Next Generation Streetlights

CALIFORNIA LIGHTING TECHNOLOGY CENTER

BAY AREA CLIMATE COLLABORATIVE

ENERGY SOLUTIONS

LED Technology and Strategies for Action

AUTHORS

The Next Generation Streetlight guide is a collaborative project of the following organizations dedicated to supporting local governments and industry with lighting solutions and enabling strategies for economic and environmental sustainability.

The Bay Area Climate Collaborative (BACC) is a 501c3 public-private partnership accelerating the clean energy economy and providing replicable models of scalable climate action. Partners include Bank of America, Pacific Gas & Electric, clean energy companies and local governments representing over 70% of the Bay Area population. The BACC drives practical market-oriented and cross-sector initiatives that reduce carbon, advance economic development, and accelerate penetration of climate solutions. Initiatives include co-facilitation of the Bay Area EV Strategic Council, the $5 million Local Government EV Fleet national demonstration project to catalyze adoption of EVs in fleets and the Bay Area Next Generation Streetlight initiative aimed at upgrading 200,000 streetlights to LED and generate $15 million in annual savings. The BACC is a project of the Silicon Valley Leadership Group Foundation. **www.baclimate.org**

The California Lighting Technology Center is a research, development, and demonstration facility whose mission is to stimulate, facilitate, and accelerate the development and commercialization of energy-efficient lighting and daylighting technologies. This is accomplished through technology development and demonstrations, as well as offering outreach and education activities in partnership with utilities, lighting manufacturers, end users, builders, designers, researchers, academics, and government agencies. **cltc.ucdavis.edu**

Energy Solutions is a California-based business that specializes in research and implementation of energy efficiency programs and codes and standards development. Founded in 1995, Energy Solutions' mission is to create large-scale energy and water savings benefits for clients by implementing market-based solutions and developing programs and policies that contribute to these goals. Energy Solutions has completed several LED street lighting emerging technology demonstrations and market research studies since 2008, working with organizations such as the Pacific Gas and Electric Company, Electric Power Research Institute, US Department of Energy, and the Northwest Energy Efficiency Alliance. **www.energy-solution.com**

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Portions of this guide were adapted from other materials including the Exterior Lighting Guide for Federal Agencies[1] developed by CLTC for the US Department of Energy, A Municipal Guide for Converting to LED Street Lighting[2] by Leotek, Environmental Finance for California Municipal Agencies by PFM, Siemens training material and other sources. All content was reviewed by CLTC and BACC. Any errors and omissions are solely the responsibility of the BACC. Lead images for sections 1, 3 and 6 were provided by CLTC (Photo Credit: Kathreen Fontecha)

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The California Energy Commission is the state's primary energy policy and planning agency. Created by the Legislature in 1974 and located in Sacramento, six basic responsibilities guide the Energy Commission as it sets state energy policy: forecasting future energy needs; licensing thermal power plants 50 megawatts or larger; promoting energy efficiency and conservation by setting the state's appliance and building efficiency standards; supporting public interest energy research that advances energy science and technology through research, development, and demonstration programs; developing renewable energy resources and alternative renewable. www.energy.ca.gov

The Pacific Gas and Electric Company, incorporated in California in 1905, is one of the largest combination natural gas and electric utilities in the United States. There are approximately 20,000 employees who carry out PG&E's primary business—the transmission and delivery of energy. The company provides natural gas and electric service to approximately 15 million people throughout a 70,000-square-mile service area in northern and central California. PG&E has one of the most aggressive utility clean energy and efficiency programs in the country. On average, over half of the electricity PG&E delivers to its customers comes from a combination of renewable and greenhouse gas-free resources. PG&E's services include technical guidance, rebates and incentives, and turnkey services for local governments to maintain and upgrade streetlights. www.pge.com

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Siemens Road and City Mobility Group works with Cities to improve infrastructure without capital expenditure. With energy-efficient streetlight retrofits and advanced parking solutions, we reduce costs and increase revenue, allowing much needed funding to be allocated to critical improvement projects. Siemens helps cities help themselves. www.usa.siemens.com/mobility

Bridgelux is the first, new US-based light-emitting diode (LED) manufacturer in the past 20 years. The Company's focus is bringing innovation to light by delivering high power, energy-efficient and cost-effective Solid-State Lighting. Bridgelux actively supports its streetlight customers by providing best-in-class service and the highest performing products. Leveraging vertically integrated chip, LED and Solutions businesses, Bridgelux delivers application-specific Solutions that will accelerate adoption of LED streetlights. http://www.bridgelux.com/

Sensity Systems uses energy-efficient LED lighting as the foundation for a high-speed, sensor-based Light Sensory Network (LSN). The company enables light owners to capitalize on the LED conversion process by embedding networking technology within both retrofit and new LED luminaires. With Sensity's open, multiservice NetSense platform, lighting owners are able to reduce energy costs and implement a variety of SensApps applications and services over the network, including public safety, environmental and weather monitoring, parking management and retail analytics. http://sensity.com/

Cooper Lighting, headquartered in Peachtree City, Georgia, is the leading manufacturer of track and recessed lighting in North America and one of the largest manufacturers of indoor and outdoor LED, fluorescent, HID, exit and emergency, vandal-resistant and complex environment lighting in the world. Cooper Lighting comprises 20 brands and has operating facilities throughout the United States, Canada and Mexico. **http://cooperindustries.com**

Leotek Electronics USA Corp., located in Silicon Valley, California since 1997, manufactures innovative LED lighting products for applications encompassing traffic and transit, street and area, commercial, and petroleum, convenience, grocery and retail stores. Leotek is committed to developing emerging solid-state technology that offers greater longevity and environmental viability than traditional lighting sources, while reducing energy consumption and maintenance costs. **www.leotek.com**

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1 INTRODUCTION

Street lighting is an essential feature of modern streets and roadways, providing illumination to ensure walkway and roadway safety. The US Department of Energy estimates that there are 52.6 million roadway fixtures installed in the United States, including 26.5 million streetlights and 26.1 million highway fixtures[3]. These lights consume significant amounts of energy, accounting for nearly ten percent of all lighting electricity consumption nationwide[a]. Street lighting technology is evolving rapidly with the development of solid-state lighting (SSL), including light-emitting diode (LED) technology. A massive global market conversion to more advanced street lighting is already underway and is expected to accelerate over the next several years. LED streetlights combine enormous savings potential (perhaps over several terawatt-hours annually) with superior lighting performance relative to incumbent technologies.

Major cities in California, such as Los Angeles and San Jose, have already begun to convert their existing streetlight inventories to next-generation LED fixtures. Many more cities and counties have completed pilot-scale evaluation projects to help plan larger-scale LED streetlight retrofits and installations. Existing deployments of LED streetlights are demonstrating significant economic and community benefits from upgrading. Furthermore, utilities such as Pacific Gas and Electric Company (PG&E) are actively promoting the implementation of advanced streetlights by offering various incentive programs including rebates, turnkey replacement services, and technology-specific tariffs.

The Bay Area has an estimated 700,000+ mostly low-efficiency streetlights. Through a survey of Bay Area agencies, the Bay Area Climate Collaborative has identified over 240,000 city-owned fixtures ripe for conversion in the 67 participating agencies (out of 109). Upgrading these streetlights to LEDs would yield annual energy savings of 60 million kilowatt-hours (kWh), enough to power 10,000 single-family California homes. With substantial incentives available, low cost of financing and attractive payback times, the opportunity for local governments to benefit from upgrades now is significant.

1.1 HOW TO USE THIS GUIDE

This guide was created to further support local governments as part of the Next Generation Streetlight Initiative, which is aimed at providing leading-edge education, resources and support to accelerate streetlight upgrades. This guide is meant to serve as a reference tool for Bay Area government leaders by providing foundational guidance and considerations for the successful implementation of LED streetlight upgrades. The target audience for this guide includes all local leaders and staff who play a role in upgrading and maintaining streetlights including public works directors, engineers, lighting specialists, city managers, county administrators, and other agency leaders and staff.

[a] Street and highway lighting accounted for 52.8 terawatt-hours in 2010 according to the DOE (http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf) and total US lighting power usage is estimated at 562 terawatt-hours in 2010 by the US Energy Information Administration (http://www.eia.gov/tools/faqs/faq.cfm?id=99&t=3.)

2 THE CASE FOR LEDS

Streetlights in the Bay Area, estimated to include well over half a million fixtures, consume significant amounts of energy. These fixtures predominantly use high intensity discharge (HID) luminaires, most of which produce relatively poor-quality light. Recent efforts have focused on developing and deploying the next generation of street lighting technologies, including light-emitting diodes (LEDs), as a means of both saving energy and improving street lighting. Solid-state roadway lighting solutions have the potential to save over 20 terawatt-hours or more of electricity annually in the U.S[4]. These technologies have been field tested in pilot studies and large-scale commercial installations, and they are proven to cut greenhouse gas emissions while also saving money in avoided energy and maintenance costs. The Bay Area has traditionally been a leader in implementing environmental initiatives, and many Bay Area agencies are considering installing—or have already installed—LED streetlights in a variety of locations.

2.1 THE OPPORTUNITY

Traditionally, high intensity discharge (HID) technologies such as mercury vapor (MV), high pressure sodium (HPS), and metal halide (MH), have dominated the street lighting market; HPS is the most common technology deployed for streetlights across the US and in California. Upgrading streetlight systems to advanced technology LEDs in place of incumbent fixtures is a proven way to cut costs, reduce maintenance requirements and lower climate change impacts while improving light quality. The US Department of Energy estimates that there are 52.6 million roadway fixtures installed in the United States, including 26.5 million streetlights and 26.1 million highway fixtures[5]. These lights consume significant amounts of energy, accounting for over nine percent of all lighting electricity consumption nationwide. Street lighting is evolving rapidly with the development light-emitting diode (LED) technology. LED streetlights combine enormous savings potential with superior lighting performance relative to incumbent technologies. As a result, a global market conversion to more advanced street lighting is already underway and is expected to accelerate over the next several years.

Many Bay Area agencies are considering installing or have already installed LED streetlights in a variety of projects to improve energy efficiency. However, only a fraction of the region's streetlights have been upgraded, leaving significant opportunity to act and derive benefits from the upgrades. A recent survey of Bay Area agencies conducted by the Bay Area Climate Collaborative showed that the existing Bay Area streetlight inventory and found that estimated that 95 percent of the existing fixtures, are high pressure sodium (HPS)[b]. The large number of local agencies interested conversion projects in the near future with particular attention going to LED.

[b] This excludes the City of San Jose fixtures, which are mostly low-pressure sodium (LPS), which are atypical of fixtures found in other Bay Area communities. 70 watt HPS make up about half of the HPS inventory. Other common HPS wattages are 100W, 150W, and 200W.

2.2 Benefits of LED Lighting

LEDs are particularly suited for street lighting applications, particularly "cobra-head" lights, and offer many benefits over the incumbent technologies, including:

Reduced energy costs: LEDs are able to achieve equivalent or improved light output while consuming 50% to 70% less power compared to their HID counterparts. Many utilities, including PG&E, offer special tariffs for LED streetlights based on rated wattages, which are typically much lower than HPS streetlights. These avoided energy cost savings help to offset the higher initial cost of LEDs.

Lowered Maintenance Costs: LED light sources last longer, requiring fewer trips up the pole to replace burnt-out lamps. As a solid-state lighting technology, LEDs are more resistant to vibration and impact when compared to HID light sources. Several LED streetlight products listed by the DesignLights™ Consortium[c] claim useful operating hours of over 150,000 hours, far greater than HPS lamp lifetimes (generally 20,000 hours or less). One of the most attractive features of LED luminaires is the promise of lower maintenance costs compared to traditional HID fixtures.

Improved lighting quality: LEDs provide greater options on color and generally provide whiter light with better color rendering. Properly designed, the fixtures can significantly improve acuity. In addition, whereas HID light sources typically create "hot spots" with more light than needed immediately beneath the fixture and "cold spots" surrounding the hot spot, LEDs can provide a more uniform light distribution that further improves visibility.

Reduced light trespass: Unlike conventional incumbent technologies, LEDs are inherently directional light sources, meaning that they can place the light where it is most needed and reduce light going in unwanted directions (such as into residences through windows).

Enhanced controllability: Unlike standard HID light sources, LEDs allow for instant on/off and light level adjustment, making them more suited for use with advanced lighting control systems. These systems can generate additional energy savings by dynamically adjusting light levels based on real-time lighting needs. For example, in the event of emergency controllable lighting could prove useful to first responders who may need to increase (or even decrease) lighting.

Reduced emissions: Reduced energy consumption delivers significant reductions in greenhouse gas emissions, supporting efforts to combat climate change. Upgrading 200,000 streetlights in the Bay Area would result in 100,000 metric tons of avoided CO2 emissions over five years – the equivalent of taking nearly 10,000 cars off the road.

Co-Benefits: Reduction in Crime

When comparing the rate of nighttime crime (7:00 p.m. to 7:00 a.m.) before and after installing new LED streetlights, Los Angeles found that crime (such as burglary, theft and vandalism) rates dropped by 10% between 2009 to 2011. Many factors can affect crime rates, but officials in Los Angeles believe the improved light quality was an important factor in the reduced crime rate, deterring criminals who take advantage of poor color rendering and "cold spots" produced by incumbent technology.

[c] The DesignLights Consortium (DLC) is a collaboration of utility companies and regional energy efficiency organizations that is committed to raising awareness of the benefits of efficient lighting in commercial buildings. DLC maintains a list of LED products that meet the organizations' minimum performance standards.

2.3 LED Readiness

LED lighting technology is rapidly penetrating the lighting market. For agencies considering whether LEDs are ready for their specific applications, it is valuable to review the significant institutional support for the technology, as well as its growing market adoption.

2.3.1 Research & Demonstration

In 2011 the worldwide LED lighting market grew by roughly 44%, from $1.2 billion to $1.8 billion[6]. Research and development investment by lighting companies is overwhelmingly shifting to LED technologies with an estimated 85-95% of total development resources in the lighting industry is now being directed towards LEDs[7].

The US DOE has placed a special emphasis on advancing solid-state lighting due to its potential for dramatic energy savings throughout the entire lighting market. Federal support includes demonstration projects (GATEWAY Program), stakeholder collaboration through the Municipal Solid-State Street Lighting Consortium, and product-testing with the CALiPER program. DOE-supported studies and demonstrations around the country that evaluate the performance and cost effectiveness of LED products in various applications have demonstrated very positive results for the ability of LEDs to adequately meet illuminance requirements in street lighting applications, as compared to baseline HID fixtures.

Over the past several years, DOE has published a total of 11 studies that focus on LED streetlights, the most current being:

LED Roadway Lighting: New York, New York (December 2011)

LED Post-Top Lighting: Central Park, New York City (September 2012)

LED Roadway Lighting: Philadelphia, Pennsylvania (September 2012)

LED Roadway Lighting Feasibility Assessment: Golden Gate Bridge (September 2012)

LED Roadway Lighting: Portland, Oregon (June 2012)

These GATEWAY studies and demonstrations generally found LED fixtures to be more than suitable replacements for incumbent fixtures and capable of generating significant energy savings[d].

LED street lighting has proven to be a significantly better light source in terms of expected maintenance, energy efficiency, and quality of light.

Edward Smalley, Seattle City Light

2.3.2 Market Adoption

The increase in LED light sales is being driven primarily by the rapid fall in prices. From 2010 to 2012 the most expensive core components of LED fixtures, the LED itself, dropped in price by 50% even as the light output has increased by 30% according to the DOE[8]. LEDs in outdoor applications are expected to climb from roughly 5% market share in 2010 to 70% by 2020[9]; LED street lighting sales are projected to rise from fewer than 3 million in 2012 to more than 17 million in 2020[10].

Large-scale deployments of LED streetlights includes the cities of Los Angeles (140,000 fixtures), Seattle (41,000), Anchorage (4,000), San Jose (2,100) and others. Los Angeles is the largest upgrade project in the country. Since the project began in 2008, the City has replaced over

[d] All of these studies can be found on DOE's website: www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html

100,000 fixtures in its cobra-head street lights[e], resulting in annual energy savings of almost 50 million kWh and avoided energy costs of almost $4.5 million per year. The project has led to a reduction of almost 30,000 metric tons of carbon dioxide equivalents (MTCO2e) per year. Installed LEDs have realized savings of over 63% of baseline fixture's energy use with good durability thus far[11]. The estimated total project cost is $57 million; the city secured a 7-year $40 million loan, along with rebates totaling $16.4 million. Estimated combined annual energy and maintenance savings once the project is complete is $10 million, resulting in an expected payback of roughly seven years[12]. This is currently the largest LED installation in the country.

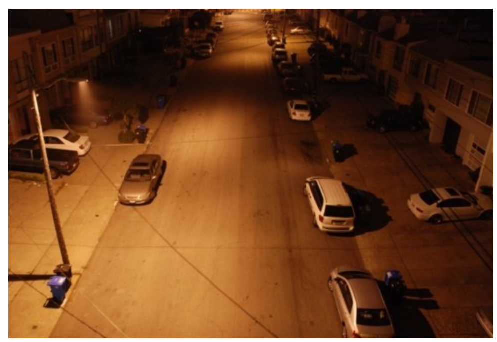
San Jose is in the process of converting 2,100 fixtures to LEDs equipped with an advanced controls system. Among other things, the City intends to use its control system to modulate the lighting on its streets in relation to activity levels as well as to generate data that can be used for billing purposes. The City is participating in a three-year pilot with PG&E that will allow the utility to adjust streetlight bills based on actual energy consumption. This project is expected to reduce the city's annual energy costs by $100,000, saving roughly 700,000 kWh and 190 MTCO2e each year. Targeting a full conversion of the entire streetlight inventory, San Jose anticipates savings of over 15 million kWh per year by 2022[13].

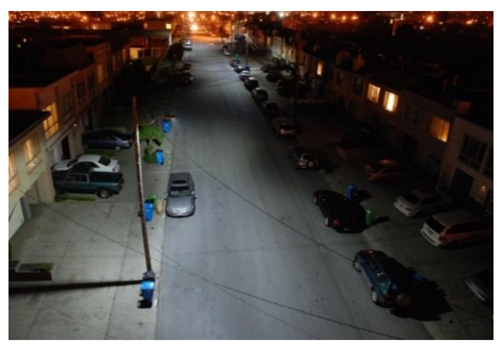
2.4 Community Acceptance

According to several studies, including DOE's GATEWAY reports and California Emerging Technologies Coordinating Council (ETCC) reports, users (residents, utility officials, other members of the public) are generally pleased with the light produced by LED streetlights, and when compared to HPS fixtures, find light from LEDs to be as good as or better in terms of color and quality. This is normally the case even when the average illuminance on the street is reduced under the LED streetlight installation. Public feedback from the cities of Los Angeles, San Jose, and Seattle, where major LED streetlight conversion projects are underway, corroborate these findings. Recent research by Clanton & Associates, Inc.[f] confirms that the public generally preferred white light options available from LED technologies over the narrow spectrum lighting from HPS and LPS. Even at half the overall lighting levels, users felt there was enough light from LED and induction streetlights.

Photographic comparisons demonstrate the qualitative difference in the look and feel of LED and traditional streetlight sources.

Figure 1 - San Francisco comparison of HPS and LED streetlights – Sunset District



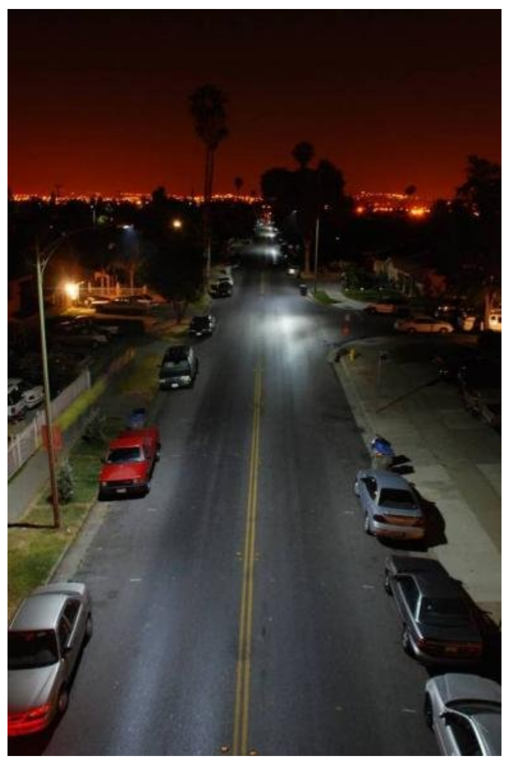


[e] The city is using induction for the less common decorative lights.

[f] Clanton & Associates, Inc. is a leading street lighting consultancy on LED and induction streetlight installations in Anchorage, San Diego, and San Jose.

Figure 2 - San Jose comparison of LPS and dimmable LED streetlights at 100% and 75% power

100%



75%

Assessing Bay Area Potential

In late 2011 and early 2012 BACC and Energy Solutions surveyed cities and counties in the Bay Area to assess the region's inventory and interest in upgrading their streetlights. 61 percent of local governments participated (67 of 109), identifying more than 290,000 non-decorative streetlights in their inventories and over 240,000 as desirable to upgrade. Many agencies indicating they would like their conversions to be complete by 2015. Seven agencies are planning to install controls as part of their conversion project, and another 20 agencies are considering potentially installing controls.

2.5 Addressing Barriers to Adoption

While agencies in the Bay Area are prioritizing conversion projects, there are reported barriers to adoption, including the following:

High Cost and Access to Funding: Nearly half the respondents cited access to funding as a significant barrier to implementing conversion projects. Though prices are falling rapidly and rebate programs from PG&E and other utilities make project costs more attractive, LEDs are still more expensive than the incumbent technology on an up-front cost basis. Identifying funding sources is the top priority.

A number of attractive financing options exist including 0% on-bill financing from PG&E, 1% financing from the California Energy Commission, as well as other public and private finance strategies. These are discussed in depth in the Incentives and Financing Section of this guide. Depending on the specific fixtures required, these finance strategies can yield payback periods of six years or less given current costs and incentives. Some cities such as Los Angeles have found these upgrades to be cost-effective even without the use of federal grants. Finally, the BACC is working with several partner agencies to pool interest among Bay Area cities and counties for regional collaborative procurement of LED streetlights to leverage scale for improved purchase terms and reduced transaction costs.

Lack of Standardization for LED Fixtures and Controls: LED technologies are relatively new to the high-volume markets. There are many products available, and it can be difficult for agencies to identify which products offer the right features at the highest value. Use of products qualified by the DLC can provide increased confidence in fixture quality.

Uncertainty of LED Performance Relative to Existing Fixtures: Some respondents expressed concern that LEDs will not provide the same quality of lighting as the existing fixtures. As noted above, DOE's GATEWAY studies, California ETCC reports, and numerous Bay Area demonstrations have found light from LEDs to be as good or better in terms of color and quality. However, there have been cases of significant community concern raised with newly installed lights, typically around issues of glare and light trespass. It is important to execute a good design process which includes community input to ensure a proper design.

Long-Term Performance: LED fixtures are rated to last substantially longer than HPS fixtures. However, since no LED streetlights have been installed for their entire rated lifetime, some agencies expressed concern over whether or not fixtures will actually last as long as manufactures claim. Since the maintenance savings attributed to longer fixture life are factored into the overall project payback, some agencies are concerned that the payback time will be increased significantly if lamps do not last as long as expected. Thus far, Los Angeles and Seattle have experienced a very low failure rate and degradation with their new LED fixtures. Due to the scale and comparatively early deployment by the City of Los Angeles, the deployment is also generating valuable data on the quality of the fixtures – lumen depreciation is reported at less than 10% over 4 years and rate of initial failures of fixtures is considerably lower than conventional technology at 0.2% (Ebrahimian 2012).

Staff Availability: With recent budget cuts and subsequent lay-offs, the remaining agency staff may find it challenging to undertake new projects. Some agencies expressed concern that staff would not have the time to manage an LED conversion project. Leveraging partners such as the BACC to assist with research and collaborative approaches is one way to reduce staff load. In addition, some agencies such as the City of Oakland opt for executing turnkey programs with third-party providers. In a turnkey program, the provider assumes most of the responsibility for design, finance procurement, and deployment. While project management oversight is still required, the overall level of effort is reduced from an agency perspective.

3 TECHNOLOGY OVERVIEW

First developed in the 1950s, LEDs are an energy-efficient light source that can be used in many different lighting applications. As semiconductors, LEDs are fundamentally different from traditional light sources, such as HID lamps, in terms of how they generate visible light. The unique properties of LEDs can offer several inherent advantages over HID lamps in streetlight applications, including longer life, superior color rendering, improved light directionality, and enhanced controllability. As the technology continues to mature and manufacturing costs continue to fall, LEDs are increasingly revolutionizing the street lighting market. Streetlights utilizing LEDs provide white light to nighttime streets, improving color rendition and facial recognition. These light sources also promise at least 50,000 hours of operation before requiring major maintenance, provided the power supply and other hardware remain in good working condition.

As solid-state lighting devices become more commonplace in street lighting, a basic knowledge of lighting is increasingly helpful. The following sections on color, directionality and controllability, as well as our nighttime perception of brightness, are intended to serve as a basic introduction to lighting fundamentals, including terminology and concepts. Please refer to the resources section of this guide to locate sources for more in-depth information.

3.1 TECHNOLOGY TREND

Over the past decade, LED technology has been quickly evolving, resulting in increased efficacy and lower manufacturing costs. DOE's Lighting Facts program tracks the performance of LED fixtures submitted by manufacturers who have evaluated their products under industry standard test procedures. Products listed in the Lighting Facts database have been rapidly increasing in both number and efficacy since the inception of the program in 2009, as shown in Figure 3[g].

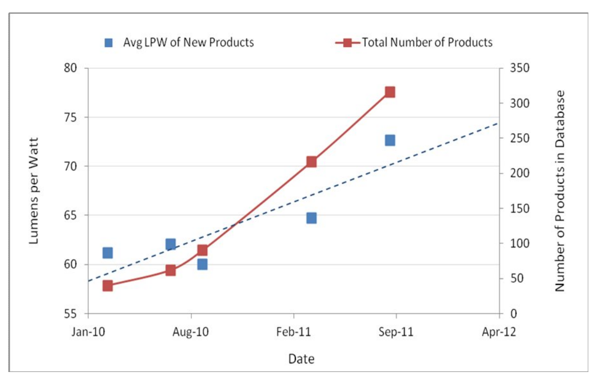


Figure 3 - Efficacy and count of products listed in the DOE Lighting Facts database

[g] More information available at: http://www.lightingfacts.com/.

While efficacies of mature technologies such as incandescent and fluorescent lighting have largely leveled off, efficacies of LEDs are continuing to improve. Efficacies for HID systems can be as high as 111 lumens per watt (lm/W); however, fixture losses can be as high as 30 to 50%. In contrast, commercial LED-based light sources have achieved efficacies of over 130 lm/W for commercially available cool white LED packages with significantly lower fixture losses.

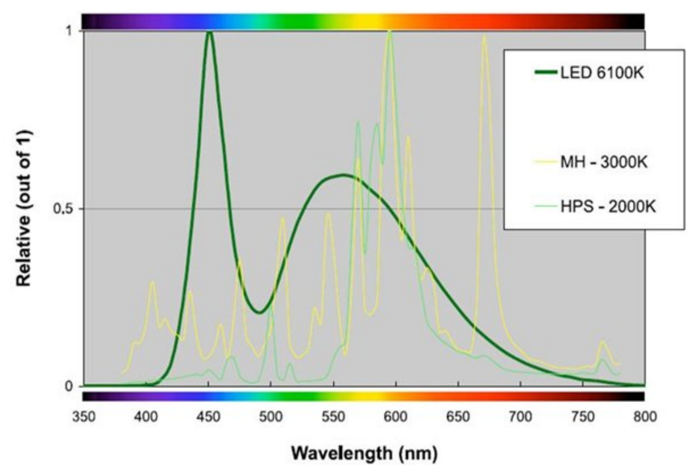
3.2 Correlated Color Temperature

One of the most visible features of an area that is transitioning to LED luminaires from HPS is the change from the yellowish light to white. The correlated color temperature (CCT) of a light source is measured in degrees Kelvin (K), and it describes the appearance of light emitted from that source in terms of how "warm" or "cool" it is. A low CCT denotes a warm color temperature while a high CCT denotes a cool color temperature. High-pressure sodium (HPS) lamps, for example, have a low CCT (generally around 2000 K), and they deliver a warm, orange-yellow light. In contrast, most general illumination LED sources have higher CCTs; they deliver white light with a relatively cooler color.

The CCTs of light sources affect the appearance of the structures and objects they illuminate. Under white light, the colors of cars parked along a street are easily distinguishable, but under streetlights with a very low CCT that renders all vehicles in a yellow hue, the colors of those same cars are more difficult to distinguish. This is because, while light may appear to be a single color, a light source actually gives off many different wavelengths of radiation. White light is a mixture of these different wavelengths, which account for the colors we perceive. The human eye simply blends these colors together when it perceives white light. When the color of a light source is deconstructed into its individual colors, the result is a light source's spectral power distribution. This is usually represented in wavelengths that range from approximately 380 to 780 nm. CCT is one way of distilling a light source's spectral power distribution (SPD) to a single number; the color rendering index (CRI), explored in section 3.3, is another.

The figure below compares the SPD of three technologies typically used in outdoor lighting. When compared to HPS, light produced by the LED source more accurately renders the full range of colors in the visible spectrum. In contrast, the HPS light, with a peak in spectral power distribution at around 600 nanometers (nm), will generally render objects a yellowish-orange—even if those objects are more accurately rendered green or blue.

Figure 4 - Color Distributions of LED[h], HPS, and MH



Source: US DOE 2008b[14]

While LEDs generally provide "cooler" light with a higher correlated color temperature, LED chips can be customized to produce light of specific CCT, as desired by the user. Three to five years ago, many LED streetlights on the market offered CCTs around 5000–6500K, a fact reflected in the figure above. Since then, lower-CCT LED luminaires, measuring around 4100K, have garnered favor and assumed most of the market share.

[h] Note that current LED streetlight fixtures are now typically in the 4000K CCT range, as opposed to 6100K. The smooth distribution though remains characteristic with LEDs.

3.3 Color Rendering Index

In addition to CCT, the color rendering index (CRI) is also used to measure how different light sources affect the appearance of the objects they illuminate. Measurements on the color rendering index (CRI) describe how accurately different light sources render colors. CRI is expressed as a number on a scale with a maximum value of 100. A CRI value of 80 or above denotes good color rendering. A very high CRI (90 or above) denotes even more accurate color rendering. The Illuminating Engineering Society of North America (IESNA) recommends a CRI of 50 or higher for streetlights. The DesignLights Consortium (DLC), a resource for high-quality, energy-efficient lighting products, also requires a minimum CRI of 50 for outdoor roadway luminaires. The U.S. DOE Municipal Solid-State Street Lighting Consortium (MSSLC) recommends a minimum CRI of 60. HPS lamps typically have a CRI of 22–70, while solid-state light sources generally measure higher on the CRI scale.

3.4 Longevity

Lifetimes of SSL technologies are significantly longer than traditional sources. As the table below indicates, induction sources offer the greatest number of lifetime hours, followed by LED sources. This extended life, coupled with fewer failures, lengthens the time between maintenance activities, yielding savings that can offset some of the initial costs of upgrading to more advanced technologies.

All lighting technologies degrade over time. This degradation is described as the lumen maintenance of a source. If a source maintains 70% of its original luminance after a given number of hours it has an L70 lumen maintenance for that period[i]. DLC technical requirements specify that outdoor roadway luminaires have an L70 of 50,000 hours and a minimum luminaire warranty of five years in order to qualify for the DLC product list. The MSSLC also recommends street lighting manufacturers provide a warranty of at least five years. The MSSLC specifies that such warranties should cover the light fixture's housing, wiring and connections, as well as the LED light source(s) and drivers (with luminaire failure defined as "negligible light output from more than 10 percent of the LED packages"). Warranties allow cities to ensure streetlights meet lifetime expectations.

Lamp Type	Demand*	Source Efficacy (L/W)***	CCT (K)	CRI	Lifetime (hrs)	Price
High Pressure Sodium	70-400	80-120	1,900-2,200	22-70	15,000-40,000	$$
Low Pressure Sodium	55-180	130-170	1,700-1,800	-	16,000-18,000	$$
Ceramic Metal Halide	70-400	75-110	3,000-4,200	80-94	10,000-24,000	$$-$$$
Metal Halide	70-400	40-70	3,000-4,200	60-80	10,000-20,000	$$
Mercury Vapor	75-1,000	20-40	3,200-6,700	15-50	16,000-24,000	$$
CFL	20-70	80-85	2,700-5,000	80-90	6,000-20,000	$
Induction	70-250	50-85	3,500-5,000	80-85	100,000	$$-$$$
LED	40-250**	Up to 130	2,700-10,000	50-90	35,000-50,000+	$$-$$$

* Typical size of lamps used in exterior applications
** Typical size of LED luminaires used in exterior applications, luminaire contains multiple LEDs
*** Based on initial lumens, system efficacy should be determined and is dependent on the specific fixture style, ballasts, and drivers employed

Figure 5 – Lighting technology characteristics

[i] L70 is considered the typical threshold at which observers will notice a change in lighting levels.

3.4 Distribution

LEDs are directional light sources, emitting light only from one side of an LED chip, unlike HID sources that excite gas in a glass lamp and are roughly omnidirectional light sources. Depending on the optic, the directionality of the LED light source can reduce fixture losses in many applications, such as light reflected back into the source that can account for 20%–30% efficacy penalties in HID fixtures. LEDs also come in a greater range of customized wattage outputs than the incumbent technology, allowing for "right-sizing" based on application. HPS lamps, on the other hand, are only available in set wattages (100W, 150W, 200W etc.) that often require lighting systems to be designed to over-light the target area to ensure that mandatory lighting requirements are met.

In addition, LED luminaires are composed of multiple LED chips, each of which can have its own lens which can direct light of that particular chip in a direction independent of the other chips. This allows designers to create precise optical distributions. These fixtures therefore inherently require less optical control to direct light to the intended targeted area, resulting in greater "target efficacy", creating more uniform light distribution and reducing overlap from adjacent fixtures. While LED deployments may utilize reduced total light levels relative to the incumbent technology, the uniformity of lighting is typically improved by LED streetlights, thereby having a positive effect on overall roadway safety.

Finally, with a properly designed and installed fixture, the directionality of LEDs can reduce light scatter in unwanted directions – including backlight, uplight and glare. Minimizing undesirable light distribution is important to prevent light intrusion into residences through windows which can disturb occupants (typically backlight), annoying or visually disabling glare compromising safety, as well as uplight skyglow which can affect wildlife and astronomy efforts.

3.5 Night Time Performance

In addition to consideration of color, the perception of a light source is a combination of the spectral power distribution (SPD) of the source, and the surrounding visual conditions under which it is viewed. There are three general types of visual conditions related to human visual response at different light levels[j]. Photopic conditions account for the majority of applications including all applications occurring under moderate to well-lit conditions, including broad daylight; scotopic conditions occur at very low light levels; and mesopic conditions are a combination of the two and account for the majority of exterior, nighttime lighting applications. Photopic and scotopic luminous efficiency functions are well-defined, although the photopic luminous efficiency function is the only function accepted for use in standard lighting practice. Much work remains to be done on the definition of a mesopic luminous efficiency function.

Measurable light levels are relative quantities based upon application of the scotopic or photopic luminous efficiency function. Application of one function or the other has the effect of biasing the measurable light level depending on the source's SPD; thus, it is important to understand which function has been applied to obtain a particular value of light output. The lighting industry usually provides light output values using the photopic luminous efficiency function.

Broad spectrum light sources like LEDs provide higher mesopic performance than HPS, which is a narrow spectrum light source. Rods are also essential for peripheral vision, which is important for nighttime driving conditions where drivers need to be aware of objects and humans that may suddenly enter the road. For these reasons, broad spectrum white lighting can provide the conditions for better visual acuity at night than conventional lighting sources.

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[j] The human eye has differing receptor cells for well-lit versus low light conditions, cones and rods respectively. These cells differ in the light wavelength to which they are most receptive, 507nm for rods (scotopic) and 555nm for cones (photopic).

This translates from theory to practice when considering lighting used primarily at night for complex tasks, such as driving. In some studies, white light sources have been preferred by user groups not just in the category of color but also in the perception of brightness. Although the lighting may not be brighter when footcandle[k] measurements are taken, but the perception of brighter light is expressed by study participants. User preference for the look and feel of broad spectrum streetlight sources has been demonstrated in California pilot installations. The International Commission on Illumination (CIE) has recently published CIE 191, a model to quantify mesopic performance of lighting systems, which can be applied for calculating or measuring luminance levels for compliance with local street lighting ordinances. The Illuminating Engineering Society (IES), which publishes recommended lighting practice commonly used in the US, has also recently updated their Lighting Handbook with guidance for inclusion of mesopic considerations in certain street lighting conditions.

3.6 Advanced Controls

Unlike HID lamps, LEDs can instantly turn on and off, making them easier to dim, amplify, and control than traditional streetlight lamps. This feature makes LEDs easy to pair with photosensors, occupancy sensors and controls, and networked lighting controls, which can further increase energy savings beyond a simple change of light source. Networked lighting controls allow cities to automatically monitor their streetlights' energy use, identify maintenance needs, and adjust operating schedules – all from a computer desktop. Networked lighting control systems are quickly expanding to incorporate new features and improved technologies. Because instant control of every light is now possible, maintenance issues can be quickly addressed without time-consuming field checks. Some of the features of networked lighting include:

- Remote data assessment, via Internet connections
- Outage detection and maintenance tracking
- Demand response control
- Power metering to take advantage of power savings from dimming
- Easily adjustable light dimming profiles
- Occupancy pattern tracking
- Programmable scheduling to replace or supplement photocell control

Adaptive Controls: San Jose

As of October 2012, the City of San Jose deployed 962 streetlights with adaptive controls. San Jose is participating in a pilot program with PG&E whereby streetlight costs are calculated on actual usage rather than the conventional "per pole" tariff. Early results show a 39% cost savings compared to the LPS lights replaced (LPS is approximately 50% more efficacious than HPS.)

The PG&E pilot is groundwork towards what is anticipated to be statewide policy direction towards metered streetlight tariffs to encourage greater efficiency.

Control of lighting levels not only allows for situational adaptation of lighting levels; they can enhance the durability of the fixtures. Adaptive lighting controls can be used to fine-tune the light levels on individual fixtures to account for the gradual dimming of the fixtures as they age. This helps to prevent over-lighting scenarios in earlier years and under-lighting in later years. In addition to reducing lighting load by dimming or turning off lights when appropriate, the controls systems can be used to monitor the entire streetlight system, alerting administrators to outages, dayburners, failing lights,

[k] Unit of illuminance or light intensity defined as the illuminance cast on a surface by a one-candela source one foot away.

rapid sequential failure of nearby lights (potentially indicating copper wire theft), and other operational issues, enabling faster corrective responses. This feature is a significant maintenance benefit for streetlight system administrators. Furthermore, some systems provide utility-grade electricity consumption metering of each individual streetlight, which may allow utilities to bill agencies based on actual consumption. Currently streetlights are unmetered loads, and utilities typically bill agencies on a fixed tariff as opposed to metered consumption.

Advanced lighting controls systems create significant new opportunities to not only save energy, but also to improve safety and security. Streetlights could potentially be linked directly into traffic signal and electronic message board networks, allowing these systems to share information to promote smoother traffic flow and more targeted light services.

In the near future, LED fixtures with integrated networked controls systems are likely to become the standard for lighting the world's streets and roadways. In fact, these technologies are already available today and are capable of instantly improving a city or county's street lighting service while reducing ongoing energy and maintenance costs. Forward-thinking cities such as San Jose are already putting in advanced controls systems to extract further benefits from their newly installed LED fixtures. Though not all cities currently appear ready to fully control their streetlight systems, one option is deployment of low or no added cost "controls-ready" fixtures which enable easy retrofit with a controls device in the future. This ensures that savings are not lost with the massive deployment of fixed output streetlights, locked at full light output for their entire rated lifetimes.

Adaptive Controls: UC Davis

In June 2012 the University of California, Davis debuted its Adaptive Campus Control System. The smart lighting network by incorporates over 1,400 adaptive street and walkway LED luminaires into a single network. Each fixture has a wireless controller and an integrated occupancy sensor, allowing the system to accurately determine an occupant's path of travel and adjust light output to the real-time needs of actual occupants. The result is maximum energy savings with enhanced maintenance options and safety features. Early results indicate savings in wall pack applications of up at 87%.

3.7 Summary of Key Characteristics and Guidance

The following table summarizes key technical characteristics of fixtures important in lighting system design and sources for guidance or standards.

Fixture Characteristics	Definition	Industry Standard Test or Guidance[l]	For More information
Light output or brightness			
Lumens	Measure of the total amount of visible light emitted by a source.	IES LM-79	
Footcandles[m]	Measure of the total intensity of light falling on a surface.	Measured at street level, using a light meter.	
Luminous Efficacy	Efficiency in converting electricity into light; measured in terms of lumens per Watt (lpw or lm/W). LEDs have much higher lpw than incandescent light sources, and are comparable to gas discharge lamps.	IES LM-79	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energy_efficiency_white_leds.pdf
Correlated Color Temperature (CCT)	The temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source. Higher CCT light sources are considered "cooler," with a blue-ish hugh; lower CCT light sources are considered "warmer," with a more yellow-ish hue. White LEDs are typically higher CCT.	IES LM-79	http://cool.conservation-us.org/byorg/us-doe/color_quality_of_white_leds.pdf
Color Rendering Index (CRI)	A quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. LEDs typically have high CRI relative to gas discharge lamps. Colors therefore tend to look more natural under LED light sources.	IES LM-79	http://cool.conservation-us.org/byorg/us-doe/color_rendering_index.pdf
Light Distribution			
IESNA Classification	A classification system for rating roadway luminaires according to their light distributions on the ground.	IES Lighting Handbook	http://www.agi32.com/kb/index.php?article=77
Backlight-Uplight-Glare (BUG) Rating	A rating of a luminaire's optical performance related to light trespass, sky glow, and high angle brightness control.	IES TM-16-07	http://www.ies.org/pdf/education/ies-fol-addenda-1-%20bug-ratings.pdf
Lifetime	Useful life for LED packages is typically defined as the number of hours before light output drops to 70% of initial light output. Note that this definition applies only to the LED package, not the entire fixture. It does take into account other LED package failure modes, or other fixture component failure modes. At this time there is no standardized way for estimating LED fixture lifetime.	IES LM-80	http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lifetime_white_leds.pdf

Note, the above is not an exhaustive list of quality factors. Additional fixture characteristics such as thermal management and ingress protection are also important.

[l] IES is the Illuminating Engineering Society of North America

[m] Technically, this is not a characteristic of the fixture, but is a function of both the lumen output of the fixture and environmental/ambient conditions

4 Financial Analysis & Approaches

Although prices are falling as SSL technology continues to mature, LED streetlights are currently still more expensive than their HID counterparts on a first-cost basis. While energy and maintenance savings have been shown to make investments in LED streetlights highly cost-effective from a life-cycle perspective, the large upfront capital cost, particularly in retrofit scenarios, requires careful attention to finance strategies. Agencies can take advantage of a number of strategies and programs designed to support investments in advanced, energy efficient street lighting technology. The current low cost of capital and high current incentives makes this an especially attractive time to act.

4.1 Financial Analysis

4.1.1 Cost Factors

A complete cost analysis should take into consideration the following factors:

Initial Costs & Incentives

- Cost of fixtures
- Cost of installation
- Reduction of costs via rebates

Savings & Cost of Capital

- Reduced cost of maintenance
- Reduced energy cost based on current and projected energy expenses
- Consideration of increasing electrical costs
- Reduction of savings from the cost of capital

A simple payback is defined as the incremental cost of a new system over the existing system, divided by the incremental annual energy and maintenance cost savings received from the new system.

$$Simple\ payback = \frac{Initial\ cost\ of\ the\ program}{Annual\ savings\ in\ energy\ and\ maintainence}$$

If the payback seems favorable based on initial calculations, agencies should complete a more rigorous financial analysis to determine Return On Investment (ROI) and the Net Present Value (NPV) of the project. This can be done with the financial analysis tool from the Municipal Solid-State Street Light Consortium (MSSLC).

4.1.2 MSSLC Retrofit Financial Analysis Tool

In conjunction with the Clinton Climate Initiative, the MSSLC has produced the “MSSLC Retrofit Financial Analysis Tool” to help agencies understand the costs and benefits of LED streetlight retrofit projects. This Excel-based model can be used to estimate energy and maintenance savings and payback periods for projects of various size and scope. It provides for mapping replacement of specific numbers of fixtures of specific sizes, rebates, tariffs, and installation costs, and it helps model different financing and implementation scenarios. The MSSLC Retrofit Financial Analysis Tool can be customized for specific projects to demonstrate estimated costs and paybacks in order to justify cost-effectiveness to decision-makers and financial institutions.

The MSSLC Retrofit Financial Analysis Tool can be downloaded from the MSSLC website: www1.eere.energy.gov/buildings/ssl/financial-tool.html.

The BACC has a populated a version of this tool which already includes PG&E tariffs and incentives at www.baclimate.org

4.2 PG&E Rebates

PG&E offers rebates to agencies purchasing and installing qualified LED streetlights[n]. The rebate amount—ranging from $50 to $200 per fixture—is tied to the baseline wattage of the fixture to be replaced (70W and above), such that replacing higher wattage fixtures with LEDs nets larger rebates. The utility rebate covers a significant portion of the total project cost and represents an excellent opportunity to reduce the payback periods to make the project more affordable.

PG&E LED Streetlight Rebate Requirements

Fixtures must be:

1) Design Lights Consortium (DLC) listed.
2) Socket ready for electronic type photo controls meeting American National Standards Institute (ANSI) standard C136.10 with a turn on value of 1.0 foot-candles and a turn off value of 1.5 foot-candles. Electro-mechanical or thermal type photo controls are not acceptable.
3) Labeled with wattage stickers identifying the fixture technology (LED) and total fixture wattage that follows ANSI Standard C136.15.

Customized Retrofit Incentive: Typically, a customer would receive a larger rebate if they decide to use PG&E's per-fixture rebate rate. However, if a customer purchases LED fixtures that do not qualify for the per-fixture utility rebate, the project may still be eligible for a Customized Retrofit Incentive, which rewards the installation of energy-saving equipment with cash payments, based on the energy savings that are achieved. For 2012, PG&E pays $0.05/kWh for savings from lighting upgrades. The Customized Retrofit Incentive could also be applicable for energy savings achieved through dimming with adaptive streetlight management. Cities could utilize this incentive to help offset the incremental cost of the controls system.

4.3 Funding & Finance Sources

To fund an LED streetlight deployment, cities may consider several sources of funding, which can be combined to achieve the most favorable financing package for the project. Potential funding sources include:

[n] Details on the PG&E's LED Streetlight Rebate Program and Customized Retrofit Incentives can are available from PG&E's website: http://www.pge.com/mybusiness/energysavingsrebates/rebatesincentives/ref/lighting/lightemittingdiodes/incentives/index.shtml and http://www.pge.com/mybusiness/energysavingsrebates/rebatesincentives/ief/.

Self-Funding: If a city has its own municipal utility it may be possible to borrow the funds from the utility and pay it back over several years (typically 5-7) out of the savings in energy and maintenance. With current interest rates, it may also be highly attractive to issue bonds or to arrange financing through private capital markets.

Federal and State Government: Many cities were able to take advantage of block grants in the 2009 American Recovery and Reinvestment Act (ARRA) for these projects. While the ARRA funds are now mostly gone, cities may find other federal grants in the form of matching funds, etc. The MSSLC may be a good resource for identifying these. The California Energy Commission has grants and low interest loan programs available for energy saving projects.

Utility Programs: Pacific Gas and Electric (PG&E) in Northern California currently has the most comprehensive LED street lighting conversion program in the U.S. This program includes special tariffs, rebates, financing and a turnkey installation program.

ESCO's: Large Energy Saving Contractors (ESCO's) offer turnkey installation programs, and can finance the project as well as purchase and install the lights. A city can pay for this over many years out of energy and maintenance savings as well as any potential energy rebates.

Manufacturers' Programs: Several large street lighting manufacturers are also willing to help finance these projects accepting payments over several years. It is wise to ask the manufacturers about their programs and possibly include these terms in the bid documents.

4.4 Financing Options

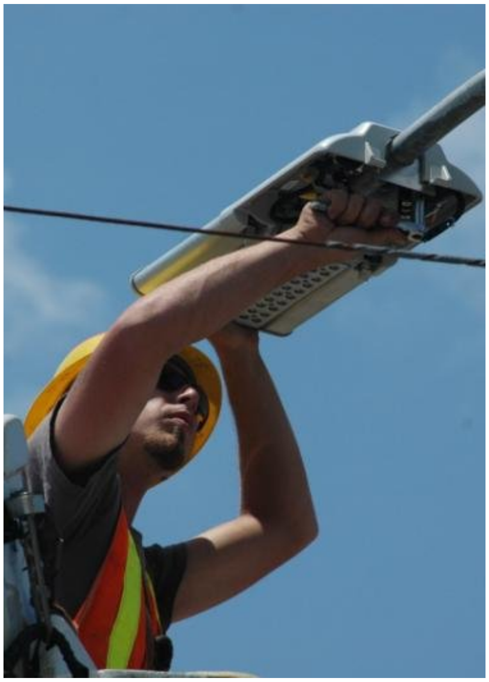
Agencies interested in upgrading their streetlight systems to LEDs can take advantage of a variety of financing options with attractive interest rates or other features designed to incentivize investment in energy efficiency projects. Agencies can consider negotiating a loan repayment structure in which payments are approximately less than or equal to the anticipated savings from the project, thus enabling a municipality to make annual payments which are offset by the annual energy savings generated from the energy, maintenance and operational savings realized from a streetlight upgrade project.

If working with an Energy Services Company (ESCO) or Energy Electrical Contractor (EEC), these organizations can facilitate the financing process and help municipalities determine the best available options. This is typically provided as a pass-through service to help facilitate financing.

Each of the financing options listed on the next pages has merits, and an agency looking to finance a large-scale project may need to consider using a combination of financing options, as appropriate.

Financing Feature	PG&E On-Bill Financing	CEC Low Interest Loans	Standard General Obligation (GO) Bonds	Qualified Energy Conservation Bond (QECB)
Purpose	Purchase and install qualifying energy-efficient equipment.	Projects with proven energy and/or demand cost savings are eligible.	Any public use allowed under state law and voter authorized parameters.	A form of tax credit bond for energy efficiency projects.
Authorized Amount	Up to $250,000.	Up to $3 million per application.	Depends on voter approved authorization, typically issued in amounts over $10 million.	$ 3.2 billion, nationally
Credit Rate	Interest free	1% interest	Market rates: 1% - 6% depending on credit quality and term.	Set by Treasury daily. 0.5% - 2.5% effective interest rate, depending on credit
Terms and Conditions	Repaid through monthly electricity bills for periods up to 120 months. Requires engineering review and location inspection to set terms.	Loan is repaid from energy cost savings within 15 years, including principal and interest (approximately 13 years simple payback.)	Repayment term up to 30 years or longer	Tax credit rates and allowable term length are set daily by the Treasury.
Issuer	PG&E.	California Energy Commission.	State or Local Government unit or any 501(C)(3) through conduit.	State or Local Government unit.
When to use	For projects with sufficient savings to repay loan within term limits, and that qualify for a rebate or incentive through a PG&E program.	For energy efficiency projects with proven savings.	For large capital projects when voter approval is available. Authorization may include ability to include energy improvements with other capital projects.	For qualified purposes and when bonds are available.
Allocation Process / Deadlines	Eligible PG&E customers on a first-come, first-served basis until program funds are no longer available.	First-come, first-served basis for eligible energy projects.	Subject to election cycle approval for new authorizations.	Allocated by treasury to States in proportion to population. State allocation process varied, CA through Treasurer's Office.
Biggest Benefit	Interest free.	Low interest rate. The repayment schedule is based on the estimated annual energy savings and is structured to have payments be less than the savings.	Low cost long-term financing.	Inexpensive. Municipality pays back principal and a portion of the interest on the bond. Bondholder receives federal tax credits or subsidy for 70% of bond interest.
Biggest Drawback	Low maximum amount and cash flow. OBF requires municipality to front the funds. OBF funds become available only after final verification.	Only approved project-related costs with invoices dated within the executed term of the loan are eligible to be reimbursed from loan funds.	Subject to state constitutional debt limitations (debt ceilings and referendum.) Voter approval process.	Few Investors. Frequently done as private placements making pricing less transparent than regular capital markets.
Risks	Verification failure jeopardizes loan.	NA	NA	Ability to receive allocation and meet financing/implementation milestones.
More Info	www.pge.com/obf	www.energy.ca.gov/fficiency/financing		www.treasurydirect.gov/govt/rates/rates_irstcb.htm

Certificates of Participation (COPs)	Tax Exempt Lease	Efficiency Savings Contracts (ESCs)	Public/Private Partnership	Private Loan
Debt issuance tool that uses a lease/lease back structure to secure the debt issuance.	Any public use allowed under state law.	ESCs provide third party ownership and maintenance of energy efficiency installations.	Service agreement with a private third party.	Private loan for any purpose
Most cost effective if over $5 million.	NA	ESC's are typically issued for amounts over $2 million.	NA	Any amount
Market rate, depending on credit quality and term. Slightly higher (0.05-0.15%) than similar credit GO.	Market -2.5% - 6%, depending on credit quality and term.	May be classified as an operating expense for the public sector.	May be classified as an operating expense for the public sector.	Market rate, but typically higher than public debt.
Payback period of up to 40 years, though term should not exceed project's useful life.	Term determined by the market. Repayment in up to 15 years, based on state laws.	Payback periods range from 7 to 10 years.	Typically 20-30 year concessions, but can vary.	Varies but may not exceed project useful life.
Local Government or Conduit Issuer	State or Local Government unit or any 501(C)(3) through a conduit.	When government agency desires off balance sheet financing and/or prefers to have operations and maintenance confirmed for the entire term of the financing.	A specially established non-profit 501 (C)(3).	Bank or via ESCO.
For capital projects when voter approval process would be inconvenient.	For capital projects when voter approval process would be inconvenient.	To keep a project off balance sheet.	To keep a project off balance sheet.	In large-scale projects, possibly supplementing other financing.
NA	NA	NA	NA	NA
COPs are relatively simple to structure and issue for relatively low project amounts.	Minimal transaction cost. Easier to get approval.	May be classified as an operating expense. Predictable energy costs through fixed payments with savings greater than projected utility costs.	May be classified as an operating expense for the public sector. May include performance guarantee.	Funds limited only by credit rating. If with an ESCO, may have performance guarantee.
For small project amounts the transaction costs can be disproportionately high.	Slightly higher pricing.	Assuring that pricing is transparent and that the provider is reputably able to deliver the terms as promised	Slightly higher pricing than standard tax-exempt financing.	Higher pricing.
Secured by General Fund. Ensuring savings provide confidence in economic benefit from the project.	NA	Payments may include escalation factors, which may exceed costs that would have been incurred otherwise.	Accounting treatment subject to project-specific interpretation.	On balance sheet.



5 Strategies for Implementation

Deployment of LED streetlights involves securing project financing, designing the new lighting system, procuring fixtures, construction and installation, and operation and maintenance. Some agencies with in-house expertise may manage the entire process, others partner with service providers or other agencies to complete one or more of the steps in the process. Some of the strategies for deployment include contracting with a turnkey provider or "piggybacking" off of another city's RFP are described in this section. Each process has distinct advantages to the City and should be explored to understand to overall benefit based upon the City's specific requirements.

5.1 Overall Process

As with any infrastructure project, agencies should approach implementation with attention to a number of key factors to ensure success. The process may vary depending on where an agency is with regards to streetlight maintenance and upgrades, whether the agency chooses to engage third-parties such as ESCOs, and whether some luminaires have been demonstrated. Certain elements of a good plan are iterative, as elements like cost, technology and deployment are interrelated. A basic process could be as follows:

1. Preliminary evaluation & objectives: Using a basic count of lights and types, use ballpark figures to evaluate the benefit of an upgrade effort. The MSSL financial modeling tool can provide a strong initial evaluation of the savings and emissions benefits. Objectives for the project should be identified such as financial benefit and light quality improvement. Initial investigation can also include exploration of current technology and strategies.

2. Engage Stakeholders: It is important to engage decision-makers and other stakeholders early on intended direction including relevant engineers, procurement, legal counsel and ultimately city councils and the community to determine project process and other requirements. Early engagement can reduce project complications in later stages.

3. Define the Scope: Scope will be iterative based on technical and financial considerations but initial specific scope will require a clear count of current fixtures, types and roadway types fixtures are on. Consideration of the design strategy (see below) and whether controls are to be considered can come here. The financial modeling can be refined here.

4. Determine funding strategy: Determining the funding or financing strategy requires engaging finance specialists for detailed evaluation. If a project is small it may be possible to self-fund an upgrade but most agencies will need finance. A number of attractive options exist (see section 4) but each carries specific implications on cash flow, risk, and timing. A detailed financial analysis should be done at this time.

5. Determine deployment strategy: Typically the most cost effective method of implementation is for agencies to buy the fixtures directly and have them installed by their own crews or by an outside contractor. Some cities however prefer having a single contractor provide a complete "turnkey solution" which may also include financing, labor warranties, etc. This approach will normally have a longer financial payback but reduced agency staff requirements. Naturally, in all cases, clear guidance and attentive project management are required. These and other considerations are discussed in the next sections.

6. Develop draft specification: As with other stages of the process developing a specification is an iterative process. It is a good idea to create an early draft specification which may be based on a simple initial set of metrics. This can serve to surface questions to address and inform research. The final specification will be an outcome of the design approach taken as discussed below. A detailed model specification is available from the Municipal Solid-State Streetlight Consortium (see Section 6) which may be customized. Some observers suggest simplifying the MSSL model specification or beginning with a simpler one[o]. To secure utility based incentives, the specifications will need to specify utility critieria such as DLC certification.

7. Do preliminary evaluation of products: If unfamiliar with lighting technology, it is recommended to do some broad-based research which may include reviewing literature from the MSSL Consortium or workshops by CLTC for orientation. In addition, contacting manufactures and inviting them in to present their luminaires and data is very important. Wherever possible, it is also advisable to include the maintenance department in these meetings. Generally the most successful LED street lighting conversion projects have been in cities that began dialogues with several manufacturers early in the process, including having them present their products and photometric analysis.

[o] A useful simple and vendor neutral specification is found in the Leotek guide for municipalities.

8. Test preferred luminaires: Agencies frequently choose to pilot fixtures before implementation to evaluate technical and subjective characteristics of prospective products. It is essential to ensure sufficient light is actually reaching the desired surfaces. In other words, "footcandles on your street/per watt" is more important than "lumens per watt." In addition, there is a strong subjective element to street lighting and it is prudent to obtain input from city council, public works department, maintenance department or installing contractors, local citizens etc. on ease of installation, quality of illumination, light trespass, glare, and other issues that are deemed important. Smaller agencies may wish to leverage pilots done in other local cities with similar condition however, because of the rapid changes and improvements in the technology (and the wide variation in luminaires) it is important to be aware that information that is even nine months old may be out of date, particularly regarding efficiency.

9. Procure: Once the evaluations are complete the specifications can be refined and finalized. To maximize the outcome of the procurement process, competitive bidding is generally recommended. If the agency has chosen to purchase the luminaires directly and will be using the city's own crews for installation, the Request for Quote (RFQ) will be for luminaires only. If an outside contractor is being used there will need to be a separate RFQ for "installation labor only". Some agencies may choose a combination of internal resources and outside support. Finally, if a contractor is being selected for a complete turnkey installation then a single RFQ can be issued for furnishing and installing the luminaires. Attention to not only technical aspects of the products but materials warranty and installation warranty conditions are especially important.

10. Implement: Post award communication with the luminaire manufacturer is also a key element for success. It is highly recommended to have a meeting with the manufacturer (or their representative) and the contractor (if applicable) immediately after the award. An additional luminaire sample should be provided at that meeting representing the exact model that will be furnished on the job. This should include any special wiring configurations, paint finish, labeling, accessories, carton, etc. This will avoid any misunderstanding of exactly what is being ordered and delivered. Attention must be given to project logistics including training, storage and staging materials, installation rates, etc. Consideration of a maintenance plan is appropriate. This may include monitoring (if lighting does not include proactive failure notification), evaluation of cleaning needs which will depend on the fixtures, weather and roadway conditions).

5.2 Design Considerations

In evaluating the needs for a streetlight upgrade (or new deployment) such as what kinds of fixtures and how to place them, there are several general factors to consider:

Geography: Urban, rural, hilly, commercial, pedestrian, residential, heavily or lightly trafficked areas will have differing requirements for amount of light and placement.

Existing Infrastructure: The specific existing poles – especially heights and spacing – affect the fixtures needed to properly place light where needed.

Safety: A core concern with lighting – in general, most attention is in putting enough lighting on the roadway (actual footcandles on the road) and it is also important to ensure placement of light in pedestrian areas and that fixtures do not create glare which can be a safety hazard.

Economic Requirements: Agency credit rating and finance strategy may constrain features.

Community: Community members may provide important input on design especially color, scatter and glare.

Regulatory & Ownership: The specific tariffs the city is under[p] and which lights are owned by the city versus owned by the utility[q] will influence deployment options.

Most agencies evaluate the above considerations and choose a **materials replacement approach**. With this approach incumbent fixture sizes are mapped to new fixtures on the basis of equivalent luminosity, with perhaps some adjustments for known locations that may be over or under lit. This approach is simple, requiring less analysis. A basic audit of streetlight inventory (fixture count by wattages and street types) may be sufficient for the foundational element of the new design – fixture luminosity. Analysis naturally will still be needed in relation to ensuring the fixtures meet other fixture technical requirements (Section 3) or design considerations (above).

Another option is to pursue a **systems approach**. With a systems approach the streetlight analysis is much deeper – a ground-up analysis modeling lighting needs of streets by type, independent of current pole and fixture characteristics. With this approach the required luminosity is not assumed accurate with the current fixtures. This kind of holistic reappraisal of illuminance needs can be of value as cities have used the same fixtures for many years even as both conditions may have changed (street and building types and usage) as well as the technical understanding of the needs. A systems approach requires greater design investment and can result in greater engineering costs but also may result in greater savings and improved light quality.

The most widely recognized standards guidance for street lighting is the American National Standard Practice for Roadway Lighting (RP-8) from the IES (see Resources).

[p] PG&E streetlight tariffs are found here http://www.pge.com/tariffs/tm2/pdf/ELEC_SCHEDS_LS-2.pdf

[q] Agencies are increasingly purchasing streetlights from their utility to manage them directly and reduce costs.

5.3 Procurement and Deployment

Multiple models exist for procurement and deployment. The following table outlines some of the options which are further described below.

	Design	Financing	RFQ, RFP or Bid	Model Type	Audit Services	Install Services	Warranty Services	Energy Savings Guarantee[r]
City Self-performance	City	City	Competitive Process by City	Bid/Build	Contract with provider	Based upon staffing	City	No
Turnkey	Included	Included	Competitive selection	Design/Build	Included	Included	Included	Optional
ESCO or EEC	Included	Included	Competitive selection	Design/Build	Included	Included	Included	Optional
Collaborative Procurement	City	City	Collaborative	Bid/Build	Collaborative or individual	In-house or contracted	City direct with manufacturer and install provider	No
Piggyback	City	City	Use existing agreement	Bid/Build	Contract with provider	In-house or contracted	City direct with manufacturer and install provider	No

Figure 5 - Deployment Strategies for LED Streetlight Conversion Projects

5.3.1 City Self-Performance

Agencies with sufficient expertise and capacity may wish to manage the entire process themselves, including design, securing finance, and handling installation. This may result in cost savings compared to engaging third-parties but engaging third-parties may result in faster execution if the agency has resource constraints.

Agencies that need assistance on one or more step in the project can issue a solicitation to acquire exactly the services they desire. This option is desirable for agencies that have some resources available and want to be involved in some aspects of the project implementation, but still need assistance on particular steps in the deployment. This option could also be favorable for agencies that want to complete detailed lighting design and engineering analyses but do not have the in-house resources to do so.

[r] Because the energy savings on streetlight conversions are highly reliable, a savings guarantee (typically via a performance-based contract) is generally considered unnecessary. However, if the project is larger and more complex, with non-streetlight elements, it may be desirable.

5.3.2 Energy Service Company (ESCO) and Energy electrical contractor (EEC) Model

Energy service companies (ESCOs) are commercial businesses that provide comprehensive energy reduction strategies to large clients. Their services optionally include the full series of actions required for deployment, including streetlight design and engineering analysis, fixture and financing procurement, installation and construction management services, and operation and maintenance of an agency's streetlight system. ESCOs typically require contracts which do not require capital investment and project costs are paid back over a period of time using the energy (and energy cost) savings.

The ESCO model is a good option for agencies that need project financing, wish to off-load a range of project tasks, and are comfortable entering into a relatively long-term agreement with an ESCO. The length of the contract with an ESCO is predetermined. Using the ESCO model can take the uncertainty out of the project financing, providing a more predictable option for agencies, even where actual payback periods are less certain. While the Cities of Antioch and Concord both used an ESCO to upgrade their existing streetlights to induction technology, the paybacks for LED streetlight upgrades are considered to be so reasonable and predictable that many cities and counties are choosing financing options that do not require long-term contracts from ESCOs.

The EEC model is very similar to the ESCO model where the organization partners with the City to develop energy efficiency projects in the City. The benefit of working with an EEC is that they typically directly develop the solution with the City using a Design/Build format. The EEC typically uses their own personnel to design, install and maintain a streetlight project, unlike an ESCO which would utilize subcontractors. Similar to an ESCO, this model allows an EEC to guarantee no change orders based upon the agreed upon scope of work and provide an energy savings guarantee which mitigates risk to the City.

5.3.3 Turnkey Solutions

Typically a turnkey provider will offer assistance from the start of a project until the fixtures are installed. Depending upon the ability of the turnkey provider, they may or may not offer operation and maintenance services upon completion of the installation project. Turnkey providers may require capital investment or facilitate third party financing with the City. When projects are financed the turnkey providers is paid out of the escrow established by the financial institution. For example, a turnkey provider may help an agency apply for loans, grants, or bonds, but they often will not provide the capital for the projects themselves. Other turnkey services include, but are not limited to, engineering and design work, fixture procurement, installation and general project management, rebate application management, and commissioning. Turnkey programs are ideal for agencies that do not have the resources to manage the project themselves or the technical expertise to complete the designs or develop technical specifications for fixtures and equipment.

NAESCO Energy Electrical Contractors and PG&E's LED Streetlight Turnkey Replacement Service offer a turnkey option for agencies. These programs manages both procurement and installation from start to finish, also providing assistance with benefits analysis, project justification, data cleanup,, and general project administration. These Turnkey Programs offer competitive pricing using volume purchasing power, a product demonstration of the LED lights before the final luminaire selection, assistance with disposal of existing fixtures, a one-year guarantee of workmanship, and a minimum five-year manufacturer warranty on the LEDs. City Self-performance

Cities can design, procure and self-perform streetlight upgrade projects and save the cost of a third party installation provider. In these examples, the City needs to consider how quickly they can implement the project and the potential of future budget cuts that may impact the team to provide the services. The goal of the project should be to accelerate savings and this should be considered when evaluating self-performance.

5.3.4 Collaborative Procurement

LED streetlight conversion projects are remarkable similar across all jurisdictions and agencies could benefit from collaborating on their LED streetlight conversion projects. Even if agencies have slightly different existing lighting systems, lighting ordinances, or general illumination desires, they can usually use the same replacement LED fixtures. Agencies that collaborate on procurement of both LED equipment and services related to their conversion projects stand to benefit from volume pricing on fixtures. The collaborative bid can also result in higher quality products being selected as the bid documents would draw from the knowledge and experience of the group and will be put through a more rigorous review process. Collaborative procurements do require a high level of coordination among multiple agencies. All participating agencies must agree on the terms of the RFP and the specifications of the fixtures, which may present a challenge in scenarios where different agencies have different lighting desires and slightly different procurement rules. Also, developing a single RFP to fit multiple agencies will likely take more time, given the additional levels of coordination and review that might be required. The benefits and draw backs of collaborating on LED street lighting projects are discussed in Section 9.

When considering collaborative procurement it is important to understand who owns responsibility for the design, financing (if required) and how the warranty process will work if the City is purchasing the lights separate from the installation services.

5.3.5 Piggybacking

Piggybacking offers the most straightforward and administratively simple prospect for collaborative procurement. An agency that completes a formal bid process can include language in the contract with the winning vendor allowing other agencies to receive the same pricing and contracting terms. If every agency that goes through a competitive bid process includes a piggyback clause in their contracts with winning bidders, a wide variety of products, pricing, and contract terms will be available to jurisdictions that prefer not to go through their own formal bid process.

Piggybacking can still be useful even if the agencies that went through the formal bid process do not explicitly include piggyback clauses in their contracts with winning vendors. Piggyback clauses help guarantee prices for the piggybacking agencies, but even if pricing is not fixed a second agency can use the first agency's procurement to select a fixture thereby avoiding the costly and time consuming process of going through a formal competitive procurement process to select their own fixture. The piggybacking agency would have to go through their own contract negotiations with the fixture supplier. Piggybacking is usually more beneficial to smaller agencies because for smaller projects the administrative cost of completing a formal bid process accounts for a larger portion of the total project cost. Smaller agencies have fewer fixtures in their inventory and may not qualify for volume pricing discounts if they issue their own solicitation. Thus, a smaller agency may be able to secure fixtures at a lower per-unit cost and save on administrative overhead by piggybacking on a larger agency's contract. It is important to evaluate when the original agreement was signed and if the original piggyback pricing is still valid in the current market.

6 STANDARDS & GUIDANCE RESOURCES

A number of organizations, industry consortia and consumer groups provide resources to assist agencies understand the basic performance metrics of LED streetlights. These resources also help manufacturers understand the key fixture specifications that are most important to end-users. The emergence of LED streetlight-specific standards and guidelines helps the market to distinguish between products of different performance and quality, and is one of the keys to promoting widespread adoption of these newer technology products.

These tools and resources represent a key subset of the library of relevant standards and guidance documents that could be used to evaluate the financials of a prospective project, to design a streetlight system, to select fixtures, or to write technical specifications for an RFP. The resources attempt to standardize the way LED projects and technologies are designed and evaluated. The resources are useful for agencies with extensive experience with LED street lighting as well as agencies with limited experience. They can help guide any agency as they proceed with a LED conversion project.

To make informed decisions on LED streetlight replacement projects, a system engineer or manager should at minimum be familiar with Illuminating Engineering Society's RP-08, and its recommended illuminance levels. For many cities, the MSSLC Model Specification for LED Roadway Lighting can then serve as the comprehensive resource that aggregates the most appropriate industry standards useful for developing an RFP to procure replacement fixtures.

6.1 MODEL SPECIFICATIONS

6.1.1 LED ROADWAY LIGHTING (FIXTURE) SPECIFICATION

The Municipal Solid State Lighting Consortium (MSSLC) is a group of engaged cities, power providers, government entities, and others assembled to collect, analyze, and share technical information and experiences related to LED streetlight projects. The MSSLC aims to increase the level of knowledge pertaining to the proper selection and application of LED streetlights, provide guidance for evaluating LED streetlight performance, and to provide a forum for buyers and implementers to learn about best practices in LED street lighting.

The MSSLC recently released its "Model Specification for LED Roadway Lighting." This document serves as a template for the technical specifications that would be included in agencies' requests for proposals for LED street lighting projects. There are two versions of the model specification: the Systems Specification and the Material Specification. The Systems Specification characterizes luminaire performance based on localized site characteristics, taking as input information such as mounting height, pole spacing, lane width, and required light level. Alternatively, the Material

Specification characterizes luminaire performance independent of site characteristics, assuming that certain key luminaire properties such as lumen output and distribution are sufficient for ensuring its performance in a given application. An agency would use either the Systems Specification or the Materials Specification.

If an agency elects to use the Systems Specification, the bidder assumes responsibility for considering the design parameters (i.e., pole height, pole spacing, etc.) and for proposing a luminaire that is suitable for the requested applications. If using the Materials Specification, the streetlight owner (agency) assumes more responsibility for considering the design parameters and determining the luminaire performance that will meet its needs. While the Systems Specification may be favorable for a single agency that is completing a formal bid process for its own fixtures, using the Systems Specification for a collaborative procurement could easily become unwieldy as participating agencies would have to provide a plethora of information about their street lighting systems. Thus, the Material Specification is better suited for collaborative procurements where performing a full systems-based evaluation for each participating agency may be too cumbersome for both agencies and bidders.

Working closely with the City of San Jose, the City of Oakland and Energy Solutions, the Next Generation Street Initiative has worked with the MSSLC model specification and customized it to be suitable for Bay Area agencies considering an LED streetlight retrofit project. The resulting specification document, based on the "Material Specification" described above, borrows key language from San Jose's recent Request for Proposals (RFP) as well as input from members of Oakland's street lighting team and the draft of Caltrans specification for LED streetlights. This regionalized version of the MSSLC model specification ensures that fixtures will meet PG&E's LED streetlight rebate requirements, are tunable and ready to be fitted with an advanced controls device, and are appropriate for use in Northern California's seismic and climatic conditions.

The MSSLC Model Specification for LED Roadway Lighting can be downloaded from the MSSLC website: http://www1.eere.energy.gov/buildings/ssl/specification.html.

6.1.2 Model LED Controls Specifications

As discussed in Section 3.4 of this report, advanced controls systems can be installed with a new LED streetlight system for added functionality and to increase energy and maintenance savings. The MSSLC is in the process of developing a model specification for LED streetlight controls systems. Similar to the Model Specification for LED Roadway Lighting, the controls specification will serve as a template to help local agencies develop bid documents for acquiring advanced controls systems. This document is due to be released in mid-2012.

6.2 Emerging Technologies Coordinating Council (ETCC)

The Emerging Technologies Coordinating Council (ETCC) is an organization supported by the major California utilities. The ETCC coordinates studies and assessments of energy efficient emerging technologies and has published over twenty studies on LED technology, four[s] of which focus specifically on LEDs in street lighting applications:

LED Street Lighting and Network Controls - San Jose (November 2009):

http://www.etcc-ca.com/images/pge_0913_san_jose_efficient_street_light_report_final.pdf

LED Street Lighting Assessment: - Southern California Edison (December 2009):

[s] There are actually a total of six ETCC studies, including the 2008 Oakland and San Francisco GATEWAY studies mentioned; however, these two studies are not re-listed here.

http://www.etcc-ca.com/images/stories/et_09.01_led_street_lighting_final.pdf

Advanced Street Lighting Technologies Assessment Report - City of San Diego (January 2010): http://www.etcc-ca.com/images/summary_report_final-5.pdf

LED Street Lighting and Network Controls - San Francisco (January 2010):

http://www.etcc-ca.com/images/san_francisco_efficient_street_lighting_report.final.pdf

These studies evaluate the suitability of LED fixtures in street lighting applications, comparing the light produced by the newer technologies with that of the incumbent technologies. The ETCC studies demonstrate a significant savings potential in transitioning to LED fixtures.

6.3 Guidance on LED Streetlight Design

6.3.1 Illuminating Engineering Society Guidance

The Illuminating Engineering Society (IES) is a member-based professional organization that develops lighting design recommendations for lighting applications from offices, healthcare and sports facilities to outdoor lighting for parking and roadways. IES is considered the leading technical authority on lighting practices in North America, and its guidance is relied upon by lighting designers and engineers throughout the US and commonly referenced in local lighting standards and ordinances.

IES publishes the *American National Standard Practice for Roadway Lighting,* a recommended practice that provides the design basis for lighting roadways, adjacent bikeways, and pedestrian ways. Also known as RP-08, this resource includes recommended levels of lighting for various roadway classes depending on traffic volume and pedestrian conflict, and provides the standard methods for measuring or calculating lighting levels. IES also publishes a Lighting Handbook, currently in its 10th edition, which contains a wide base of knowledge and recommendations related to lighting and lighting design. Included in the new edition are illuminance determination procedures that incorporate mesopic adaptation for some roadway lighting applications.

6.3.2 San Jose Streetlight Design Guide

In February 2011, the City of San Jose published its Streetlight Design Guide, which makes use of current lighting science and nationally and internationally recommended street lighting design practices to improve the city's streetlight systems. The document establishes design guidelines for determining appropriate replacement fixtures for existing streetlights, installing new streetlights, and dimming public streetlights when reduced activity levels justify lower light levels. The San Jose Streetlight Design Guide makes use of guidelines set forth by the IES and the CIE. San Jose has applied the policies outlined in this design guide to retrofitting its own streetlights with LEDs.

San Jose's Streetlight Design Guide can be downloaded from the City of San Jose's website: http://www.sanjoseca.gov/transportation/SupportFiles/greenvision/Public_Streetlight_Design_Guide.pdf.

6.4 Fixture Quality and Performance

6.4.1 Industry Standards for LED Roadway Lighting

The American National Standards Institute (ANSI) released an LED roadway and area lighting industry standard in June 2011[t]. ANSI C136.37-2011 relies on several existing regional and international LED standards and current practices to specify requirements for LEDs fixtures used in roadway and area lighting applications. The standard addresses several key LED fixture properties, such as CCT, mounting provisions, operating temperatures, etc. This standard is referenced in the MSSLC model spec.

ANSI C136.37-2011 is available for purchase from ANSI's website: http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI+C136.37-2011.

6.4.2 DesignLights Consortium Listed Products

The DesignLights Consortium (DLC) is a collaboration of utilities and regional energy efficiency organizations serving as a resource for high-quality, energy-efficient, commercial lighting design and information. The DLC provides lists of qualified products for several different lighting applications; these products have met specific testing and performance requirements. These lists are often useful in guiding utility rebate programs.

LED streetlights that are DLC-listed must meet minimum light output and efficacy requirements, CCT and CRI specifications, and lifetime and warranty requirements. At present, over 4,100 LED streetlights are listed by the DLC. PG&E requires that LED streetlights be DLC-listed to qualify for their streetlight rebate program.

The DLC list of qualified products can be downloaded from the DLC website: http://www.designlights.org/documents/NEEPDLCQPL.xls.

6.4.3 Illuminating Engineering Society Fixture Test Method

IES has developed the industry-accepted testing methodologies for LED lighting fixtures, LM-79, the *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*. LM-79 describes the method of absolute photometry testing for LED products, and the procedure used to measure LED streetlight output, distribution, color temperature, efficacy, and various other metrics. Recently, IES has also published TM-21, *Projecting Long Term Lumen Maintenance of LED Light Sources*, a technical memorandum on the approved methodology for determining LED lifetime and depreciation based on extrapolation of chip-level testing data.

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