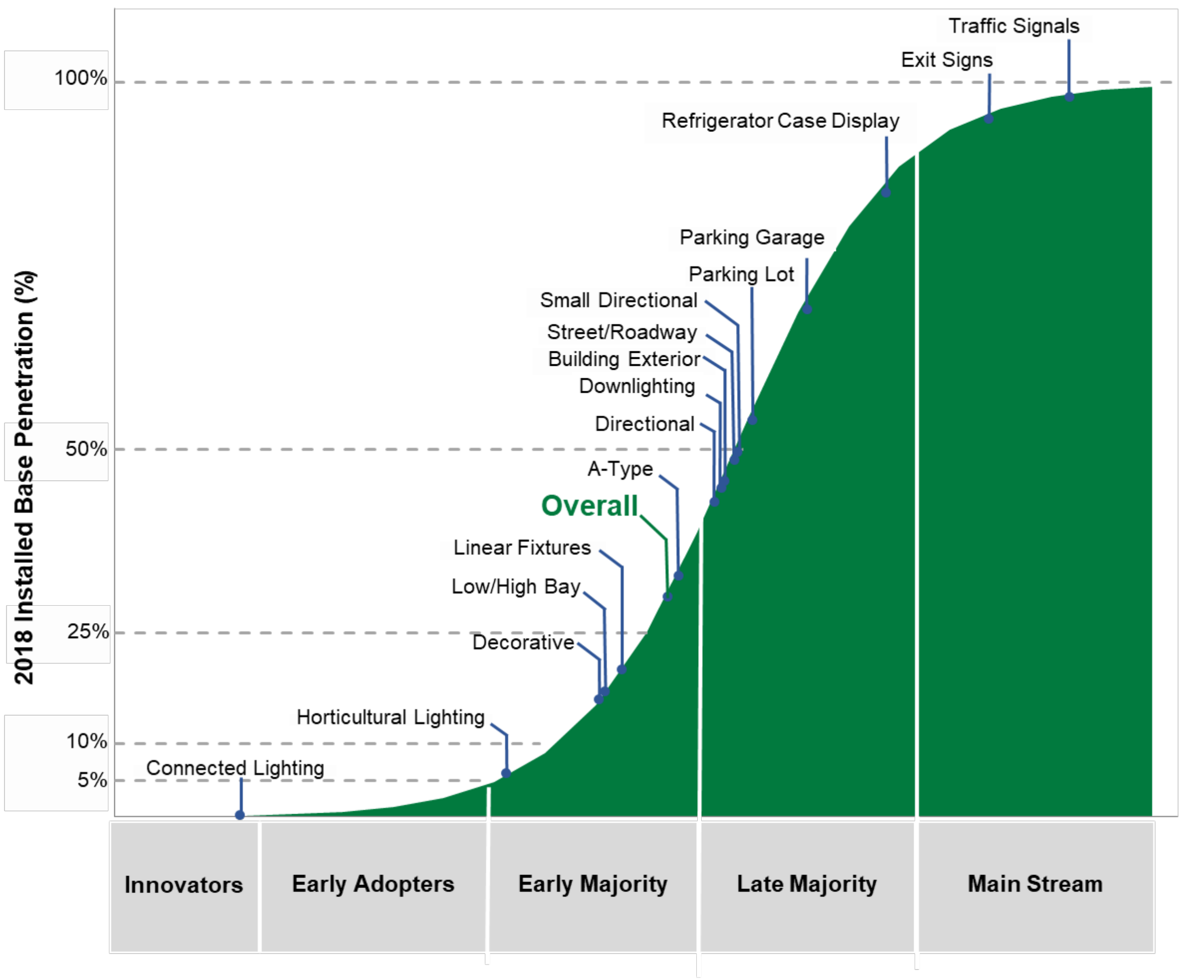


Figure 3.2 2018 Installed Adoption of LED Lighting Applications. Many general illumination LED applications have now reached the early and late majority phases of adoption.

As the installation of LED lighting continues to grow in general lighting applications, so do the energy savings. As seen in Figure 3.3 below, annual source energy savings in 2018 have nearly doubled since 2016, growing from 718 to 1,328 tBtu, which is equivalent to an annual energy cost savings of more than $14 billion. In 2018, LED products in low/high bay applications resulted in the greatest energy savings of any of the evaluated applications, providing approximately 15% of the total realized energy savings. This was followed closely by parking lot and A-Type products at 14% and 13%, respectively. Additionally, of the 2018 LED energy savings, it was estimated that the connected lighting systems installed in the U.S. contributed 15.7 tBtu of the overall savings enabled by LED technology.

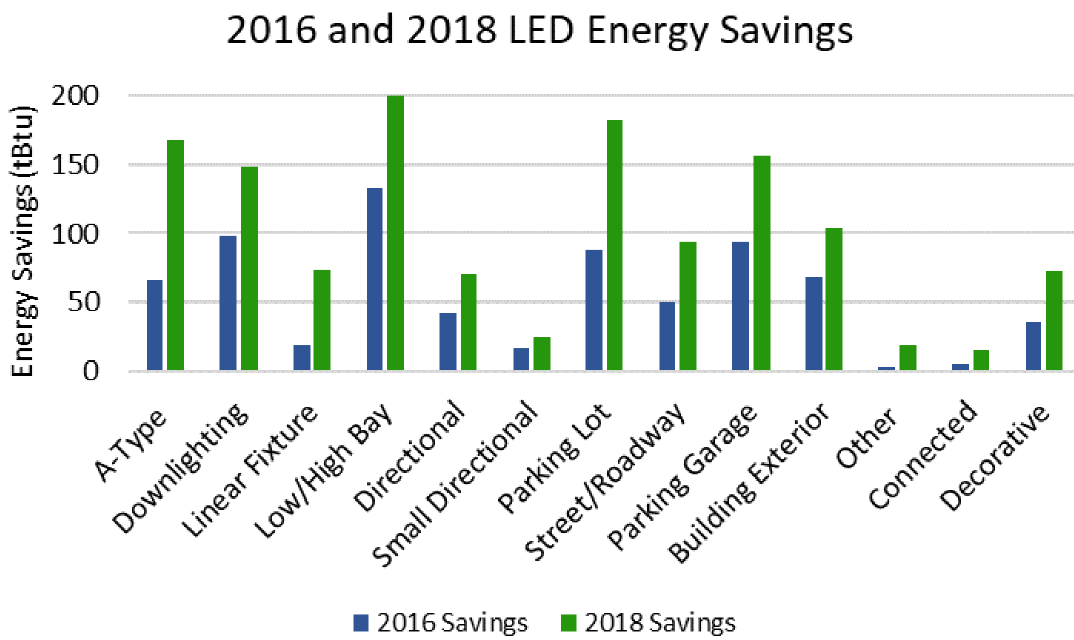


Figure 3.3 Comparison of 2016 and 2018 LED Energy Savings. Between 2016 and 2018, the annual energy savings attributed to the LED installed base nearly doubled, with low/high bay and area/parking lot applications contributing the most energy savings.

When considering the results of the 2018 Technical Potential scenario, it becomes clear that LED lighting combined with connected controls has much more to offer. If all 7.7 billion lighting systems in the U.S. were switched instantaneously to LED products that offer top-tier 2018 efficacy performance, they would provide 3,953 tBtu (about 4 quads) of energy savings. If these same top-tier LED products were also configured with connected controls, they would enable an additional 1,101 tBtu of energy savings for a total of 5,054 tBtu (about 5 quads). Energy savings of this magnitude would result in a total annual energy cost savings of about $56 billion.

While the energy savings results for the 2018 LED Adoption and 2018 Technical Potential scenarios are significant, the extent of energy savings depends not only on efficiency, but also the number of installations and the hours each installation is operated. For example, in 2018, 45% of U.S. lighting installations were A-type lamps, with over three billion units in use. However, the majority of A-type lamps are used in the residential sector and operate an average of less than two hours per day. Meanwhile, only 105 million low/high bay products were installed in the U.S. as of 2018, but they operate for an average of about 12 hours per day in the commercial and industrial sectors. Therefore, as shown in Figure 3.4, low/high bay fixtures have a total potential energy savings (attributed to LED savings) greater than A-type lamps (728 tBtu compared to 487 tBtu, respectively) despite the huge disparity in number of available installations.

Linear fixture applications also represent a significant portion of the total 2018 energy savings at 74 tBtu, and they are the second highest application in terms of the total 2018 potential energy savings attributed to LED savings (674 tBtu). However, when paired with connected controls, the vast remaining technical potential for linear fixtures becomes apparent. This impact is particularly evident in Figure 3.4 for linear fixture applications, where these savings represent 44% of total linear fixture potential. The connected controls savings potential for low/high bay applications is also significant, representing 20% of total low/high bay potential. Connected controls in these linear fixture and low/high bay applications are most impactful due to the long operating hours and high lumen outputs associated with the space types where these products are installed.

In the future, LED savings for linear fixtures could be much larger. In 2018, the 95th percentile efficacies for LED linear fixture lamp and luminaire products were 145 lm/W and 138 lm/W, respectively, while the U.S. DOE Lighting R&D Program anticipated in 2017 that troffer luminaires could reach 200 lm/W by 2020.[15] If these expected LED efficacy increases are realized in the future (near or long term), linear fixture applications will represent an even greater opportunity for potential LED energy savings.

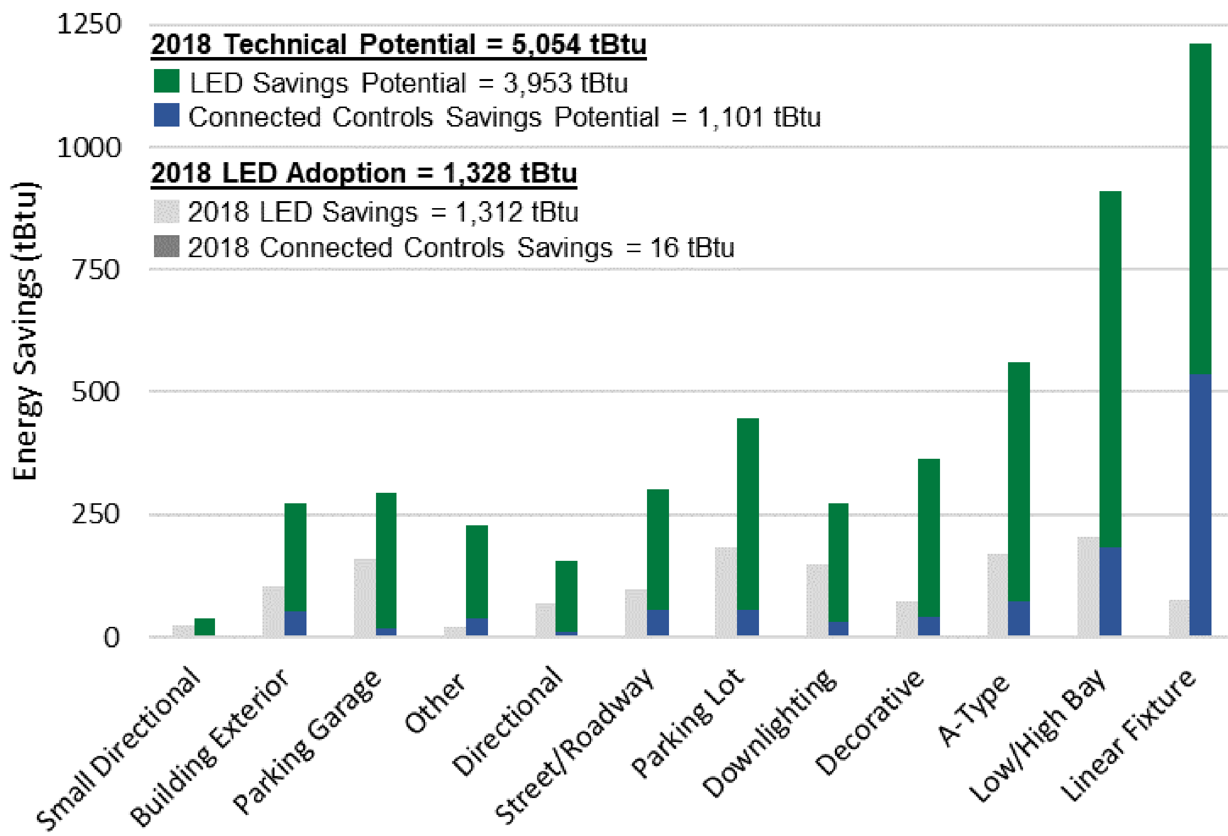


Figure 3.4 Current and Potential Energy Savings for LED Lighting and Connected Controls. Linear fixture and low/high bay applications offer the highest technical potential due to their long operating hours and high light outputs.

3.1. A-Type

Application	Type	Description	Examples
A-type	Lamp	A-type lamp shapes with a medium-screw base.	

This section presents the 2018 LED Adoption and 2018 Technical Potential results for LED replacements in the A-type lamp market, which includes standard A-type incandescent lamps, halogen lamps, CFLs, LED

[15] U.S. DOE Lighting R&D Program, *2017 Suggested Research Topics Supplement*, September 2017.

luminaires, and LED replacement lamps used in omnidirectional indoor applications. A-type lamps are considered the classic type of light bulb that has been used for general purpose lighting for over 100 years. These lamps have a medium screw base and typically have a pear-like shape. CFLs with a spiral/twister or mini-spiral/twister shape are also included in this section.

With nearly 3.5 billion A-type lamps installed in 2018, this represents the largest lighting market and one of the greatest opportunities for the LED lighting industry in terms of the number of available sockets and energy savings. In recent years, LED lamps have surged to nearly one-third (32.9%) of the A-type lamp market. Figure 3.5 below shows the growth (and respective decline) of each lighting technology between 2016 and 2018, and the LED growth can be attributed to a significantly decreased price and a boom in residential utility energy efficiency programs since 2012. The 2017 average price of an LED-based dimmable A19 60 W-equivalent lamp was $5.90 per lamp ($7.74/klm), while the early products introduced to the market between 2007-2009 had a typical cost over $50 per lamp.[16]

CFLs, though limited in current sales quantities, are still estimated to comprise the largest A-type market share at approximately 44%. This is due to their rise to popularity earlier in the decade and longer lifetimes. As with CFLs, the rapid rise of LED lamps in this market over the past two years occurred partially at the expense of halogen lamps, which combined with incandescent lamps, represent nearly a quarter of the market. Although utility programs have begun to phase out LED incentive programs due to the currently cost-competitive LED pricing (compared to conventional technologies), the pace of LED installations has yet to decline. In coming years, as sockets are continually filled with LED products with long lifetimes, this rapid installation rate will inevitably decline as LEDs reach main stream levels of adoption.

Connected LED products, however, have the market flexibility to eventually fill sockets currently occupied by both conventional and LED technologies. Though LED A-type products that offer color-changing and wireless controllability have become more prevalent in the A-type market, the penetration of LED lamps with connected controls is still estimated to be small, with an estimated stock of approximately one million (0.09% of the LED A-type market) units in 2018.

[16] U.S. DOE Lighting R&D Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared by Navigant Consulting, Inc., December 2019. The full report can be found at: https://www.energy.gov/sites/prod/files/2019/12/f69/2019_ssl-energy-savings-forecast.pdf

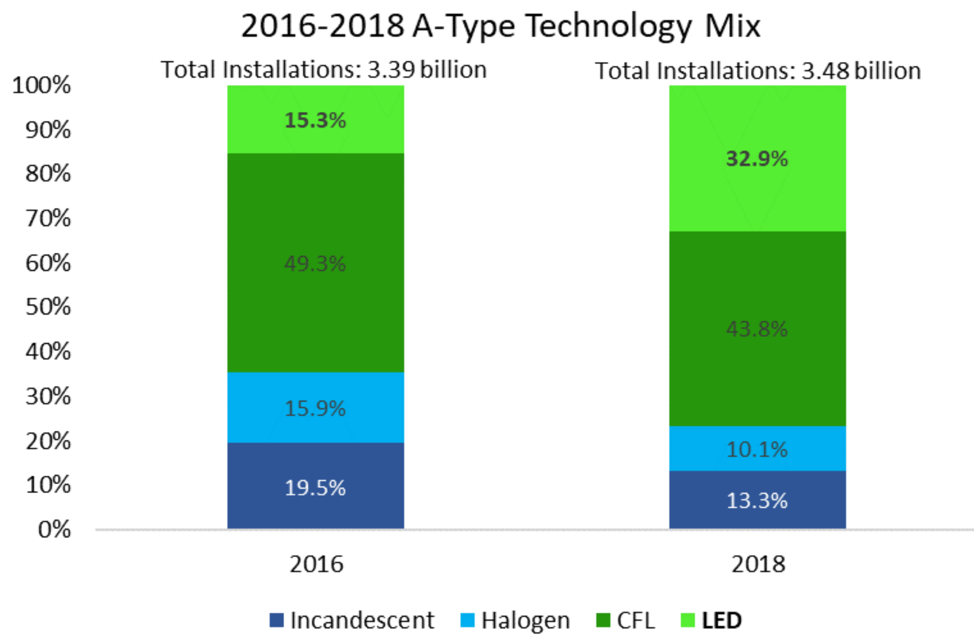


Figure 3.5 U.S. A-Type Installed Stock Technology Mix from 2016 to 2018. LED A-Type lamps have penetrated nearly one-third of the market.

The total energy consumption of A-type lamps decreased by roughly 16% from 616 tBtu to 515 tBtu since 2016. This decrease in energy use is largely due to the implementation of the EISA 2007 standards, which contributed to the reduction of incandescent lamps in favor of more efficient options (including LED lighting options), and price reductions of LED lamps. LED A-type lamps are the most prevalent product type in terms of installed units and the fourth most prevalent indoor product type in terms of installed penetration, and it was estimated that they saved about 17.6 TWh of site electricity, or about 167.9 tBtu of source energy, in 2018. Table 3.1 depicts the total energy savings due to LED A-type lamps to date and the potential energy savings if the entire nationwide installed base was converted instantaneously to LED technology.

In 2018, there were nearly 3.5 billion A-type lamps installed in the U.S., 1.1 billion of which were LED products. If all 3.5 billion installations were to switch to LED lamps that represented 95th percentile of efficacy performance in 2018 (110 lm/W), the switch would save 50.9 TWh of site electricity, or about 487 tBtu of source energy. If these same LED lamps were also configured with connected controls, they would enable savings of an additional 7.7 TWh of site electricity, or about 74 tBtu of source energy, for a total of 560 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $6 billion.

Table 3.1 A-Type LED Energy Savings Summary

A-Type	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	15.3%	32.9%	100%
LED Installed Base (Millions of units)	520	1,144	3,476
LED Energy Savings (tBtu)	65.9	168	487
Connected Controls Energy Savings (tBtu)	0.018	0.020	73.7

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.2. Decorative

Application	Type	Description	Examples
Decorative	Lamp and Luminaire	Bullet, candle, flare, globe, and any other decorative lamp shapes, as well as integrated chandelier, single head pendant, wall sconce, lantern, and cove luminaire products.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in decorative applications. Decorative is a generic term that is used to cover a wide range of bulb shapes, including bullet, globe, flame, and candle, among others. These lamps are most common in the residential and commercial sectors and are intended for use in decorative fixtures, including chandeliers, pendants, wall sconces, lanterns, and nightlights. Unlike CFLs, which are not well suited for decorative applications due to size and form factor constraints, LED products are available for most existing decorative lamp shapes. In recent years, manufactures have developed a "filament" style design that arranges very small LED emitters in a linear strip inside the bulb to mimic the appearance of a traditional filament of an incandescent lamp. These "filament" and "vintage" style LED lamps are becoming increasingly popular as they offer an aesthetic appearance as well as a significant energy savings compared to incandescent products. Additionally, fully integrated decorative LED luminaires, which typically offer even greater energy savings due to more design flexibility, are available to replace decorative fixtures entirely.

Because of their relative low cost, aesthetic appeal, and absence of federal efficiency standards, incandescent lamps remain the dominant player in the decorative submarket, representing 73.4% of the 1.3 billion decorative installations in 2018. LED products, while available for most existing decorative lamp shapes, only recently began offering replacements that meet the aesthetic criteria (and lumen outputs) preferred by most consumers. LED lamps and luminaires have grown from a negligible penetration in 2010 to, as seen in Figure 3.6, 16% in 2018, with an estimated 207 million installations in the U.S. The growth over the last two years has primarily occurred at the expense of incandescent lamp market. Compared to 2016, the percent penetration of LED lighting in decorative applications has more than doubled. Of these 207 million LED installations as of 2018, it is estimated that 81% were LED lamps, while the remaining 19% were LED luminaires. The penetration of connected controls in decorative applications is estimated to be approximately 0.5% of the installed LED base in 2018 (approximately 1 million units).

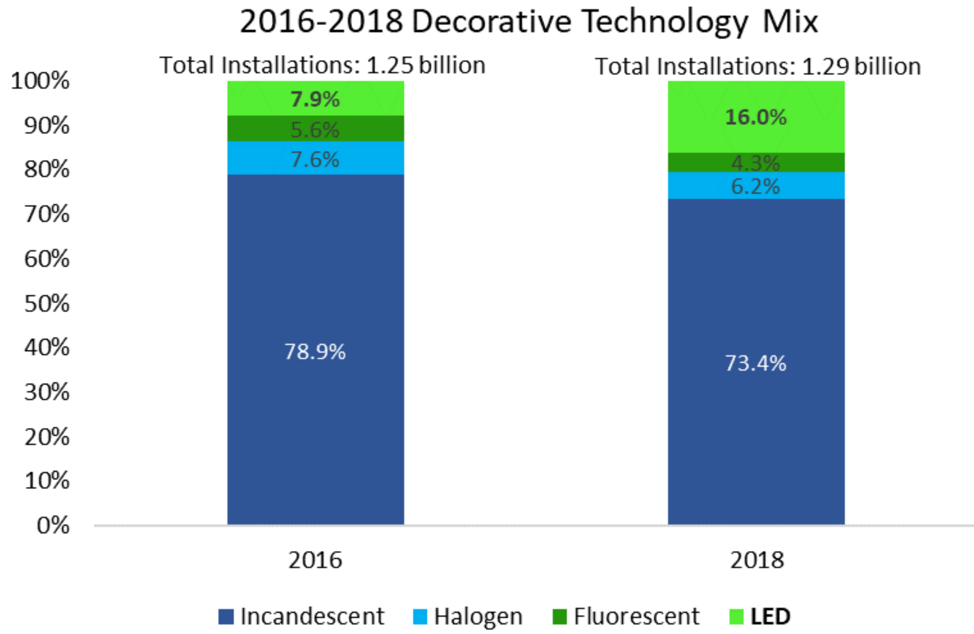


Figure 3.6 U.S. Decorative Installed Stock Penetration from 2016 to 2018. Between 2016 and 2018, the LED decorative market penetration doubled, reaching 16.0% of all decorative installations.

From 2016 to 2018, the total energy consumption of decorative applications decreased by approximately 7.7% from 372 tBtu to 343 tBtu, due to the continued market penetration of LED lighting. With its increased decorative market share, and these LED lamps and luminaires are estimated to have saved about 7.6 TWh of site electricity, or about 72.2 tBtu of source energy, in 2018. Table 3.2 depicts the total 2018 energy savings due to LED decorative lamps and luminaires and the potential energy savings if the entire nationwide installed base was converted instantaneously to LED technology.

In 2018, there were 1.3 billion decorative systems installed in the U.S., 207 million of which were LED lamps and luminaires. If all 1.3 billion installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (104 lm/W and 109 lm/W, respectively), the change would save 33.7 TWh of site electricity, or about 322 tBtu of source energy. If these same products were also configured with connected lighting controls, they would enable savings of an additional 4.2 TWh of site electricity, or about 40 tBtu of source energy, for a total of 362 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $4 billion.

Table 3.2 Decorative LED Energy Savings Summary

Decorative	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	7.9%	16.0%	100%
LED Installed Base (Millions of units)	99.2	207	1,290
LED Energy Savings (tBtu)	35.2	72.2	322
Connected Controls Energy Savings (tBtu)	0.03	0.08	40

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.3. Directional

Application	Type	Description	Examples
Directional	Lamp and Luminaire	Reflector (R), bulged reflector (BR), and parabolic reflector (PAR) lamps, as well as track heads and integrated track luminaires.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in directional applications. Directional fixtures are commonly used for accent, track, pendant, recessed, and architectural lighting in spaces including households, retail displays, restaurants, museums, and office buildings. Directional lamps are predominately reflector lamps and include incandescent, halogen, CFL, and LED reflector (R), bulged reflector (BR), and parabolic aluminized reflector (PAR) shaped lamps. Multifaceted reflector (MR), such as MR16, lamps are also considered directional lamps; however, because MR lamps have a significantly smaller form-factor and lower light output, they are generally used in different applications compared to PAR, BR, and R lamps. Thus, small directional lamps are evaluated separately in Section 3.4 of this report.

This section considers large LED directional lamps and integrated LED luminaires that replace incandescent, halogen, and CFL reflector lamps (e.g., PAR, BR, and R lamps) installed in accent and track fixtures. The DOE has regulated the energy efficiency level of many directional lamps since 1992,[17] and the reflector lamp market has undergone significant changes due to the enactment of energy conservation standards. These standards promote the adoption of higher efficiency reflector lamp products, including halogen infrared (IR) lamps, CFLs, and LED replacement lamps. Halogen IR lamps are more expensive than standard halogen lamps on the market today (gas mixtures and IR capsules largely contribute to increased cost), which increases the competitiveness of CFLs and LED directional lamps. However, adapting fluorescent technology for directional lamp applications presents several problems. Reflector CFL products are typically bulky and emit light from a larger area compared to an incandescent reflector, making it difficult to create an effective directional lighting source. LED replacements for reflector lamps, on the other hand, have distinct advantages due to the directionality of emitted light and their inherent form factor design flexibility.

As seen in Figure 3.7, LED lamps and luminaires surged ahead in 2018 as the technology with the largest market share (43%) and an estimated 218 million lamps and 10.6 million luminaires, overtaking the previous lead from incandescent lamps in 2016. The exponential growth associated with LED lighting has been at the expense of CFLs, incandescent, and halogen lamps, which have all been in a steady decline in recent years. Compared to 2016, the penetration of LED lamps and luminaires in directional applications nearly doubled. The penetration of connected controls in directional applications is estimated to have increased since 2016, but it remains small at 0.2% of all LED installations.

[17] U.S. DOE EERE, "Appliance & Equipment Standards – Incandescent Reflector Lamps", Accessed September 25, 2019. https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=23

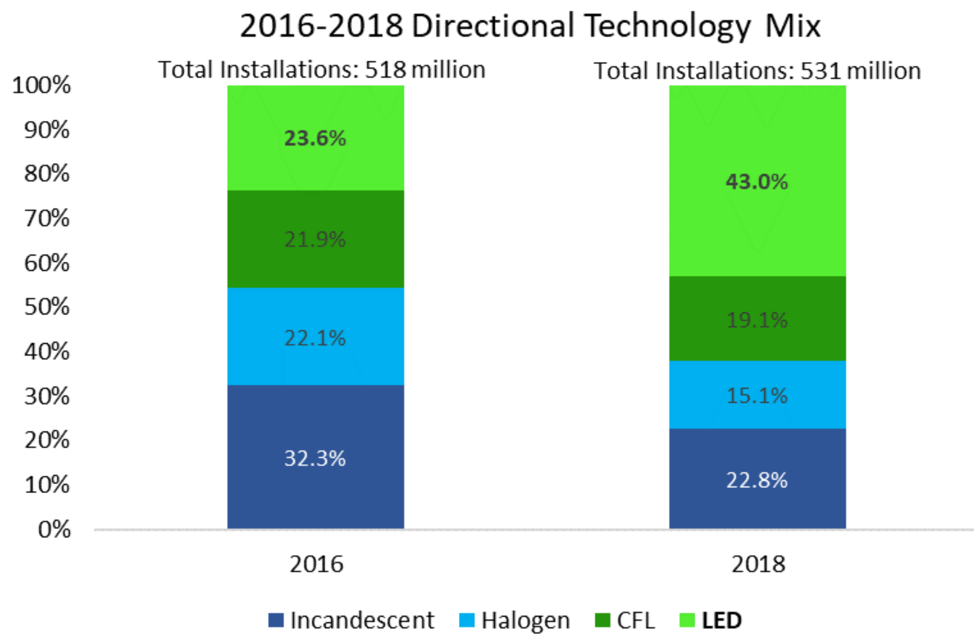


Figure 3.7 U.S. Directional Installed Stock Penetration from 2016 to 2018. LED directional products overtook incandescent lamps as the most prevalent lighting technology among 2018 directional installations.

From 2016 to 2018, the total energy consumption of directional applications decreased by 18% from 145 tBtu to 119 tBtu due to the increasing penetration of LED lighting. It is estimated that LED directional lighting saved about 7.37 TWh of site electricity, or about 70.4 tBtu of source energy in 2018. Table 3.3 depicts the total energy savings due to LED directional products to date and the potential energy savings if the entire nationwide installed base was converted instantaneously to LED technology.

In 2018, there were 531 million directional lighting systems installed in the U.S., 228 million of which were LED products. If all 531 million installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (95 lm/W and 119 lm/W, respectively), the switch would save 15.1 TWh of site electricity, or about 145 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 1.2 TWh of site electricity, or about 11 tBtu of source energy, for a total of 156 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $1.7 billion.

Table 3.3 Directional LED Energy Savings Summary

Directional	2016 LED Adoption	2018 LED Adoption	2018Technical Potential
LED Installed Penetration (%)	23.6%	43.0%	100%
LED Installed Base (Millions of units)	122	228	531
LED Energy Savings (tBtu)	42.7	70.4	145
Connected Controls Energy Savings (tBtu)	0.01	0.05	11

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.4. Small Directional

Application	Type	Description	Examples
Small Directional	Lamp	Multifaceted reflector (MR) lamps.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in small directional applications. Similar to the directional lamps (PAR, BR, and R) discussed in the previous section, small directional applications, largely comprised of MR16 lamps, were traditionally comprised of halogen incandescent light sources. However, MR16 lamps are unique among directional lamps because they are often operated at low voltage and their design is constrained by a small form-factor.[18] These lamps are widely used for accent, task, and display lighting in museums, art galleries, retail stores, residential settings, and entertainment venues. Although MR16 lamps are used in similar spaces to the directional applications discussed in Section 3.3, MR16 lamps are particularly optimal for jewelry and other display applications due to their high color rendering index (CRI) values and tightly-controlled, high-intensity beams.

The small form-factor, required dimmability, and optical control of MR16 lamps cannot be duplicated with CFL technology, but it can be met by LED lighting products. In addition, the efficiencies of LED lighting greatly outpace that of the incumbent technology. Traditional halogen MR16 lamps are only capable of efficacies between 10 lm/W and 25 lm/W, while the average of LED MR16 products are around 74 lm/W, with the top 5% of products introduced in 2018 reaching efficacies of 83 lm/W or greater.

For MR16 lamps, beam angle and center beam intensity are typically the most important performance attributes. Center beam intensity values for halogen MR16 lamps range from 230 to 16,000 candelas and are affected by both the lamp wattage (as it relates to light output) and the beam angle of the lamp. Depending on the application, a narrow beam (nominal 10 or 12 degree) with a high center beam intensity may be needed, or a wider beam (nominal 25 to 40 degree) with lower center beam intensity may be appropriate.

The overall market size for small directional lighting was estimated to be approximately 88 million units in 2018. With this estimate, the halogen market share was approximated at 50.3%, and the remaining 49.7% market share is attributed to LED products. This application currently has the highest LED lighting penetration (in %) of all indoor product types, and Figure 3.8 shows this nearly even split of small directional installations between LED and halogen lighting. One main driver for this LED adoption is that many of the technology challenges of early LED MR16 lamps have been addressed and product solutions offer improved dimming, thermal management, and efficiency that have enabled LED technology to serve this application. The penetration of connected controls in small directional applications is estimated to be 0.5% of LED installations in 2018.

[18] Most MR16 lamps are operated using voltages lower than 120 volts, typically 12 volts; however, GU10-base options at 120 volts are also available.

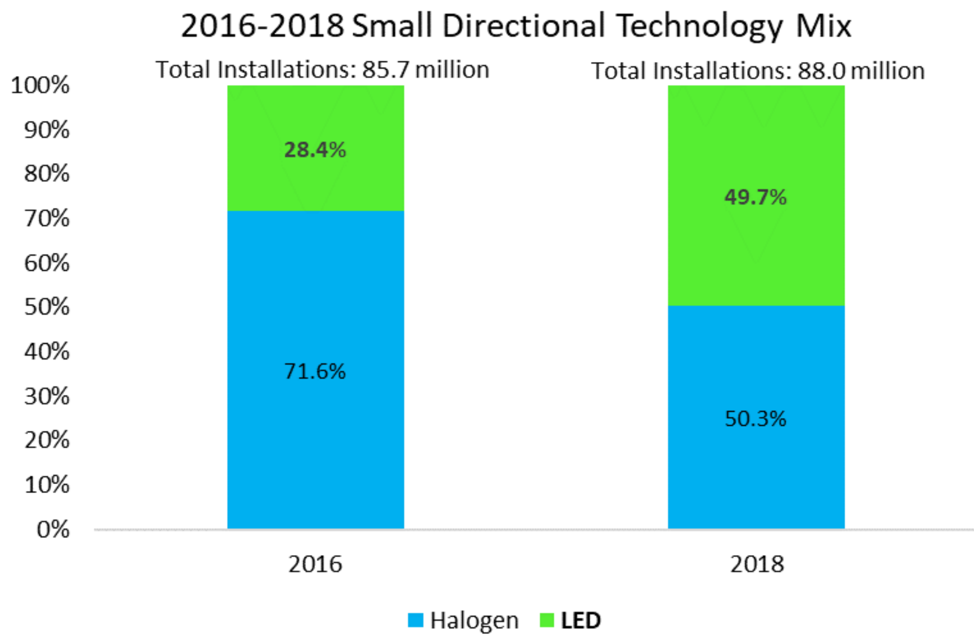


Figure 3.8 U.S. Small Directional Installed Stock Penetration from 2016 to 2018. LED and halogen small directional products reached a near even split in installations as of 2018.

Due to the increasing penetration of LED lighting and improved efficiencies, the total energy consumption of small directional applications decreased by 32% between 2016 and 2018 from 23.7 tBtu to 16.2 tBtu. LED small directional lamps and luminaires are nearly the majority of installations and it is estimated that LED lamps saved about 2.6 TWh of site electricity, or about 25.0 tBtu of source energy in 2018. Table 3.4 depicts the total energy savings due to LED small directional products to date and the potential energy savings if the entire nationwide installed base was converted instantaneously to LED technology.

In 2018, there were 88 million small directional lighting systems installed in the U.S., 38 million and 5.6 million of which were LED lamps and luminaires, respectively. If all 88 million installations were to switch to LED lamps that represented 95th percentile of efficacy performance in 2018 (83 lm/W), the switch would save 3.7 TWh of site electricity, or about 35.5 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 0.28 TWh of site electricity, or about 2.69 tBtu of source energy, for a total of 38.2 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $423 million.

Table 3.4 Small Directional LED Energy Savings Summary

Small Directional	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	28.4%	49.7%	100%
LED Installed Base (Millions of units)	24.4	43.7	88.0
LED Energy Savings (tBtu)	17.1	25.0	35.5
Connected Controls Energy Savings (tBtu)	0.01	0.02	3

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.5. Downlighting

Application	Type	Description	Examples
Downlighting	Lamp, Retrofit Kit and Luminaire	Reflector (R), bulged reflector (BR), and parabolic reflector (PAR) lamps used for downlighting, as well as, retrofit kits and integrated downlight luminaires.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in downlighting applications. Downlights are a staple of residential, hospitality, and commercial lighting, usually providing ambient illumination, but sometimes focal lighting. These fixtures can be recessed or surface-mounted and have become popular because they are inexpensive and can provide inconspicuous ambient lighting. Originally, downlights featured directional incandescent or halogen lamps – although, in some cases, omnidirectional lamps were installed, with substantial reductions in efficiency. Later, pin-based CFL downlights became a dominant part of the market, offering higher efficacy and longer lifetimes. However, CFL-based downlights often have low luminaire efficiency due to the omnidirectional lamp emissions, as well as some lighting quality issues.

This section considers LED downlight lamps, retrofit kits, and integrated LED luminaires that replace incandescent, halogen, and CFL reflector lamps (e.g., PAR, BR, and R lamps) installed in downlight fixtures. LED downlight luminaires were some of the earliest applications for SSL in general illumination. The release of the Cree LED LR6 recessed downlight in 2007 marked the beginning of viable LED downlight luminaire products. While the efficacy of LED downlights is lower than most other LED luminaire products, it is much higher than the efficacy of conventional sources. The lower performance is at least partly due to different optical requirements in downlights, but the relatively low performance of conventional halogen and CFL downlights provides less incentive for continued efficacy gains in LED downlights, compared to luminaire types competing against linear fluorescent or high-intensity discharge incumbents. Despite these challenges, LED downlight products have improved, with the average efficacy of retrofit kits and luminaire products at approximately 75 lm/W and the top 5th percentile at 85 lm/W and 110 lm/W, respectively.

In 2018, LED products have made substantial market progress, as they closed in on nearly half of the 687 million unit market at 45%. Incandescent and halogen lamps were estimated to comprise 18.6% and 12.4% of the market, respectively, as LED lighting gained significant market share on the value of higher efficiency and longer lifetimes, especially in the commercial market. This LED market rise – now with an estimated 308 million unit installed base and as shown in Figure 3.9 – has increased primarily at the expense of CFLs and incandescent lighting, which have both declined for much of this decade. Compared to 2016, the penetration of LED lighting in directional applications has nearly doubled. The penetration of LED lamps, retrofit kits, and luminaires with connected controls in downlight applications has increased to 1.2% of the LED installations in 2018, totaling an estimated 3.6 million units.

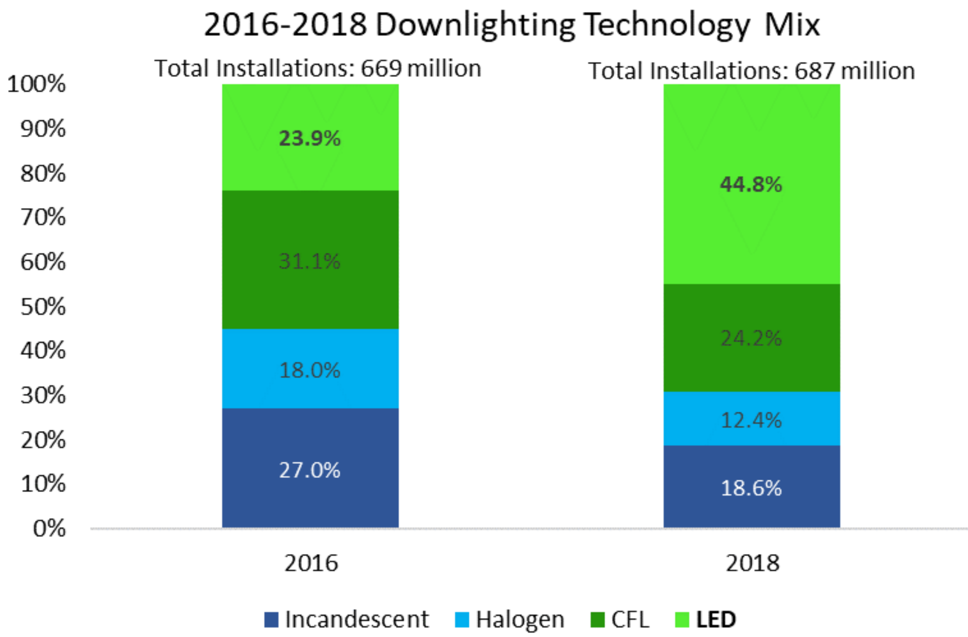


Figure 3.9 U.S. Downlight Installed Stock Penetration from 2016 to 2018. LED downlight lamps, retrofit kits, and luminaires achieved the majority of installations through 2018, as they closed in on nearly half of the market.

From 2016 to 2018, the total energy consumption of downlighting applications decreased by about 19% from 249 tBtu to 202 tBtu. As LED downlights have gained the predominant market share, it is estimated that LED lighting saved about 15.5 TWh of site electricity, or about 148 tBtu of source energy in 2018. Additionally, the estimated 3.6 million connected lighting systems are estimated to have saved about 1.2 tBtu of source energy in 2018. Table 3.5 depicts the total energy savings due to LED downlight products to date and the potential energy savings if the entire nationwide installed base was converted instantaneously to LED technology.

In 2018, there were 687 million downlighting systems installed in the U.S., 308 million of which were LED products. If all 687 million installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (85 lm/W and 110 lm/W respectively), the switch would save 25.4 TWh of site electricity, or about 242 tBtu of source energy. If these same LEDs were also configured with connected lighting controls, they would enable savings of an additional 3.3 TWh of site electricity, or about 31.2 tBtu of source energy, for a total of 273 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $3 billion.

Table 3.5 Downlight LED Energy Savings Summary

Downlighting	2018 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	23.9%	44.8%	100%
LED Installed Base (Millions of units)	160	308	687
LED Energy Savings (tBtu)	98.0	148	242
Connected Controls Energy Savings (tBtu)	0.34	1.15	31

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.6. Linear Fixture

Application	Type	Description	Examples
Linear Fixture	Lamp, Retrofit Kit and Luminaire	Lamp replacements for T12, T8, and T5 fluorescent lamps, as well as retrofit kits and luminaires replacing traditional fluorescent fixtures (i.e., troffers, linear pendants, strip, wrap around, and undercabinet).	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in linear fixture applications and covers LED replacements of linear fixtures including all troffer, panel, suspended, and pendant luminaires. However, linear fixture systems used in low/high bay and parking garage applications are covered separately in Sections 3.7 and 3.9.2, respectively.

Linear fluorescent systems (with T5, T8, and T12 lamps) are widely utilized for commercial and industrial establishments because they offer a low-cost, highly efficient, and long-lifetime light source. As a result, these fluorescent systems represent over a fourth of all lighting energy consumption in the U.S. across all sectors (excluding those in low/high bay and parking garage applications), creating a significant energy savings opportunity for LED lighting. However, modern linear fluorescent systems (lamp and ballast) remain tough competitors in terms of efficacy, as well as initial and lifecycle costs, with efficacies as high as 108 lm/W and prices as low as $4/klm. Although fluorescent troffers have evolved into a well-defined system of modular products, the LED market is more fragmented, especially in retrofit applications. LED products intended for use in troffer applications include lamps, retrofit kits, and dedicated LED luminaires – and sometimes the lines between these can be blurry. These three product types are all available in multiple sizes and match – or exceed – the performance of fluorescent troffers to varying degrees.

In 2018, fluorescent lamps are still estimated to represent the majority of the 1.1 billion linear fixture installations, with T12 at 14.4%, T8 at 58.7%, and T5 at 6.7%. However, LED products have begun to penetrate this market, now accumulating a 20.1% market share (224 million installations) as shown in Figure 3.10. The penetration of LED luminaires with connected controls in linear fixture applications is growing and up to 1.8% of the LED market and over four million installations.

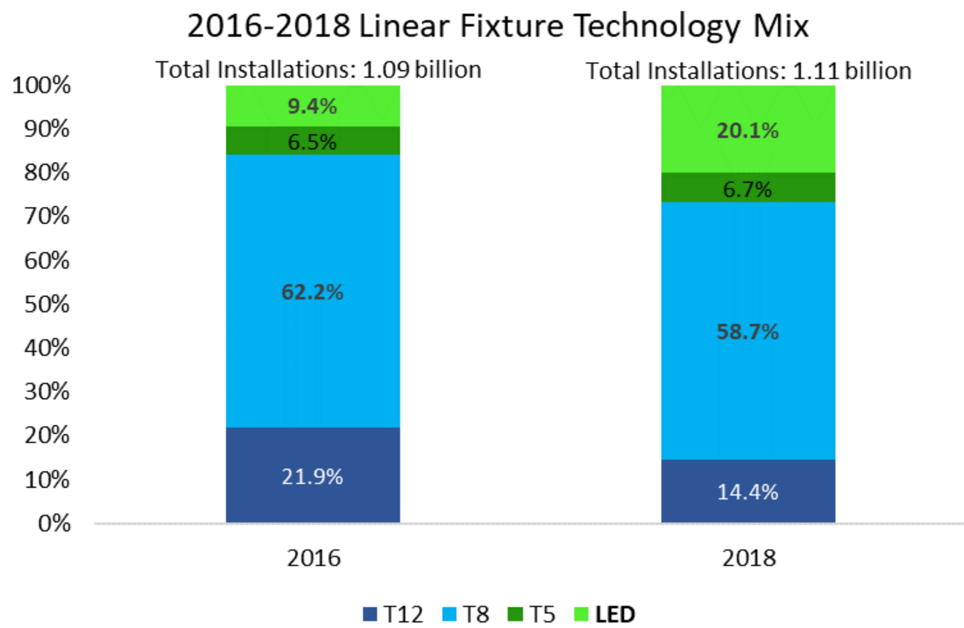


Figure 3.10 U.S. Linear Fixture Installed Stock Penetration from 2016 to 2018. LED products in the linear fixture application doubled to 20% penetration in 2018, though fluorescent lamps still comprise the majority of this application.

From 2016 to 2018, the total energy consumption of linear fixture applications decreased by about 2.6 % from 1,684 tBtu to 1,641 tBtu due to continued penetration of LED lighting. LED products are still in the minority of installations compared to fluorescent sources; however, it is estimated that linear LED lighting saved about 7.7 TWh of site electricity, or about 74 tBtu of source energy in 2018. Additionally, the four million connected lighting systems are estimated to have saved about 3.3 tBtu of source energy in 2018. Table 3.6 depicts the total and potential energy savings due to LED linear fixture products and connected controls to date.

In 2018, there were 1.1 billion linear fixture lighting systems installed in the U.S., 224 million of which were LED products. If all 1.1 billion installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (145 lm/W and 138 lm/W respectively) it would save 70.5 TWh of site electricity, or about 674 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 56.3 TWh of site electricity, or about 538 tBtu of source energy, for a total of 1,211 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $13.4 billion.

Table 3.6 Linear Fixture LED Energy Savings Summary

Linear Fixture	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	9.4%	20.1%	100%
LED Installed Base (Millions of units)	103	224	1,113
LED Energy Savings (tBtu)	18.6	73.8	674
Connected Controls Energy Savings (tBtu)	1.4	3.3	538

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.7. Low/High Bay

Application	Type	Description	Examples
Low/High Bay	Lamp and Luminaire	High wattage lamp replacements as well as low and high bay integrated fixtures.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in low and high bay applications. Low and high bay fixtures are commonly used in both the commercial and industrial sectors to illuminate large open indoor spaces in big-box retail stores, warehouses, and manufacturing facilities. Typically, low bay fixtures are used for ceiling heights of 20 feet or less, while high bay is used for heights of greater than 20 feet. Because of the large areas and lofted ceilings, these spaces require high lumen-output luminaires, with low bay options offering between 5,000 and 15,000 lumens per fixture and high bay providing 15,000 to as much as 100,000 lumens per fixture. This market was historically dominated by HID lamps, although fluorescent lamps, particularly high output T5 lamps, have become a major player due to their superior lumen maintenance and enhanced control options.

Only in the past few years have technological and cost improvements allowed LED lighting to penetrate the market in significant quantities. In addition, while less efficient than LED luminaire options, LED retrofit lamps designed for direct replacement for HID and fluorescent lamps are now also available and penetrating low and high bay applications. In 2018, the low and high bay submarket represented 17% of all lighting energy use – the second highest energy consumption of all the applications evaluated, making this a key application for LED lighting energy savings.

As seen in Figure 3.11, fluorescent lamps made up the majority of the 2018 low and high bay installations at 60.8%. Of this, T8 systems dominate, followed by T5 and T12, respectively. Similar to linear fixture applications, DOE energy efficiency standards for GSFLs have had the effect of causing a transition away from inefficient T12 lamps towards higher efficiency T8 and T5 lamps, as well as LED lighting. The installed stock of HID lamps in low and high bay applications has also steadily decreased, from which is where LED lighting has gained most of its market share. Overall, LED lighting represented 18.0 million installations in 2018, of 8.2% were LED replacement lamps, and 91.8% were integrated LED luminaires or retrofit kits. Of these total 18.0 million LED installations as of 2018, 1.8 million (approximately 10%) operated with connected lighting controls.

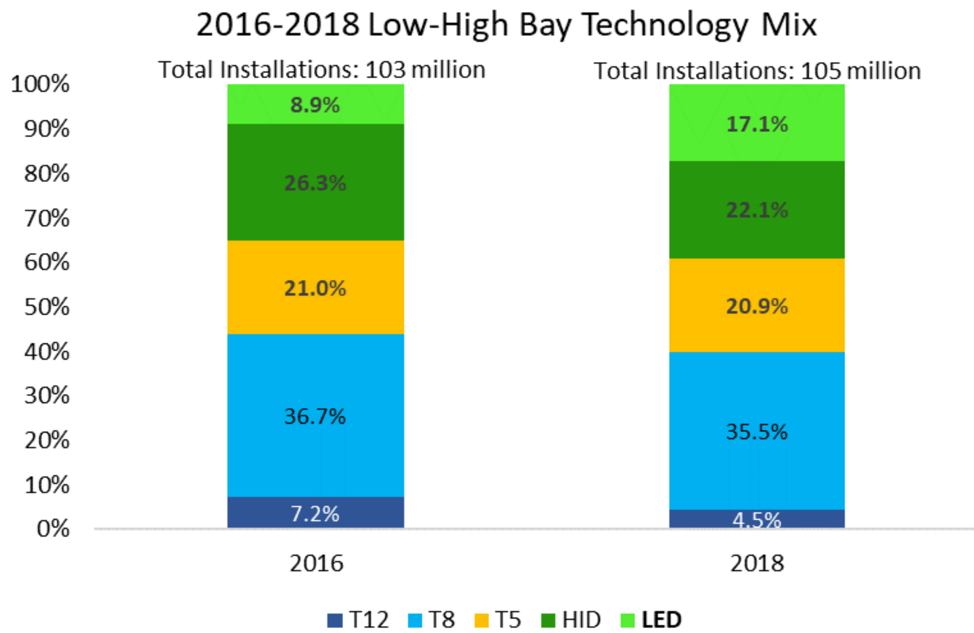


Figure 3.11 U.S. Low/High Bay Installed Stock Penetration from 2016 to 2018. LED low/high bay products nearly doubled in market penetration between 2016 and 2018; however, fluorescent lamp products continue to make up the majority of this application.

From 2016 to 2018, the estimated total energy consumption of low and high bay applications decreased by 8.0% from 900 tBtu to 828 tBtu, due to the increased penetration of LED lighting at the expense of all other technologies filling the low and high bay applications. LED products are still in the minority of installations; however, it is estimated that they saved about 20.9 TWh of site electricity, or about 199 tBtu of source energy in 2018. Additionally, the 1.8 million connected lighting systems are estimated to have saved about 3.8 tBtu of source energy in 2018. Table 3.7 depicts the total and potential energy savings in 2018 due to LED low and high bay installations and connected controls.

In 2018, there were 105 million low and high bay lighting systems installed in the U.S., 18 million of which were LED products. If all 105 million installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (139 lm/W and 151 lm/W, respectively) it would save 76.2 TWh of site electricity, or about 728 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 19.1 TWh of site electricity, or about 183 tBtu of source energy, for a total of 910 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $10 billion.

Table 3.7 Low/High Bay LED Energy Savings Summary

Low/High Bay	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	8.9%	17.1%	100%
LED Installed Base (Millions of units)	9.1	18.0	105
LED Energy Savings (tBtu)	132	199	728
Connected Controls Energy Savings (tBtu)	1.2	3.8	183

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.8. Street/Roadway

Application	Type	Description	Examples
Street/Roadway	Lamp and Luminaire	Replacement lamps and luminaires installed in street and roadway applications.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lighting in street and roadway applications. Street and roadway luminaires serve to illuminate streets and roadways to improve visibility for drivers as well as to illuminate outdoor pedestrian walkways. Traditionally, this application has been dominated by HID light sources, such as high pressure sodium (HPS), metal halide (MH), and mercury vapor (MV) lamps, because they offer relatively high efficacy, operate effectively over a wide temperature range, and produce high lumen outputs, which enable them to be mounted on widely spaced poles.

LED products are particularly advantageous in street and roadway lighting applications because they are excellent directional light sources, are durable, and exhibit long lifetimes. LED street and roadway luminaires also significantly decrease the amount of light pollution compared to incumbent HID fixtures because their improved optical distribution substantially reduces the amount of light wasted upward into the atmosphere. In addition to offering energy savings, LED street and roadway luminaires have typical rated lifetimes exceeding 50,000 hours, more than three times that of many HID systems. This is particularly attractive when considering the long operating hours along with the difficulty and expense of required maintenance.

Because of these advantages, many local jurisdictions have initiated projects to completely transition to LED street and roadway lighting. As of 2018 (and shown in Figure 3.12), LED products have taken the lead in this application, reaching an approximate 48.6% penetration of the 49.7 million total street and roadway installations. This increase in LED market saturation has coincided with a steady decline in HPS lighting since 2010. Of the total 24.2 million LED installations in 2018, 2.1 million operated with connected lighting controls.

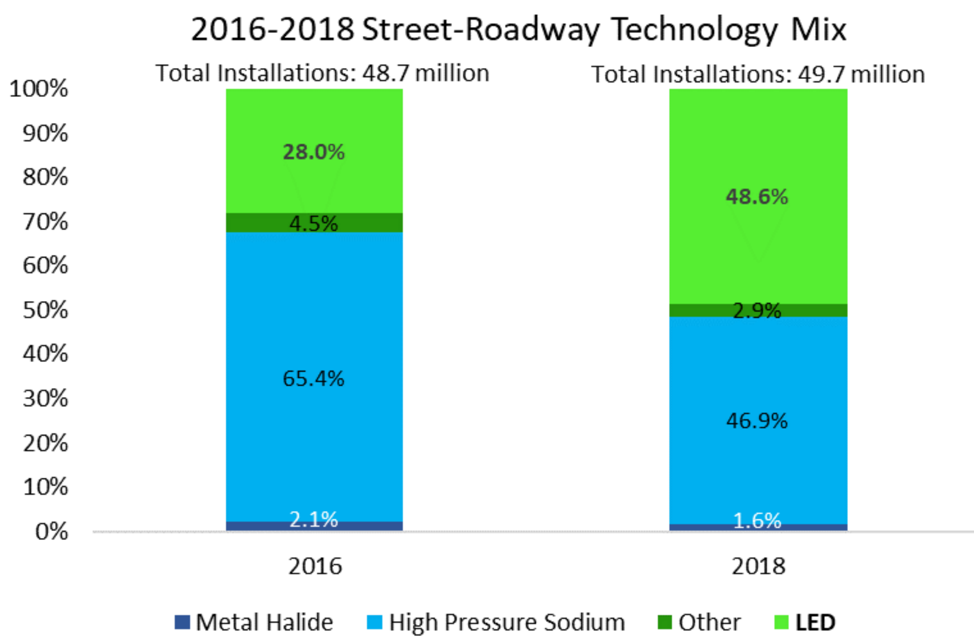


Figure 3.12 U.S. Street/Roadway Installed Stock Penetration from 2016 to 2018. LED products in street/roadway applications surged to become the most predominant lighting type in this area at 49% LED adoption.

From 2016 to 2018, the total energy consumption of street and roadway applications decreased by about 12% from 320 tBtu to 282 tBtu due to the significant penetration of LED lighting. It was estimated that LED products saved about 9.8 TWh of site electricity, or about 93.3 tBtu of source energy in 2018. Additionally, the 2.1 million connected lighting systems are estimated to have saved about 3.4 tBtu of source energy in 2018. Table 3.8 depicts the total and potential energy savings in 2018 due to LED street and roadway installations and connected controls.

In 2018, there were 49.7 million street and roadway lighting systems installed in the U.S., 24.2 million of which were LED products. If all 49.7 million installations were to switch to LED luminaires that represented 95th percentile of efficacy performance in 2018 (138 lm/W) it would save 25.6 TWh of site electricity, or about 245 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 5.9 TWh of site electricity, or about 56.6 tBtu of source energy, for a total of 302 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $3.3 billion.

Table 3.8 Street/Roadway LED Energy Savings Summary

Street/Roadway	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	28.0%	48.6%	100%
LED Installed Base (Millions of units)	13.7	24.2	49.7
LED Energy Savings (tBtu)	49.8	93.3	245
Connected Controls Energy Savings (tBtu)	1.2	3.4	57

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.9. Parking

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lamps and luminaires in parking applications. In this analysis, the parking application has been divided into parking lots and covered garages, and it does not consider street-side parking, as those areas are covered in the street and roadway application discussed in Section 3.8. In addition, outdoor area lighting for pedestrianized spaces and outdoor parks and recreation areas is included within the parking lot analysis.

3.9.1. Area/Parking Lot

Application	Type	Description	Examples
Area/Parking Lot	Lamp and Luminaire	High wattage lamp replacements, as well as luminaires used in parking lot and top deck parking garage illumination.	

Given the high lumen output and long operating conditions associated with both parking lots and street lighting, the type of lighting used for parking lots is similar to the technologies used for street lighting (discussed in Section 3.8). Despite the similarities, penetration of LED lighting in parking lot lighting is estimated to exceed that of street and roadway. LED lighting offers a distinct advantage in both area and parking lot applications, and, in particular, it can significantly improve light utilization.[19]

As of 2018, LED lighting now represents the majority of lighting in this application at 54.0%. Of the 50.1 million installations, metal halide and HPS represent 40.1% of the market. Figure 3.13 demonstrates this market shift over the past two years, as LED installations now have outpaced HPS and metal halide

[19] These energy savings benefits are also due to improved uniformity ratios and minimum illuminance criterion for parking lot applications in IES RP-20-14 – Lighting for Parking Facilities.

installations. Of these total 27 million LED installations in 2018, 0.9 million are estimated to operate with connected lighting controls.

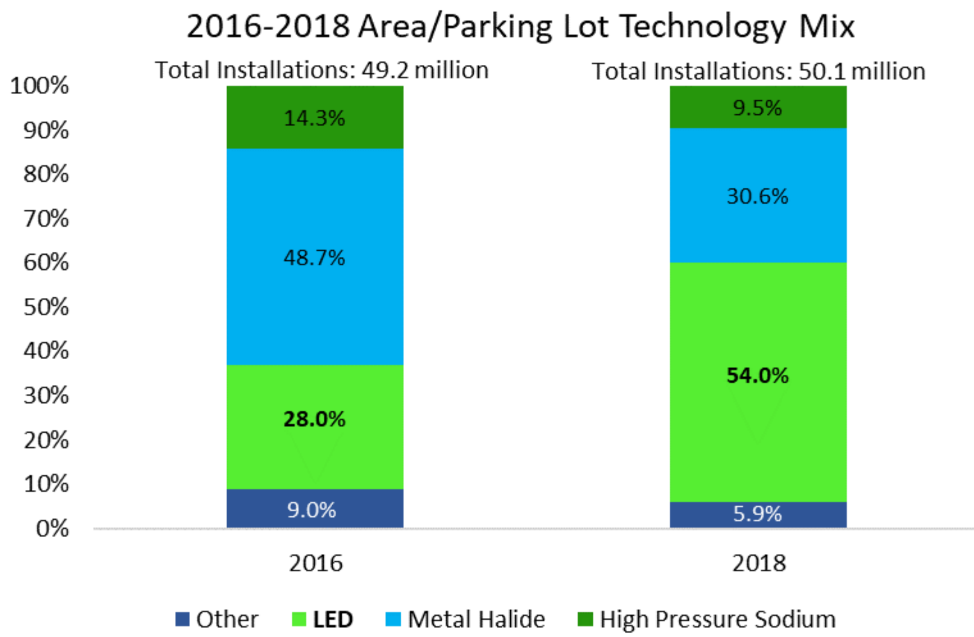


Figure 3.13 U.S. Area/Parking Lot Installed Stock Penetration from 2016 to 2018. As of 2018, LED lighting now comprises the majority of this application at 54% LED penetration.

From 2016 to 2018, the total energy consumption of parking lot lighting applications decreased by about 21% from 436 tBtu to 344 tBtu due to the increasing penetration of LED lighting. It was estimated that LED lighting saved about 19.1 TWh of site electricity, or about 183 tBtu of source energy in 2018. Additionally, the 0.9 million connected lighting systems are estimated to have saved about 1.7 tBtu of source energy in 2018. Table 3.9 depicts the total and potential energy savings due to LED parking lot installations and connected controls to date.

In 2018, there were 50.1 million area and parking lot lighting systems installed in the U.S., 27.1 million of which were LED products. If all 50.1 million installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (135 lm/W) it would save 41.1 TWh of site electricity, or about 392 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 5.7 TWh of site electricity, or about 54.4 tBtu of source energy, for a total of 447 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $4.9 billion.

Table 3.9 Area/Parking Lot LED Energy Savings Summary

Area/Parking Lot	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	28.0%	54.0%	100%
LED Installed Base (Millions of units)	13.8	27.1	50.1
LED Energy Savings (tBtu)	88.1	183	392
Connected Controls Energy Savings (tBtu)	0.6	1.7	54

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.9.2. Parking Garage

Application	Type	Description	Examples
Parking Garage	Lamp	Replacement lamps and luminaires for attached and stand-alone covered parking garages.	

Parking garage structures are unique in the outdoor sector because lighting fixtures are well protected from the elements and mounting height is generally limited by low ceilings. While HID lamps are used for lighting parking garage structures, the low-mounting heights of lighting fixtures require a large number of fixtures in order to meet desired illumination distributions. These conditions favor linear fluorescent fixtures, although MH and HPS systems are also prominent in this market.

Building code requirements are also helping to bolster the prevalence of LED lighting in parking garage applications. LED lighting is well suited for use with control systems and have been shown to provide additional energy savings of 20% to 60% depending on the application and use-case. Due to this large technical potential of lighting controls, in the most recent Title 24 building code,[20] the state of California expanded its requirements for the use of advanced dimming controls, along with occupancy and daylight sensors. As a result, lighting in parking garages in California must have occupancy controls, with power required to reduce by a minimum of 30% when there is no activity detected within a lighting zone for 20 minutes.[21] While these building code requirements are only effective in California, this represents a significant opportunity for LED lighting to help impact energy savings in parking garage applications across the U.S.

Figure 3.14 shows the estimate for the installed base of LED parking garage lamps and luminaires from 2016 to 2018. In 2018, LED products are estimated to represent 69.1% of lighting installations for parking garages with about 19.0 million. Connected controls are also penetrating garage applications. In 2018, it is estimated that 0.9 million LED lighting systems in parking garage applications operated with connected lighting controls.

[20] For more information on Title 24 please see: http://www.dgs.ca.gov/dsa/Programs/progCodes/title24.aspx
[21] ANSI/ASHRAE/IES Standard 90.1-2013, Energy Standard for Buildings except Low-Rise Residential Buildings.

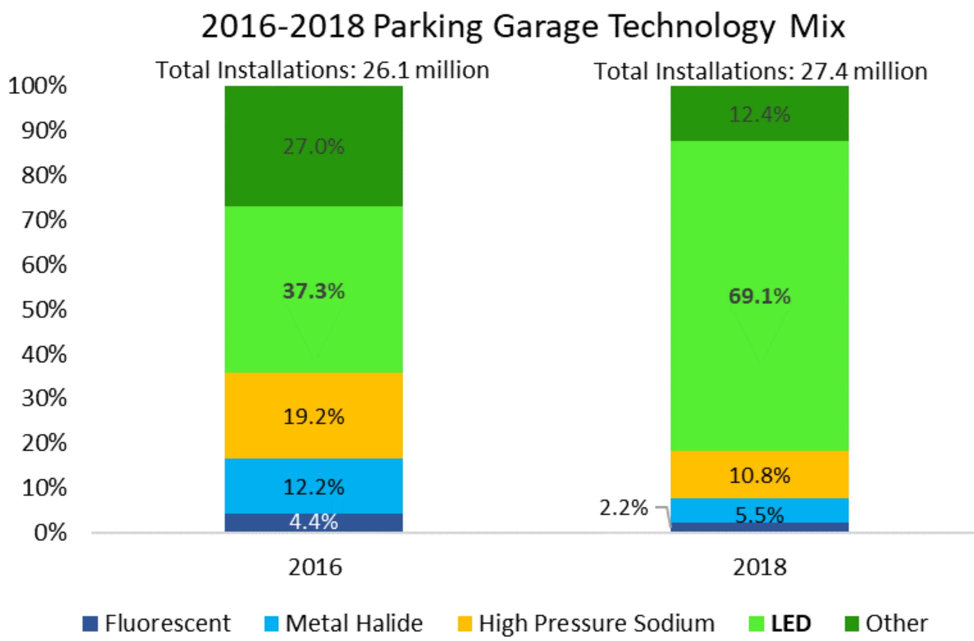


Figure 3.14 U.S. Parking Garage Installed Stock Penetration from 2016 to 2018. LED lighting in parking garage applications reached the highest market penetration of all lighting applications.

From 2016 to 2018, the total energy consumption of parking garage applications decreased by 22% from 278 tBtu to 216 tBtu. LED products are now estimated at 69.1% of all garage installations, and it is estimated that they saved about 16.4 TWh of site electricity, or about 157 tBtu of source energy, in 2018. Additionally, the 0.9 million connected lighting systems are estimated to have saved about 1.7 tBtu of source energy in 2018. Table 3.10 depicts the total and potential energy savings in 2018 due to LED parking garage installations and connected controls to date.

Through 2018, there were 27.4 million parking garage lighting systems installed in the U.S., 19.0 million of which were LED products. If all 27.4 million installations were to switch to LED lamps and luminaires that represented 95th percentile of efficacy performance in 2018 (131 lm/W), it would save 28.9 TWh of site electricity, or about 276 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 2.0 TWh of site electricity, or about 18.7 tBtu of source energy, for a total of 295 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $3.3 billion.

Table 3.10 Parking Garage LED Energy Savings Summary

Parking Garage	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	37.3%	69.1%	100%
LED Installed Base (Millions of units)	9.7	19.0	27.4
LED Energy Savings (tBtu)	94.1	157	276
Connected Controls Energy Savings (tBtu)	0.6	1.7	19

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

3.10. Building Exterior

Application	Type	Description	Examples
Building Exterior	Lamp and Luminaire	Lamps and luminaires installed in façade, spot, architectural, flood, wall pack, bollard, and step/path applications. Not including solar cell products.	

This section addresses the 2018 LED Adoption and 2018 Technical Potential results for LED lamps and luminaires in building exterior applications. Building exterior lighting is designed to illuminate walkways, steps, driveways, porches, decks, building architecture, or landscape areas, and it can be used to provide security outside of residential, commercial, and industrial buildings. Wall packs and floodlights are a common choice for these applications, with CFL, MH and HPS systems historically being the most commonly used, especially where a high lumen output is required.

LED lighting has penetrated virtually every aspect of building exterior lighting as qualities such as instant-on, white-color, low maintenance, and good performance have made them increasingly viable options. The ability of LED products to offer low-profile lighting has also made installation easier in areas with tight clearance and offers building managers and specifiers more effective options for lighting narrow areas, such as under benches or accent planters. These small form-factors and the ability to precisely place light sources can result in less light pollution in building exterior applications. LED products may also offer better wall-washing or wall-grazing options for building façades through color tunability and better controllability, thus making them a top choice over incumbent sources.

Building exterior LED lighting includes both lamp and luminaire products; however, reporting in this section has been combined due to the lack of available data on each separately. As of 2018, LED sources represent nearly half (45.8%) of the 86.2 million building exterior installations. The next most prevalent technology, fluorescent lighting (CFLs, in particular), was attributed a 29.8% market share. As seen in Figure 3.15, the remaining installations are comprised primarily of halogen, HPS, and metal halide conventional lamp products. The penetration of connected controls in building exterior applications is estimated to be 0.4% of LED installations in 2018.

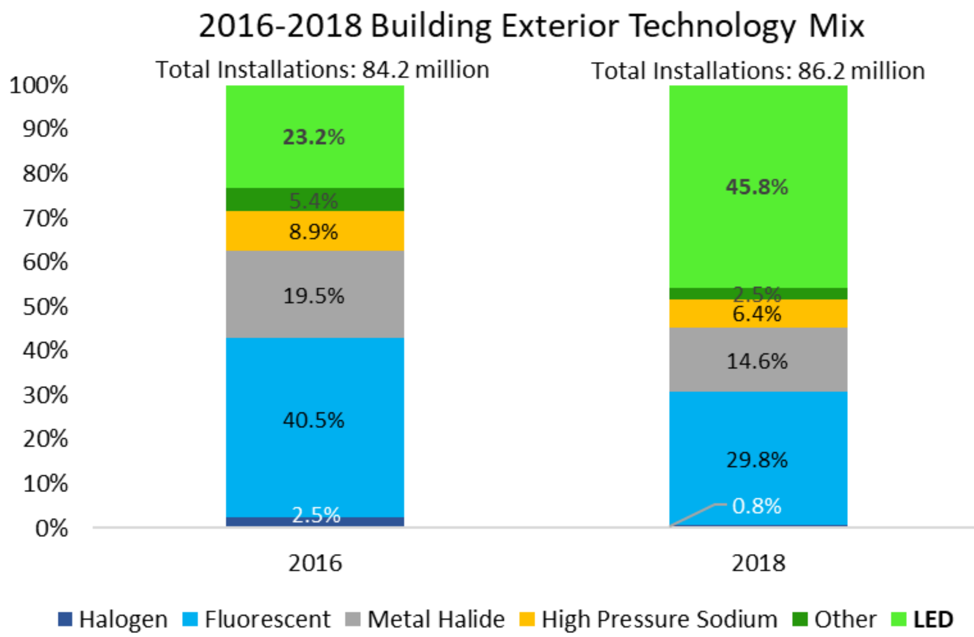


Figure 3.15 U.S. Building Exterior Installed Stock Penetration from 2016 to 2018. LED lighting overtook fluorescent in 2018 as the most prevalent lighting technology in building exterior applications.

From 2016 to 2018, total energy consumption for building exterior applications decreased by 11% from 275 tBtu to 244 tBtu. LED products now represent the most common installation, and it is estimated that they saved about 10.8 TWh of site electricity, or about 103 tBtu of source energy in 2018. Table 3.11 depicts the total energy savings due to LED building exterior products to date and the potential energy savings if the entire nationwide installed base was converted instantaneously to LED technology.

In 2018, there were 86.2 million building exterior lighting systems installed in the U.S., 39.5 million of which were LED products. If all 86.2 million installations were to switch to LED products that represented 95th percentile of efficacy performance in 2018 (122 lm/W), it would save 22.8 TWh of site electricity, or about 219 tBtu of source energy. If these same LED products were also configured with connected lighting controls, they would enable savings of an additional 5.6 TWh of site electricity, or about 53.5 tBtu of source energy, for a total of 272 tBtu. Energy savings of this magnitude would result in an annual energy cost savings of about $3 billion.

Table 3.11 Building Exterior LED Energy Savings Summary

Building Exterior	2016 LED Adoption	2018 LED Adoption	2018 Technical Potential
LED Installed Penetration (%)	23.2%	45.8%	100%
LED Installed Base (Millions of units)	19.5	39.5	86.2
LED Energy Savings (tBtu)	67.8	103	218
Connected Controls Energy Savings (tBtu)	0.2	0.4	54

1. Installed stock is presented in terms of lighting systems (lamp(s), ballast and fixture are counted as one unit).

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