GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light Emitting Diode (LED) Street Lighting

Host Site: City of Oakland, California

Final Report prepared in support of the U.S. DOE Solid-State Lighting Technology Demonstration Gateway Program and PG&E Emerging Technologies Program

Study Participants:
U.S. Department of Energy
Pacific Gas & Electric
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Pacific Gas and Electric Company®

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Emerging Technologies Program

Application Assessment Report #0714

LED Street Lighting
Oakland, CA

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Preface

Energy Solutions provided monitoring, data collection, and data analysis services for an LED Street Lighting Assessment project under contract to the Emerging Technologies Program of Pacific Gas and Electric Company. The project replaced high pressure sodium luminaires in an Oakland, CA neighborhood with new 'Beta' LED luminaires from Ruud Lighting.

Acknowledgements

This project was funded by the Emerging Technologies Program of Pacific Gas and Electric Company. Energy Solutions would like to gratefully acknowledge the direction and assistance of Pacific Gas and Electric Company, the City of Oakland, Pacific Northwest National Laboratory (representing the United States Department of Energy), and Ruud Lighting for their participation and support of this project.

Executive Summary

This report summarizes an LED street lighting assessment project conducted to study the applicability of LED luminaires in a street lighting application. In the first of two phases, the project team took pre- and post-installation measurements in a parking lot owned by the City of Oakland to assess the likelihood of any negative safety impacts from the installation of the LED luminaires on a public street. With no significant concerns so identified, the project progressed to the second phase involving installation on actual public roadways. Quantitative and qualitative light and electrical power measurements were taken on all streets, and economic costs estimated and qualitative satisfaction gauged with a resident survey. This report documents the results of this second phase[1].

In Phase 2 of the project, fifteen 78 watt LED luminaries replaced a like number of 121 watt high pressure sodium (HPS) luminaires (100 nominal watts) on Sextus and Tunis roads between Empire Rd and Coral Rd in a residential area of Oakland. To allow a variety of comparisons, Sextus Rd was illuminated with fresh HPS luminaires on the eastern half and LED luminaires on the western half, and Tunis Rd was illuminated exclusively with LED luminaires, while the adjacent Cairo Rd was entirely relamped with new HPS lamps. All luminaires have heights of 28.5' above the road surface, with spacings of approximately 110', 120', or 165' between luminaires.

Measured results from the study are tabulated in Table ES-1 below. The metered LED luminaire drew an average of 77.7 watts, roughly 35% (43.3 watts) less than the metered HPS luminaire. With an estimated 4,100 annual hours of operation,[2] annual electrical savings are estimated to be approximately 178 kWh per luminaire replaced.

Table ES-1: Potential Demand and Estimated Energy Savings[3]

Luminaire Type	Average Power (W)	Power Savings (W)	Annual Energy Savings (kWh)
High Pressure Sodium Luminaire	121.0	-	-
LED Luminaire	77.7	43	178

Measured illuminance levels under both the HPS and LED luminaires are shown in Table ES-2. The lighting distribution of HPS luminaires is such that they typically over-light the area directly beneath the luminaires (creating 'hot spots') in order to maintain minimum levels further away. This variance is evident in the measured HPS values listed in the table. As a result, the lower average illuminance levels measured under the LED luminaires do not denote inferior light performance; the LED luminaires maintained minimum light levels across all spacings while significantly reducing uniformity ratios (i.e., increasing overall uniformity) compared to the HPS. The greater uniformity means that overall lighting levels can be reduced from what is required with HPS to achieve significant energy savings. This is even more pronounced when the HPS lamps are new, as they need to account for lumen depreciation or reduced output over the course of their life. Lighting guidelines must consider the maintenance of a minimum illumination level even at the

[1] It is essential to note that the specific results reported, while perhaps characteristic of LED technology in general, still primarily apply to the specific product tested. Readers are urged to use caution in extrapolating these results to other products or lighting situations.

[2] From PG&E LS-2 Rate Schedule, Appendix G.

[3] See 'Electrical Demand and Energy Savings' section.

light source's worst point (i.e., its end of life); thus the issue of over-lighting is greatest when the HPS lamps are fresh. LEDs have a much lower lumen depreciation curve over their lifetime in comparison with traditional light sources, so that the need for initial over-lighting is much reduced.

Table ES-2: Photopic Illuminance Levels[4]

	Average Illuminance (fc)	Minimum Illuminance (fc)	Avg. to Min. Uniformity Ratio	Max. to Min. Uniformity Ratio
HPS Luminaires				
110' Spacing	1.00	0.19	5.40:1	19.00:1
120' Spacing	0.80	0.09	8.66:1	40.00:1
165' Spacing	0.47	0	>10.16:1	>60.00:1
LED Luminaires				
110' Spacing	0.58	0.19	3.11:1	6.50:1
120' Spacing	0.53	0.09	5.68:1	16.00:1
165' Spacing	0.35	0	≥7.47:1	≥26.00:1

Due to the as yet undemonstrated useful life of these LED luminaires, economic and reliability claims are based on the best available information from the manufacturer and DOE reports. The payback periods in this particular case study are shown in Figure ES-1 using different assumed maintenance scenarios. In this particular study, the estimated incremental cost for installing LED luminaires in a new construction scenario was on the order of $500. The detailed economic analysis is provided in the Economic Performance Section.

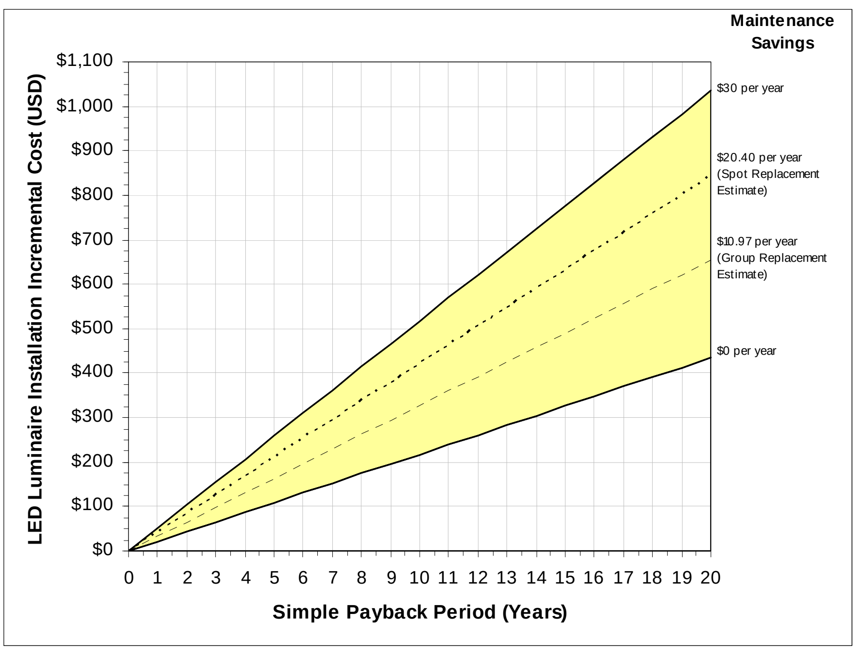

Figure ES-1: Estimated LED Luminaire Payback[5]

[4] See 'Lighting Performance' section.

While the results of this assessment estimated a relatively long payback period for this specific LED street light product under current conditions, payback periods are sensitive to installation-specific maintenance costs and electrical costs. In addition, other performance attributes combined with operating cost savings may be such that longer payback periods are acceptable. These could include various benefits from improved visibility, as highlighted in the Customer Acceptance section of the report that documents the resident feedback on the new LED lighting.

The commercial viability of LED luminaires is dependent on a number of factors. Two of the most significant of these are luminaire efficacy and initial cost, and LED technology continues to advance rapidly in both of these respects. Product costs to consumers can also be expected to decrease both as economies of scale are realized and as competition increases in their manufacture. Both of these aspects are encouraged through sales of existing products. Means of reducing costs to consumers in the short term will serve to promote sales and are thus recommended to organizations interested in accelerating the potential energy savings realized from this rapidly advancing technology.

The potential for energy savings from LED street lights is very large. It is estimated that 860 GWh of electricity is used annually for roadway lighting in PG&E's service territory, a large share of which is made up by cobra-head luminaires similar to those studied here.[6] The LED luminaires used in this study reduced energy by over 1/3 compared to the previous luminaires. As LED technology advances and efficacies improve, these savings will likely improve as well.

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[5] See 'Economic Performance' section.

[6] See 'Project Background' section.

Project Background

Project Overview

The LED Street Lighting Assessment project studied the applicability of light-emitting-diode (LED) luminaires on existing street light poles. High pressure sodium (HPS) luminaires were replaced with new LED luminaires on a street located in Oakland. The applicability of the technology was determined by light output, energy and power usage, economic factors, and qualitative satisfaction. The LED Street Lighting Assessment project was conducted as part of the Emerging Technologies Program of Pacific Gas and Electric Company. The Emerging Technologies program "is an information-only program that seeks to accelerate the introduction of innovative energy efficient technologies, applications and analytical tools that are not widely adopted in California…. [The] information includes verified energy savings and demand reductions, market potential and market barriers, incremental cost, and the technology's life expectancy."[7]

Technological Overview

At the time of this assessment, LEDs are beginning to be installed in outdoor settings because of luminaire ability to provide greater control of light dispersion and greater maintenance savings compared to traditional sources, as well as changing industry perception of higher quality light for exterior use. One corresponding application is street and roadway luminaires. Currently, streets are illuminated with high pressure sodium, and less frequently metal halide, low pressure sodium, or other lights. HPS lights are used primarily because of their long rated life and high efficiency relative to other conventional options, but have low color rendition. LEDs have the potential for even longer life than HPS, reduced maintenance, high color rendition, and reduced operating cost including lower energy usage. Currently however, the initial cost of LEDs is much higher than conventional light sources.

The US Department of Energy reports the technology is changing at a rapid pace. Overall, the performance of LED luminaires is advancing in efficiency at a rate of approximately 35% annually, with costs decreasing at a rate of 20% annually.[8]

Market Overview

A report by Navigant Consulting in 2002 estimates that lighting makes up approximately 22% of IOU kWh sales on a national scale. Of that amount roughly 4%, or 1% of total IOU kWh sales, are for roadway lighting.[9] Using kWh sales figures from a 2006 study,[10] the total consumption in PG&E's service territory for lighting is calculated to be on the order of 21,500 GWh in 2002, with a resulting 860 GWh for roadway lighting. Although these figures are not exclusively for the cobra-

[7] Pacific Gas and Electric Company (2006). Program Descriptions, Market Integrated Demand Side Management, Emerging Technologies. *PGE2011*

[8] Navigant Consulting, Inc. (2006). "Solid State Lighting Research and Development Portfolio. Multi-Year Development Plan. FY'07-FY'12."

[9] Navigant Consulting, Inc. (2002). "US Lighting Market Characterization, Volume I."

[10] Itron Inc., et al (2006). "California Energy Efficiency Potential Study."

head luminaires analyzed in this study, cobra-head luminaires represent a large share of this energy usage.

Project Objectives

The objectives of the project were to examine electrical, lighting, and economic performance of cobra-head HPS luminaires as compared to LED luminaires. The potential electrical demand and energy savings were measured in terms of average wattage and estimated annual kWh usage. Lighting performance was measured in terms of illuminance, uniformity, correlated color temperature (in Kelvin), and by the satisfaction and concerns of interested parties. Finally, economic performance was calculated as simple-payback for substitution in new installation or replacement scenarios, accounting for lamp life-span, maintenance costs, and electrical costs.

Methodology

Host site information

Fifteen LED luminaires were installed on Sextus and Tunis roads between Empire Rd and Coral Rd near the Oakland International Airport in Oakland, California. To allow a variety of comparisons, Sextus Rd was illuminated with fresh HPS luminaires on the eastern half and LED luminaires on the western half, and Tunis Rd was illuminated exclusively with LED luminaires, while the adjacent Cairo Rd was entirely relamped with new HPS lamps. The pre-installation streetlights on Tunis Road were high pressure sodium cobra-head luminaires.

This is a residential neighborhood, where all luminaires have heights of approximately 28.5' above the road surface, with spacings of approximately 110', 120', or 165' between luminaires.

Monitoring Plan

Two similar Monitoring Plans for each phase were developed for this assessment. Each called for pre-installation and post-installation field visits. In both cases, the monitoring area was set-up during our first site visit but before taking measurements. In the first phase, the project team took pre- and post-installation measurements in a parking lot owned by the City of Oakland to assess the likelihood of any negative safety impacts from the installation of the LED luminaires on a public street. With no significant concerns so identified, the project progressed to the second phase involving installation on actual public roadways. Therefore, the following describes the Phase 2 Monitoring Plan.

The pre-installation field visit and grid set-up were combined and occurred prior to installation of the LED luminaires. It was intended to document the existing condition of the lighting system. The HPS lamps had been replaced and the luminaires had been cleaned in anticipation of this work. The HPS lamps were burned in for approximately 100 hours prior to installation. All light measurements were taken after dusk.

Photopic and scotopic illuminance measurements were taken on a 395' x 36' grid over an area containing four luminaires. The distance between the first and second luminaires is 110', the distance between the second and third luminaires is 165', and finally the distance between the third and fourth luminaires is 120'. Ideally, luminaires are spaced equally for lighting uniformity, but in reality, street lights tend to be located at the intersection of property lines so that the street light is not solely located in one yard. The grid spacing was 12' north-south over the entire area, modified from the planned 10' because of the street width. Grid spacing in the area between the luminaires located 120' apart was 12' east-west and 10' apart in the areas between the luminaires located 165' and 110' apart. The measurement area is visually depicted in Appendix B.

The luminaires were located approximately 28.5' above the finished grade, on 6' mounting arms from wood poles. The illuminance levels were taken with a Solar Light PMA220 meter with photopic and scotopic detectors at a height of 18" above ground. This meter has a precision of 1 lux (0.09 foot-candles).

It should be noted that the measurements taken differ slightly from those defined in the "IESNA Guide for Photometric Measurement of Roadway Lighting Installations." The Illuminating Engineering Society of North America (IESNA) recommends that the grid be laid out so that measurements are taken beginning at one-half the grid spacing from the spot directly beneath the luminaire. In this study, the measurement grid was laid out such that measurements were taken at the areas directly underneath luminaires and the midpoints between luminaires, corresponding to the predicted maximum and minimum illuminance levels in the test area. This was done to capture the full effect of differing uniformity in the HPS and LED luminaires. IESNA also recommends that care be taken to level the detector before each measurement and that the detector be less than 6" off the ground. The monitoring team determined that the former recommendation was of greater import, so measurements were taken at 18" – the lowest level that could achieved with the combination of leveling tripod and detectors.

Periodic temperature measurements were also taken throughout the testing period. These measurements were taken approximately every 20 minutes with a digital thermometer for both the HPS and LED measurements. In addition, during the night of the LED measurements, relative humidity and additional temperature measurements were taken every 30 second with a HOBO Instruments U12 datalogger.

For measurement locations and geometry, see Appendix B1. Measurements were taken consistent with Appendix B2. The information gathered at each of the HPS and LED field visits was:

1. On-site photographs
2. Power, illumination, correlated color temperature and ambient temperature readings

The following monitoring equipment used in the execution of this Monitoring Plan was obtained from the Pacific Energy Center:

Illuminance Meter

Solar Light SnP Meter (PMA220) with Photopic Detector (PMA2130) and Scotopic Detection (PMA2131), last calibrated 10/2007

Correlated Color Temperature Meter

Konica Minolta Chroma Meter, Model CL-200, last calibrated 10/2007

Power Meter

Dent ElitePro Datalogger, last calibrated 4/2007

Ambient Temperature

Digital Thermometer (GE61290DWT)

Hobo Instruments U12 Datalogger, last calibration unknown

Project Results and Discussion

Electrical Demand and Energy Savings

Power data were logged using the DENT ElitePro Datalogger for a single HPS luminaire and a single LED luminaire. The HPS measurements were taken over the course of three nights, from 10/08/2007 to 10/10/2007. This HPS luminaire was then replaced with an LED luminaire, which was measured over the course of 13 nights, from 10/17/2007 to 10/30/2007.

Because the meter was intended to be left over a period of days, it had to be installed at a height that was not within reach from the ground. As such, the monitoring team relied upon the City of Oakland and their street lighting maintenance crew to install and remove the meter. The number of days metered for both the LED and HPS luminaires is a product of when the data meter could be installed and removed. No significant variations in power consumption occurred during the measured period.[11]

The HPS luminaire consumed an average of 121 watts per luminaire over an average of 11.97 hours per day.[12] As a result, the estimated annual power consumption for the luminaire, assuming 4100 hours of operation annually, is 496 kWh.

The LED luminaire consumed an average of 78 watts per luminaire over an average of 12.75 hours per day.[13] As a result, the estimated annual power consumption for the luminaire, assuming 4100 hours of operation annually, is 319 kWh.

Table 1: Measured Power Demand and Estimated Energy Usage

Luminaire Type	**Voltage** (v)	**Current** (a)	**Power** (w)	**Power Factor**	**Estimated Annual Consumption** (kWh)
HPS	120.2	1.0	121.0	0.995	496
LED	120.5	0.7	77.7	0.988	319

Table 2: Potential Demand and Energy Savings

Luminaire Type	**Power** (W)	**Power Savings** (W)	**Estimated Annual Energy Savings** (kWh)
HPS	121.0	-	-
LED	77.7	43.3	178

The variation in hours of operation between the two luminaire types results from the photocell regulation of the on-off cycle. The primary influence on the hours of operation is the amount of time between sunset and sunrise; since the LED luminaire was monitored closer to the winter solstice than the HPS luminaire, the operating hours were slightly longer.[14]

[11] See Appendix A4.

[12] Ibid.

[13] Ibid.

[14] See Appendix A4.

Lighting Performance

ILLUMINANCE

Photopic and scotopic illuminance[15] measurements were taken on a 395' x 36' grid over an area containing 4 different luminaires at spacings of 110', 120', and 165' as described in the 'Monitoring Plan' section.

It should be noted that due to the layout of the test area and the orientation of the luminaire arms, measurements were not necessarily taken directly under luminaires.[16] However, any deviation was deemed to be of small enough order to have minimal effect on the overall analysis. In addition, due to the in situ nature of the monitoring, some measurement locations were obstructed. When possible, data for these locations was estimated to be the same as that from equivalent locations on the grid.[17]

The average illuminance levels for each luminaire spacing, as wells as for the entire test area, were calculated and converted to footcandles for ease of use.[18] These average illuminance levels, along with the maximum and minimum measured values, were then used to calculate the average- and maximum- to-minimum uniformity ratios.

There is a section in the middle of the 165' spacing where both photopic and scotopic illuminance values were below the sensitivity of the meter. As a result, exact uniformity ratios in the 165' spacing area, as well as over the entire test area, could not be calculated. Instead, the smallest possible uniformity ratios for those areas were calculated, using a minimum illuminance of the lowest level detectable by the meter (0.5 lux). The actual uniformity ratio can then be said to be greater than this value.[19] It should be noted that the number of locations where the meter indicated zero measurements was less with the LED luminaires.

The LED luminaires maintained equal or higher minimum light levels across all spacings when compared to the HPS luminaires, and reduced uniformity ratios (increasing overall uniformity).[20] However, reduced average illuminance for LED luminaires may not be indicative of decreased performance. This is because the LED luminaire was dimmer than the HPS luminaire directly beneath the fixture resulting in better uniformity for the LED luminaire.[21]

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[15] For information on types of illuminance, see 'Discussion' section.

[16] See Appendix A.

[17] These locations are denoted with italics in Appendix A5.

[18] The raw illuminance data was measured in lux and converted to footcandles by a factor of 0.0929.

[19] I.e. if the average illuminance were 5 lux and the measured minimum were 0, the average-to-minimum uniformity ratio would be greater than $5 \div 0.5 = 10$.

[20] For comparison to City of Oakland new residential street lighting requirements, see 'Discussion' section.

[21] See 'Discussion' section.

Table 3: Measured Photopic Illuminance Levels

Measured Circuits	Average Illuminance (fc)	Max Illuminance (fc)	Min Illuminance (fc)	Avg. to Min. Uniformity Ratio	Max. to Min. Uniformity Ratio
HPS (Entire Test Area)	0.67	3.72	0	>14.49:1	>80.00:1
LED (Entire Test Area)	0.45	1.49	0	>9.64:1	>32.00:1
HPS (110' Spacing)	1.00	3.53	0.19	5.40:1	19.00:1
LED (110' Spacing)	0.58	1.21	0.19	3.11:1	6.50:1
HPS (120' Spacing)	0.80	3.72	0.09	8.66:1	40.00:1
LED (120' Spacing)	0.53	1.49	0.09	5.68:1	16.00:1
HPS (165' Spacing)	0.47	2.79	0	>10.16:1	>60.00:1
LED (165' Spacing)	0.35	1.21	0	>7.47:1	>26.00:1

Scotopically, the LED luminaires maintained or increased minimum illuminance levels across all spacings compared to the HPS luminaires. Uniformity ratios were increased with the LED luminaires in spacings other than 110', where they were reduced. Average scotopic illuminance levels were also increased with the LED luminaires in all spacings.

Table 4: Scotopic Illuminance Levels

Measured Circuits	Average Illuminance (fc)	Max Illuminance (fc)	Min Illuminance (fc)	Avg. Uniformity Ratio	Max. Uniformity Ratio
HPS (Entire Test Area)	0.51	2.88	0.00	>10.89:1	>62.00:1
LED (Entire Test Area)	0.88	3.07	0.00	>18.86:1	>66.00:1
HPS (110' Spacing)	0.77	2.69	0.09	8.30:1	29.00:1
LED (110' Spacing)	1.16	2.32	0.28	4.16:1	8.33:1
HPS (120' Spacing)	0.60	2.88	0.09	6.43:1	31.00:1
LED (120' Spacing)	1.03	3.07	0.09	11.05:1	33.00:1
HPS (165' Spacing)	0.35	2.14	0.00	>7.47:1	>46.00:1
LED (165' Spacing)	0.67	2.32	0.00	>14.38:1	>50.00:1

Surface plots of the measured photopic and scotopic illuminance levels were generated using Microsoft Excel, and are shown below:

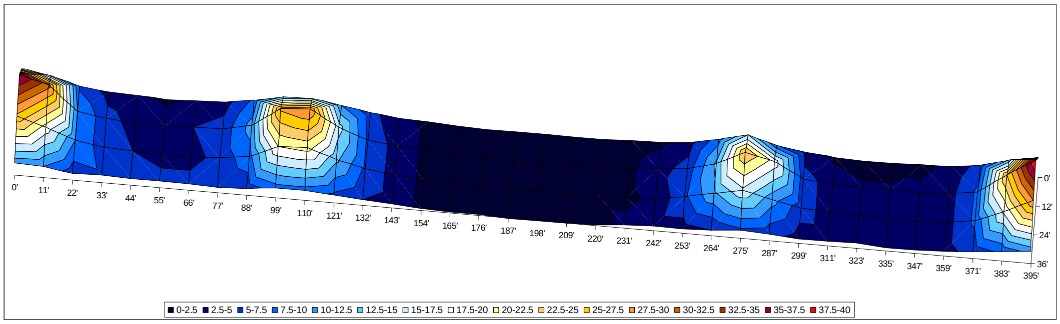

Figure 1: HPS Photopic Illuminance Plot (in lux)

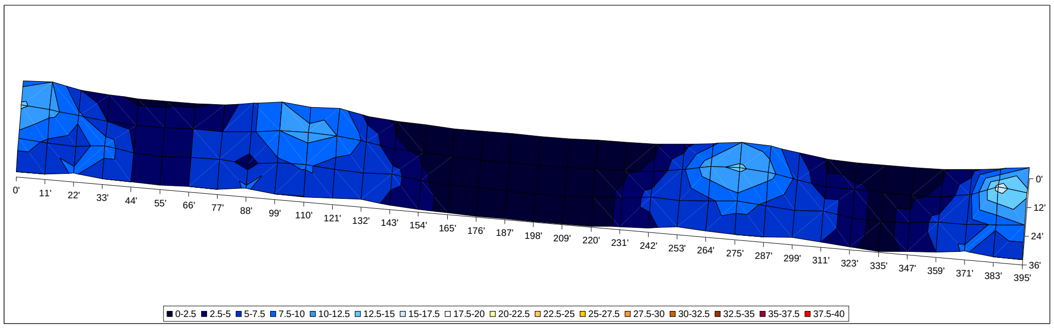

Figure 2: LED Photopic Illuminance Plot (in lux)

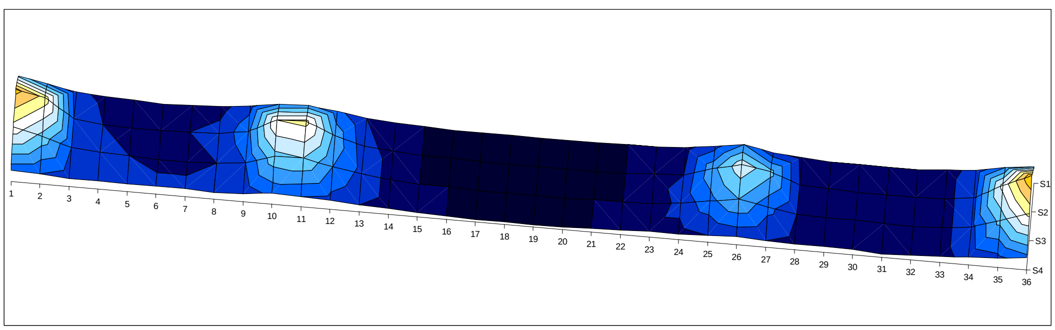

Figure 3: HPS Scotopic Illuminance Surface Plot

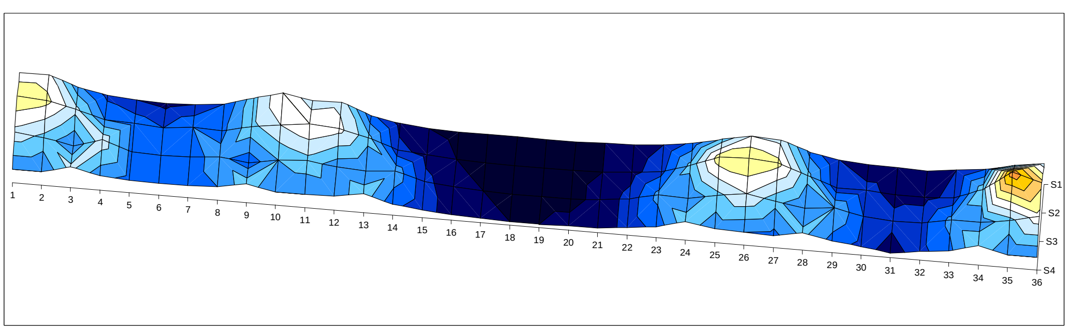

Figure 4: LED Scotopic Illuminance Surface Plot

LUMEN MAINTENANCE

LED manufacturers claim that LED lumen depreciation is minimal compared to conventional lighting sources. The manufacturer of the LED used in this study provided the chart below corresponding to their estimates of lumen maintenance of their product for various ambient temperatures. It should be noted however, that since the expected average annual nighttime temperature is below 25 degrees C, and no comparable luminaire has been operated for over 100,000 hours (nearly 25 years at 4,100 hours per year), no independent data is available to corroborate these estimates. In January 2008, the Illuminating Engineering Society of North America (IESNA) plans to publish standards for lumen depreciation testing which will allow measurement of lumen maintenance performance.

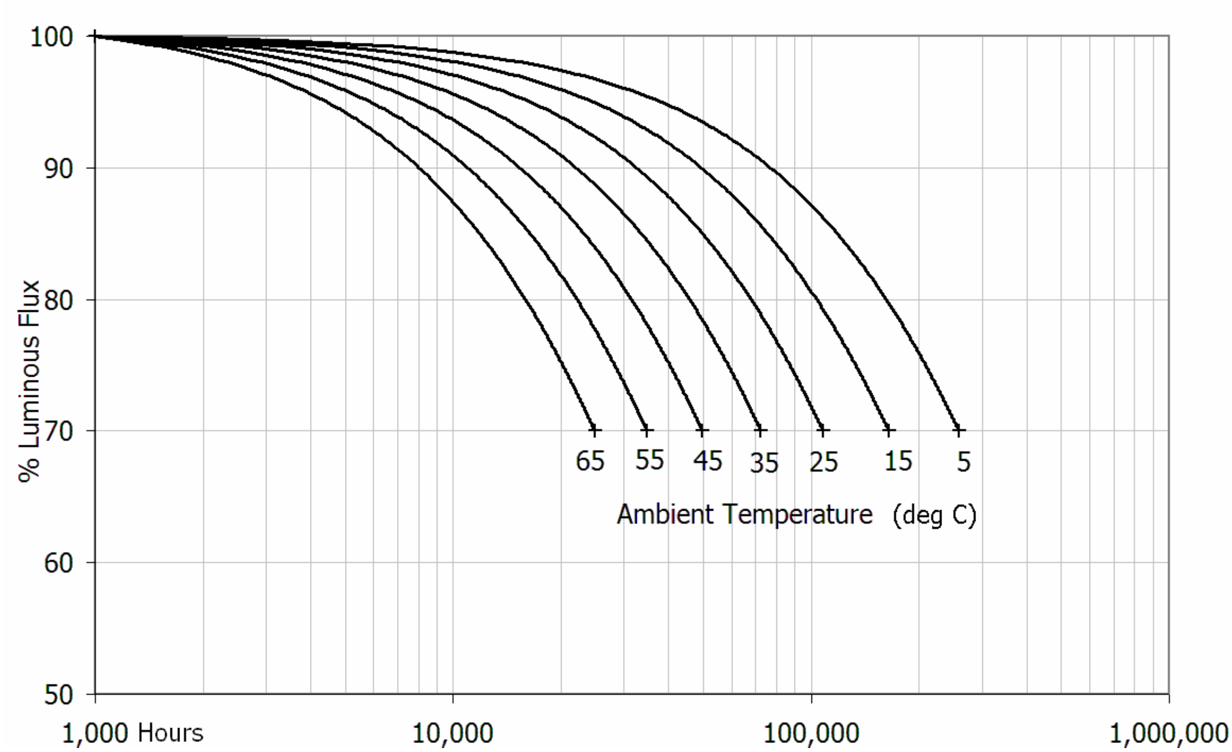

Figure 5: LED Lumen Maintenance Curve

The HPS lamp used in this assessment was a nominally-rated 100 watt lamp. The manufacturer provided the following lumen maintenance graph. The shaded area in the graph represents the range of lumen maintenance found within the manufacturer's HPS family. It is calculated based on the average of products (lamp wattage) in the company's HPS line.

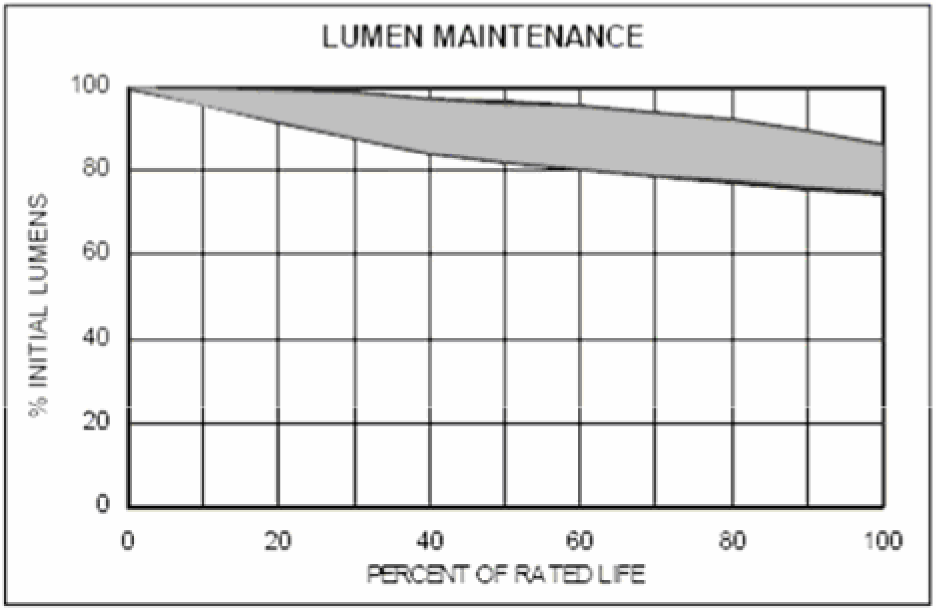

Figure 6: HPS Lumen Maintenance Curve

The rated life of this HPS lamp is 30,000 hours. At 30,000 hours, the HPS lamp would be expected to provide 75-85% of initial lumens. The LED luminaire, if the manufacturer's predictions are correct and ambient conditions average 25°C or below, will still be providing more than 90% of its initial lumens at this point.

Because the bottom surface of the LED luminaire is an acrylic resin, lumen maintenance is also affected by the yellowing of that resin. The Cyro Acrylite resin used by Ruud Lighting is projected by the manufacturer to experience a relatively minor yellowing. Under climate conditions similar to that in Arizona, transmittance (the fraction of incident light that passes through the resin) would, after ten years, decrease by approximately 2%. Further information on the yellowing index of this resin is available in Appendix F.

CORRELATED COLOR TEMPERATURE

Color measurements were measured using a Konica Minolta Chromameter under 3 sample luminaires of each type; LED and HPS. For the LED luminaires, measurements of correlated color temperature were taken directly. For the HPS luminaires, the chromameter was unable to calculate the correlated color temperature, so tristimulus values were measured and then converted to correlated color temperature. The average correlated color temperature under the LED luminaires was 6255 K. The average under the HPS luminaires was 1991 K. Due to difficulties in obtaining the chromameter prior to the installation of the LED luminaires, the HPS color temperature measurements were not taken under the luminaires used for illuminance measurements.

Table 5: Correlated Color Temperature

HPS Luminaires	Correlated Color Temperature
1	1851
2	1965
3	2156
Avg	1991
LED Luminaires	
1	6284
2	6212
3	6269
Avg	6255

To qualitatively analyze color rendition, photos were taken of each luminaire type. They were taken with a Nikon D80 digital camera, and the white balance was also adjusted from the initial 4000k to 4200k for each photo. This value was chosen as the average of the literature values for color temperature for the HPS lamps (1900k) and the LEDs (6500K).

The camera settings were identical on each photo:

Flash: No
Focal Length: 18 mm
F-Number: F/6.3
Exposure Time: 5 sec.
White Balance: 4000k (adjusted to 4200k)

Two photos for each luminaire type are shown below:

Figure 7: HPS Photograph 1

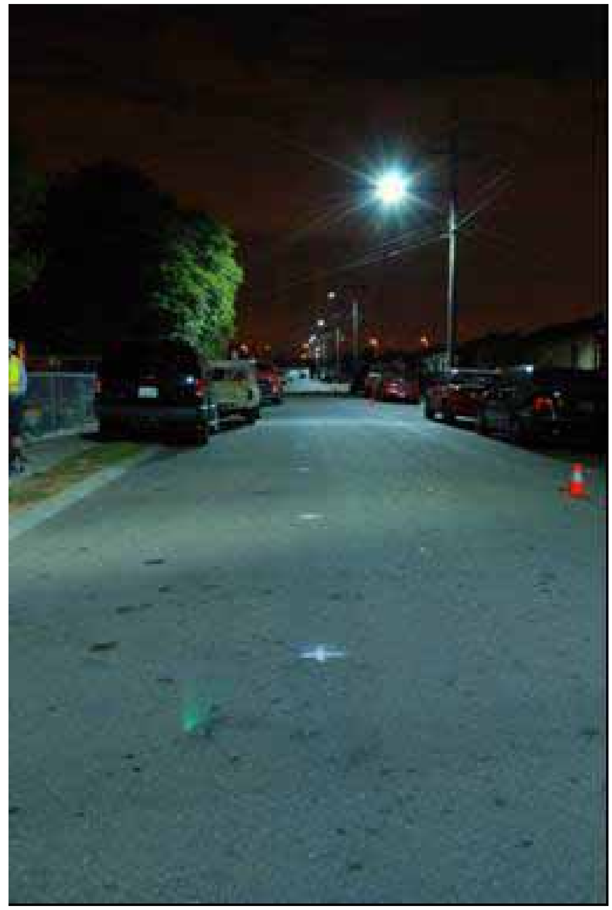

Figure 8: LED Photograph 1

Figure 9: HPS Photograph 2

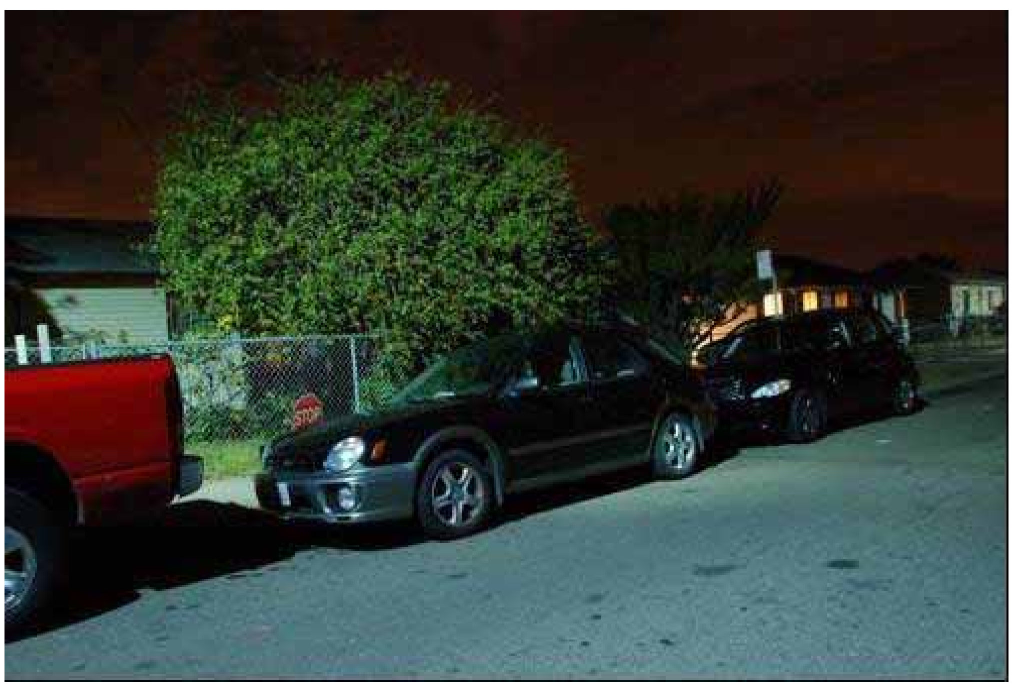

Figure 10: LED Photograph 2

CUSTOMER ACCEPTANCE

The Pacific Northwest National Laboratory managed the customer opinion survey for this assessment. A public opinion research firm, Fairbank, Maslin, Maullin & Associates, was engaged to contact residents of the neighborhood by telephone and obtain their feedback on the new lights. Phone numbers were obtained for 49 of the households on streets with new streetlights on their blocks, and for 106 of the households elsewhere in the neighborhood. Contact was attempted during the period November 30 through December 19, and reached 60 households in total. A copy of the survey, as well as full results, are presented in Appendix D.

The first question asked of residents was if they had in fact noticed the change in street lighting. A "no" to this question meant skipping most of the rest of the questions, other than the final demographic questions on age and gender. Ultimately, only 16 residences on the streets directly under the lighting and 4 residences elsewhere in the neighborhood were reached that reported noticing the new lights. The results below are therefore limited to 20 responses; a number sufficient to note any overwhelming trends but insufficient to perform any statistical extrapolation to a larger population.

In all, 17 out of the 20 respondents felt that the new streetlights were at least as preferable (i.e., either had no preference or preferred the new lights outright) as the old streetlights, if not significantly better. See Table 6 below.

Table 6: Preferences Expressed for the New or the Old Streetlights

Preference	Number of Respondents
Strongly Prefer New Streetlights	12
Somewhat Prefer New Streetlights	2
Total Preferring New Streetlights	**14**
No Expressed Preference	3
Strongly Prefer Old Streetlights	0
Somewhat Prefer Old Streetlights	3
Total Preferring Old Streetlights	**3**

All respondents that had noticed the new streetlights felt that that the new streetlights at least maintained or improved their neighborhood's overall appearance, nighttime safety and nighttime visibility. See Table 7.

Table 7. Neighborhood Impact of New Streetlights

Aspect of Neighborhood	# Believing that the New Streetlights have Strongly or Somewhat Improved	# Believing that the New Streetlights have Strongly or Somewhat Not Improved	# Believing that the New Streetlights do not have a Noticeable Impact
Overall Appearance	15	0	5
Nighttime Safety	14	0	6
Nighttime Visibility	16	0	4

In three questions regarding different aspects of visibility (visibility as a driver, visibility as a pedestrian and recognition of people at night), respondents indicated improvements with the new streetlights. Fourteen respondents indicated that the new streetlights strongly improved roadway visibility when they were driving, while 13 indicated that the new streetlights strongly improved their ability to see as pedestrians. Additionally, 13 indicated that the new streetlights had made it much or somewhat easier to recognize people at night. These results are consistent with respondents' overall preference of the new streetlights, given that the primary goal of streetlights is to improve nighttime visibility.

Of respondents that noticed the new streetlights, opinions were somewhat more varied with regards to the other subjective measures of streetlight effectiveness – glare, brightness and shadow creation. While opinions were much more uniformly positive about the new streetlights' effect on visibility and the overall neighborhood, opinions were a bit more mixed when it came to the potential secondary effects. Ten respondents felt that the new streetlights reduced glare, while 7 did not notice a change in glare; 3 respondents indicated that the new streetlights created more glare. The results were somewhat similar for the questions regarding shadow creation, with 12 respondents not indicating any change one way or another in terms of the shadow creation by the new streetlights, suggesting that shadow creation may have not been a problem with the old streetlights.

Although this somewhat small sample size does not permit statistical conclusions with much specificity, the preponderance of those interviewed indicated strong and consistent preference for the new streetlights. Much of this appears to be attributable to improved visibility for drivers and pedestrians and the overall positive effects of the new streetlights on several aspects of the neighborhood's overall appearance and nighttime safety. This is consistent with the open-ended responses of those preferring the new streetlights; half of which indicated that their expressed preference was based upon improved visibility.

Economic Performance

Economic performance was evaluated primarily by simple payback of the LED luminaires versus the HPS luminaires. To calculate this, maintenance and energy costs were taken into account assuming current energy and materials costs.

To estimate energy cost, a 2007 PG&E LS-2 rate schedule was used.[22] Under this rate schedule, streetlights are billed a monthly set rate based on the type of lamp and an assumed 4100 hours of annual operation. One hundred-twenty volt, nominal 100 watt HPS luminaires are billed at a rate of $5.329 per luminaire month. While PG&E is planning to generate rates for LED lamp types not presently covered, currently there is no available rate for luminaires comparable to the LED luminaires tested. As a result, the HPS rate schedule was broken down into its component charges of $0.12533 per kWh and a fixed $0.1904 per luminaire per month. The energy costs for the LED luminaires were then calculated assuming these charges, corresponding to $3.5175 per luminaire per month.

Maintenance estimates for HPS luminaires include lamp, photodiode, starter, ballast, and fixture material costs, as well as estimated labor and vehicular costs for the work performed. In accordance with information from the City of Oakland, lamps were assumed to be replaced during each maintenance visit. Estimates from the City of Oakland were then used for the frequency with which the other items must be replaced concurrent with the lamps. The City of Oakland is using a 'group replacement' maintenance scheme in which working lamps will be replaced every 6 years. In this scheme, an electrician is estimated to be able to replace 25 lamps in 8 hours.

Maintenance costs were also estimated for another common maintenance scheme, 'spot replacement', in which lamps are replaced on an individual basis at failure. For this scheme, the assumed replacement period is the rated life of roughly 7 years (30,000 hours at 4,100 hours per year). This is a conservative estimate, because the lamp would also be replaced if the failure was caused by any other item. Estimates of other item failure frequencies were assumed to be the same as in group replacement. This is also a conservative estimate, because with the lengthened replacement period, the likelihood that an item other than the lamp has caused the maintenance visit is increased.

It should be noted that some spot replacement will still take place in the group replacement scheme upon the premature failure of lamps, making the group replacement maintenance estimates also conservative.

Of the total maintenance cost per luminaire, not all components can be assumed to vary greatly with the performance characteristics of the luminaire. For example, administrative overhead is not likely to be significantly decreased as a result of decreased lamp failure rates. In addition, organization-wide maintenance cost averages may be skewed by a small number of luminaires that are more expensive to maintain than 100 watt HPS luminaires. For this analysis, estimates were used of the variable portion of the maintenance cost per 100 watt HPS luminaire on a non-discounted annualized basis.

The LED luminaires were assumed to have zero regular maintenance cost over the course of their useful life, due to the robust nature of LED technology and its tendency towards rare catastrophic failure.[23] In addition, the dramatic downward trend in LED luminaire costs and the uncertainty

[22] See Appendix G.

[23] This is a common assumption, but is acknowledged to be speculative at this point due to the lack of actual field experience.

regarding the useful life of the luminaires are such that LED luminaire replacement was not incorporated into maintenance estimates. Normally this cost could be annualized, effectively saving money each year toward eventual luminaire replacement. Since this was not done, there were no variable maintenance costs for the LED luminaires.

For the HPS luminaires, maintenance accounted for roughly 25% of the total annual cost under the spot replacement scheme. With the group replacement scheme, maintenance accounted for roughly 15% of the total annual cost. Since variable maintenance costs for the LED luminaires were effectively assumed to be zero, the energy costs accounted for 100% of the annual cost.[24]

Table 8: Annual Luminaire Costs

Luminaire Type	Annual Maintenance Cost (per Luminaire)	Annual Energy Cost (per Luminaire)	Total Annual Cost (per Luminaire)
HPS (with Spot Replacement)	$20.40	$63.95	$84.34
HPS (with Group Replacement)	$10.97	$63.95	$74.92
LED	$0.00	$42.21	$42.21

Two economic scenarios were considered: a 'new construction' scenario in which LED luminaires are installed in place of planned 100 watt HPS luminaires, and a 'retrofit' scenario in which LED luminaires were assumed to be installed in place of existing and operational 100 watt HPS luminaires. In each scenario, evaluations were conducted with comparisons based on both HPS group replacement and HPS spot replacement maintenance schemes. The details of these scenarios are presented in Appendix E.

Currently, the cost of the LED luminaires is approximately 3.75 times that of the HPS luminaires (including lamp and photocell). In the new construction scenario, the initial investment for HPS installation is the HPS luminaire cost plus the cost of installation. Since the cost of installation is assumed to be the same for both luminaire types, the total incremental cost of installation for LED luminaires, $487, is the difference in material costs between the LED luminaires and the HPS luminaires. The resulting simple payback periods are 11.6 years in the spot replacement scheme, and 14.9 in the group replacement scheme.

Table 9: New Construction Economics

Luminaire Type	Initial Investment	Incremental Cost	Annual Savings	Simple Payback (Years)
HPS	$346	--	--	--
LED (vs. HPS with Spot Replacement)	$833	$487	$42	11.6
LED (vs. HPS with Group Replacement)	$833	$487	$33	14.9

In the retrofit scenario, there is no assumed initial investment in the HPS luminaires. As a result, the incremental cost of LED installation is the full estimated cost of the LED luminaire installation, or $833. The resulting simple payback periods are approximately double those for the

[24] For further details, see Appendix E.

new construction scenario: 19.8 years in the spot replacement scheme, and 25.5 in the group replacement scheme.

Table 10: Retrofit Economics

Luminaire Type	Initial Investment	Incremental Cost	Annual Savings	Simple Payback (Years)
HPS	$0	--	--	--
LED (vs. HPS with Spot Replacement)	$833	$833	$42	19.8
LED (vs. HPS with Group Replacement)	$833	$833	$33	25.5

If a luminaire has a calculated simple payback period longer than its useful life, it will not have recouped the initial investment. The payback periods in this particular case study correspond to a range of roughly 50,000 to 100,000 hours of operation. It should be noted that the manufacturer provides a 5-year warranty with their product (corresponding to 20,500 hours of operation at 4,100 hours per year), although a much longer useful life is anticipated.[25]

It should be noted that the simple payback periods were based on bulk-purchased luminaire costs. Individual luminaire purchases, or purchases in small numbers, would carry increased luminaire cost, and thereby lengthen the simple payback period.

In addition, the calculated simple payback periods are sensitive to estimated maintenance savings, which are in turn highly dependent on the specific installation scenario. It is also conceivable that maintenance visits may be required for the LED luminaires (such as for cleaning), but this is not incorporated due to lack of information. As a result of these uncertainties and the noted sensitivity, ranges were calculated for each economic scenario considered around the estimated annual maintenance savings, from $0 per luminaire to $30 per luminaire.

Cost curves were generated showing requisite LED luminaire costs for simple paybacks under 20 years, and are shown below.

[25] See 'Lumen Maintenance' section.

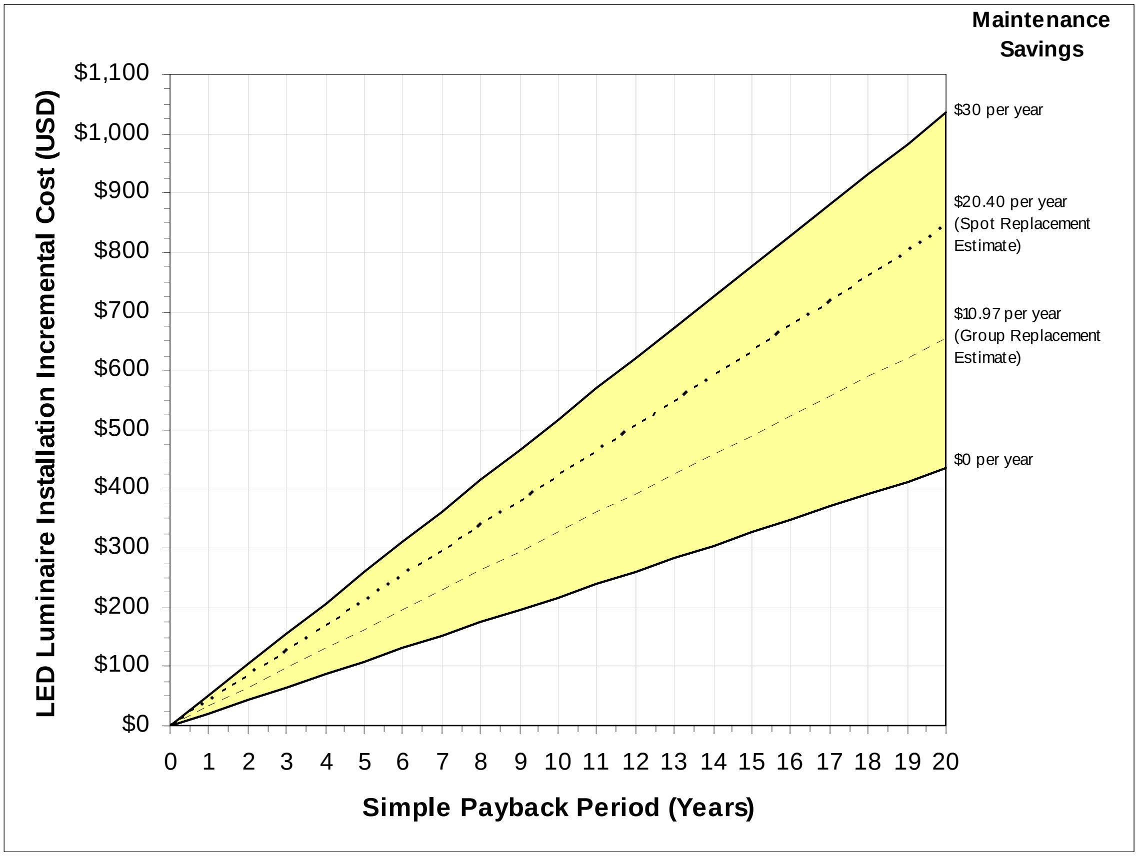

Figure 11: Estimated LED Luminaire Payback

LED luminaire cost is the other key component of the simple payback periods. Currently, the majority of this cost is comprised by the cost of LEDs, which is declining rapidly. Indeed, Haitz's Law predicts that the light output of LEDs increases by a factor of 20 every 10 years, while the cost decreases by a factor of 10 over the same period of time. This has held approximately true beginning with red LEDs in the late 1960's and continuing with the more recent white LEDs.[26] At the same time, the cost per lumen output has declined at a rate of 20% per year.[27] The remainder of the luminaire cost includes research and development costs, design, general overhead, manufacturing, and other material costs.

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[26] Steele, Robert V (2006). "The story of a new light source." Nature Photonics 1, 25 – 26. *10.1038/nphoton.2006.44*

[27] Navigant Consulting, Inc. (2006). "Solid State Lighting Research and Development Portfolio. Multi-Year Development Plan. FY'07-FY'12"

Discussion

LED luminaires offer potential energy savings in outdoor lighting while maintaining or improving lighting performance. The LED luminaires used in this particular study each drew 43 watts less power than the 121 watt HPS luminaires they replaced (100-watt nominal lamp), providing approximately 36% percent electrical savings. If the same savings could be achieved with 1/2 of the estimated electrical usage for roadway lighting in PG&E's service territory, the resulting savings would be over 150 GWh.

The HPS luminaires used in this study had an estimated maintained efficacy of roughly 60 lumens per watt, based on the rated mean lamp lumens (8550 lumens), average cobra-head downward efficiency (85%[28]), and measured power usage (121 watts). While the LED luminaires used in this study had an efficacy of 57.5 lumens per watt, slightly less than the HPS luminaires, they enhanced lighting quality such that sufficient lighting performance could be achieved with reduced (photopic) lumen output, and therefore reduced power. There is also potential for further savings as LEDs become more efficacious. In addition, the use of LED light sources will allow for advanced operating procedures such as bi-level operation or dimming in accordance with prescribed conditions.

The LED luminaires provided sufficient illumination to meet the City of Oakland's street lighting requirements, and proved to be a practicable replacement for the 100 watt HPS luminaires. The City of Oakland standards for new residential installations require an average photopic illuminance of greater than 0.4 footcandles and max to min uniformity ratio of less than 6:1. These standards were generally met by the LED luminaires, with the exception of the uniformity ratio at the largest spacing. It should be noted that these standards apply to new, residential installations, which may not be the same as those that applied at the time that the poles were installed. The full standards for new street lighting installations are available at http://www.oaklandpw.com/Asset550.aspx.

While the LED luminaires had decreased average photopic illuminance, this does not necessarily denote inferior light performance. This is because the lighting distribution of HPS luminaires is such that they must over-light the area directly below (creating 'hot spots') in order to maintain minimum levels further away. Indeed, compared to the HPS luminaires, the LED luminaires maintained minimum photopic light levels across all spacings, while reducing uniformity ratios (i.e., increasing overall uniformity).

Human perception of light follows two distinct spectral response curves, depending on the light level. The spectral response curve that dominates during typical daytime conditions is the photopic response curve, and results from the "cones" in human eyes. During very low light conditions, perception follows the scotopic response curve, which in contrast results from the "rods" in the human eye. The peak spectral luminous efficacy of the scotopic response curve (1700 lumens per watt, at 507 nanometers) is significantly greater than that of the photopic response curve (683 lumens per watt, at 555 nanometers).

Traditionally, light levels have only been measured in accordance with the photopic response curve. In recent years however, interest has grown in scotopic light due to the human eye's ability to perceive objects more clearly from sources with enhanced scotopic quality, particularly at night. In this study light levels were measured according to both the photopic and scotopic spectral response curves, resulting in two sets of values: 'photopic illuminance' and 'scotopic illuminance'.

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[28] Lighting Research Center (2004). "Parking Lot and Area Luminaires." National Lighting Product Information Program Specifier Reports, Vol 9, Num 1.

The relative importance of scotopic illuminance and photopic illuminance at low light levels are still uncertain.[29] However, it is reasonable to assume that better lighting performance will result if photopic illuminance is maintained while scotopic illuminance is increased. In this study minimum photopic levels were maintained, as mentioned above, and scotopic illuminance levels were either maintained or increased.

Despite the electrical savings, the present high upfront cost of LED street lighting luminaires may be a barrier to their current adoption. In choosing between an HPS or LED luminaire for new poles, the simple payback of the LED luminaire in this particular study would be on the order of 15 years. Under a scenario in which the customer had the option to replace a fully operational HPS luminaire with a new LED luminaire, the simple payback would be on the order of 26 years. To meet a simple payback of 2 years or less, the cost of an LED luminaire would need to be on the order of $250 in the new construction scenario (not including installation costs, which are assumed to be the same for both LED and HPS luminaires). To meet a simple payback period of 5 years or less, the LED luminaire cost would need to be near $350. Due to installation costs in the given retrofit scenario, it would be difficult for the LED luminaire to meet a 2 year simple payback period, and the price would have to be below $100 to meet a 5 year simple payback.

However as previously noted, these simple paybacks are sensitive to the maintenance costs associated in specific circumstances. Group replacement procedures for HPS lamps have the potential to reduce maintenance costs by replacing lamps slightly before failure, because the largest maintenance expense is for labor. This would result in a less favorable comparative economic performance for the LED luminaires. In addition, with the rapid advancements in LED efficacy and a reduction in the cost of semi-conductors, the payback of any LED luminaire installation can be expected to improve in the future. Various incentive programs could also help bring the price down to this level for consumers even sooner.

PG&E uses this and other Emerging Technologies assessments to support development of potential incentives for emerging energy efficient solutions. Because the performance and quality of the LED fixtures are critical to the long-term delivery of energy savings, it is important that incentive programs include quality control mechanisms. Incentive programs should include performance standards for qualifying products that include minimum criteria for warranty, efficacy, light distribution, and other important criteria.

[29] For more information, see mesopic results and discussion in Appendices A1 and A6.

Conclusion

LED street lighting has great potential for energy savings. While this demonstration provides further evidence of the improvements in performance of LED luminaires, the particulars of costs and savings for this demonstration show economics that are still at the outskirts of acceptability for the majority of commercial customers. Performance of the LED luminaires combined with growing industry acceptance of their higher performance vs. high pressure sodium luminaires may provide early adopters the impetus to invest in the emerging technology. Utility or government incentive programs could also help to tip the scale towards greater adoption of LED luminaires for streetlight applications by reducing the initial investment. These utility incentive programs should require minimum performance standards for qualifying products in order to ensure long-term energy savings.

Appendix A: Phase 2 Monitoring Data

APPENDIX A1: SCOTOPIC AND MESOPIC ILLUMINANCE LEVELS

Although it is well established that the scotopic response curve dominates at very low light levels, the extent to which the rods influence our vision at mid-to-low light levels (the 'mesopic' range) remains a matter of debate in the lighting community. This is of significant import for roadway lighting, where levels commonly lie within the mesopic range. As a result, one of the competing models was used to calculate 'mesopic illuminance' levels despite the controversy.

The model used to calculate mesopic illuminance in this study is the Mesopic Optimization of Visual Efficiency (MOVE) model. The MOVE model is a performance-based model developed at the Lighting Laboratory at the Helsinki University of Technology for the European Community. It was developed using the results of vision experiments which evaluated subjects' ability to complete various tasks required for night-time driving.

The MOVE model uses photopic and scotopic luminance values to calculate mesopic luminance values. The photopic and scotopic illuminance data recorded during the course of this assessment were converted into luminance, assuming that the roadway was a lambertian reflective surface with a reflectance value of 0.07. The conversion formula is as follows: L (luminance) = E (illuminance) * P (reflectance of the surface) / Π. The resulting photopic and scotopic luminance values were then used to calculate mesopic luminance values, which were then converted to mesopic illuminance values by the same formula.

Mesopically, the LED luminaires maintained or increased minimum light levels and maintained or decreased uniformity ratios across all spacings compared to the HPS luminaires. With the LED luminaires, average mesopic illuminance was slightly decreased across the entire test area, resulting from a significant decrease in the 110' spacing, a slight decrease in the 120' spacing, and a slight increase in the 165' spacing.

Table A1.1: Mesopic Illuminance Levels

Measured Circuits	Average Illuminance (fc)	Max Illuminance (fc)	Min Illuminance (fc)	Avg. Uniformity Ratio	Max. Uniformity Ratio
HPS (Entire Test Area)	0.62	3.57	0.00	>13.30:1	>76.95:1
LED (Entire Test Area)	0.59	1.85	0.00	>12.60:1	>39.76:1
HPS (110’ Spacing)	0.94	3.38	0.13	7.31:1	26.41:1
LED (110’ Spacing)	0.76	1.49	0.23	3.28:1	6.40:1
HPS (120’ Spacing)	0.74	3.57	0.09	7.97:1	38.48:1
LED (120’ Spacing)	0.68	1.85	0.09	7.37:1	19.88:1
HPS (165’ Spacing)	0.42	2.66	0.00	>9.14:1	>57.28:1
LED (165’ Spacing)	0.45	1.49	0.00	>9.71:1	>31.99:1

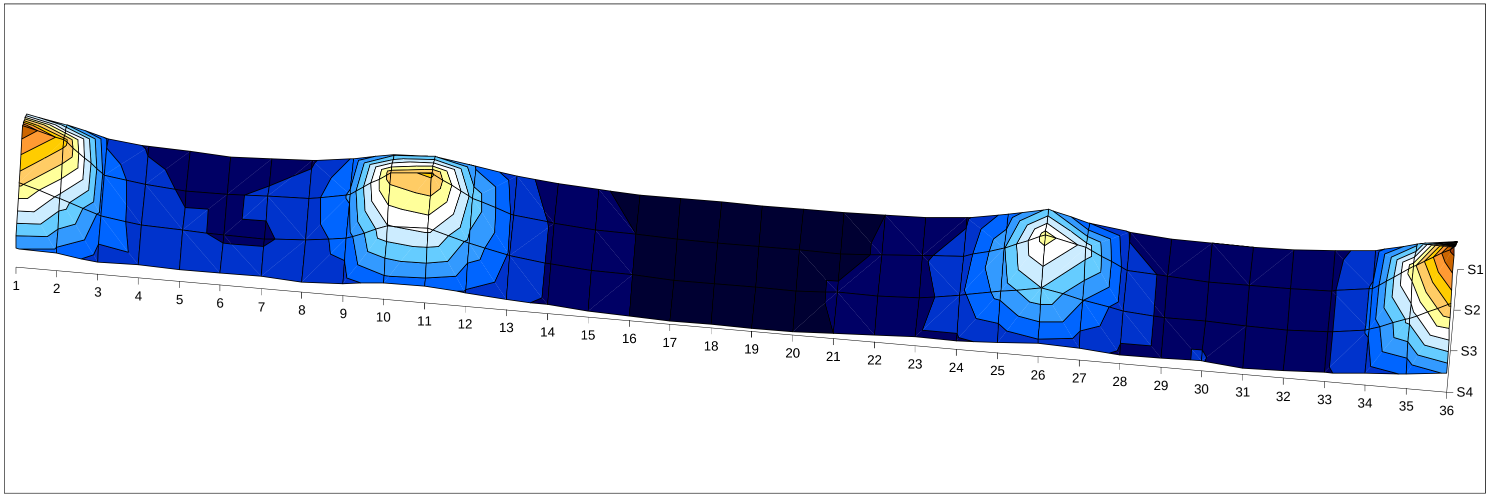

Figure A2.1: HPS Mesopic Illuminance Surface Plot

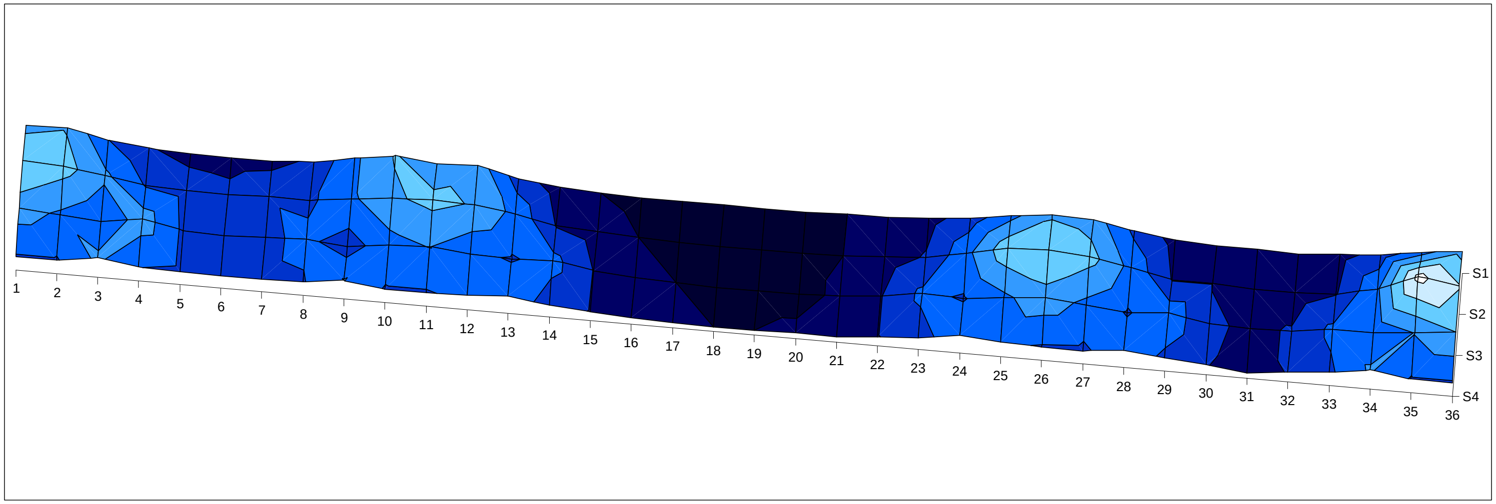

Figure A2.2: LED Mesopic Illuminance Surface Plot

APPENDIX A3: AMBIENT DATA

Table A3.1: Ambient Temperature Measurements. (Measured with Digital Thermometer GE61290DWT)

Circuit	Date	Time	Ambient Temperature (°F)
HPS	10/10/07	21:04	50.5
	10/10/07	21:21	49.8
	10/10/07	21:46	49.1
LED	10/11/07	20:10	55.0
	10/11/07	20:40	53.2
	10/11/07	21:00	54.7
	10/11/07	21:40	55.8

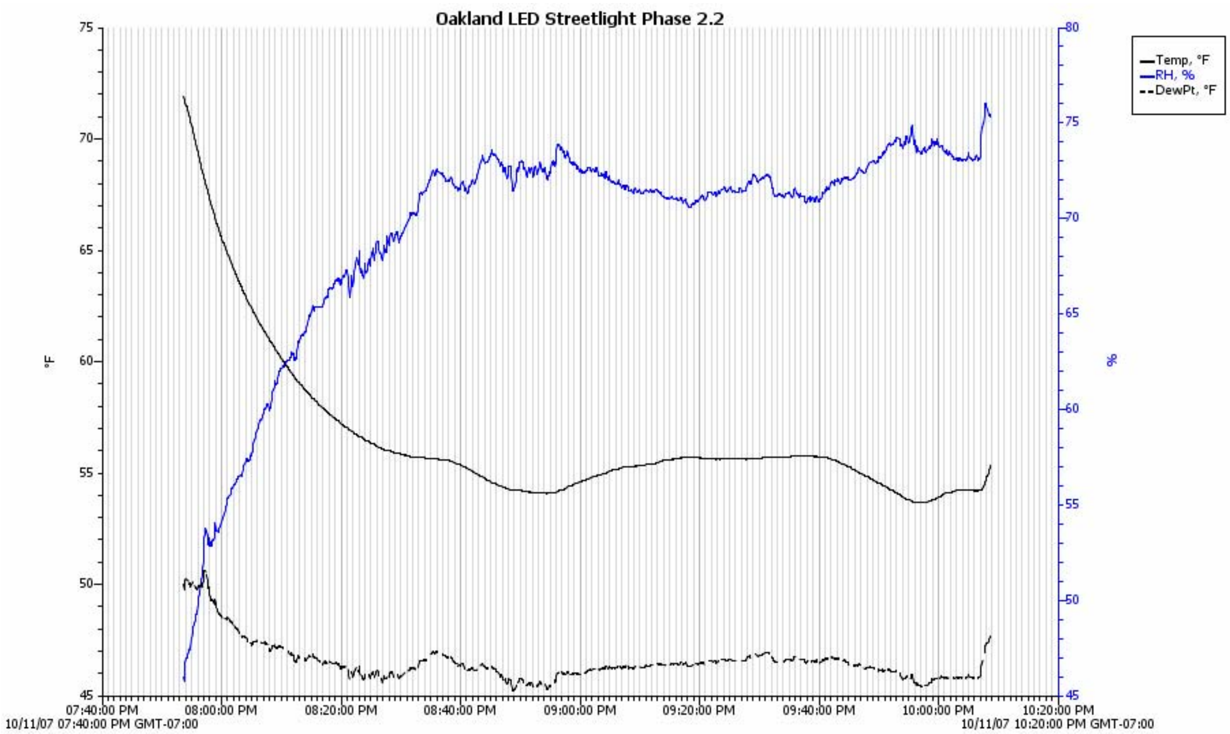

Figure A3.1: Detailed Ambient Conditions during LED Measurements. (Measured with HOBO U12)

Location: W122 13, N37 47

OAKLAND, CALIFORNIA
Rise and Set for the Sun for 2007

Astronomical Applications Dept.
U. S. Naval Observatory
Washington, DC 20392-5420

Pacific Standard Time

	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
Day	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
01	0724	1701	0713	1732	0641	1802	0555	1832	0513	1859	0449	1925	0451	1935	0512	1918	0539	1838	0604	1752	0634	1710	0705	1650
02	0725	1701	0712	1733	0639	1803	0553	1833	0512	1900	0448	1926	0451	1935	0513	1917	0540	1837	0605	1751	0635	1709	0706	1650
03	0725	1702	0711	1735	0638	1804	0552	1833	0511	1901	0448	1926	0452	1935	0514	1916	0540	1835	0606	1749	0636	1708	0707	1650
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05	0725	1704	0709	1737	0635	1806	0549	1835	0509	1903	0447	1928	0453	1934	0516	1914	0542	1832	0608	1746	0638	1706	0709	1650
06	0725	1705	0708	1738	0634	1807	0547	1836	0508	1904	0447	1928	0453	1934	0516	1913	0543	1831	0609	1745	0639	1705	0710	1650
07	0725	1706	0707	1739	0632	1808	0546	1837	0507	1905	0447	1929	0454	1934	0517	1911	0544	1829	0610	1743	0640	1704	0711	1650
08	0725	1707	0706	1740	0631	1809	0544	1838	0506	1906	0447	1929	0454	1933	0518	1910	0545	1828	0611	1742	0641	1703	0712	1650
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22	0720	1721	0650	1755	0610	1822	0525	1851	0454	1918	0447	1934	0504	1926	0530	1853	0557	1806	0624	1722	0656	1653	0721	1654
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26	0718	1726	0645	1759	0604	1826	0519	1855	0451	1921	0449	1935	0507	1923	0534	1847	0600	1800	0628	1717	0700	1652	0723	1656
27	0717	1727	0643	1800	0602	1827	0518	1856	0451	1922	0449	1935	0508	1922	0535	1846	0601	1758	0629	1716	0701	1651	0723	1657
28	0716	1728	0642	1801	0601	1828	0517	1856	0450	1922	0449	1935	0509	1921	0535	1844	0602	1757	0630	1715	0702	1651	0723	1658
29	0715	1729			0559	1829	0516	1857	0450	1923	0450	1935	0510	1921	0536	1843	0603	1755	0631	1714	0703	1651	0724	1658
30	0715	1730			0558	1830	0515	1858	0450	1924	0450	1935	0511	1920	0537	1841	0603	1754	0632	1713	0704	1650	0724	1659
31	0714	1731			0556	1831			0449	1924			0511	1919	0538	1840			0633	1711			0724	1700

Add one hour for daylight time, if and when in use.

Figure A3.2: 2007 Sunrise and Sunset Times.

APPENDIX A4: POWER DATA

Table A4.1: Averaged Power Measurements. (Measured with DENT ElitePro Datalogger, 10/08/2007 to 10/11/2007).

	Voltage (v)	**Current** (a)	**Power** (w)	**Power Factor**	**Nightly Energy Usage** (kWh)
LED Luminaire	120.53	0.65	77.69	0.9888	0.93
HPS Luminaire	120.22	1.01	121.01	0.9947	1.45

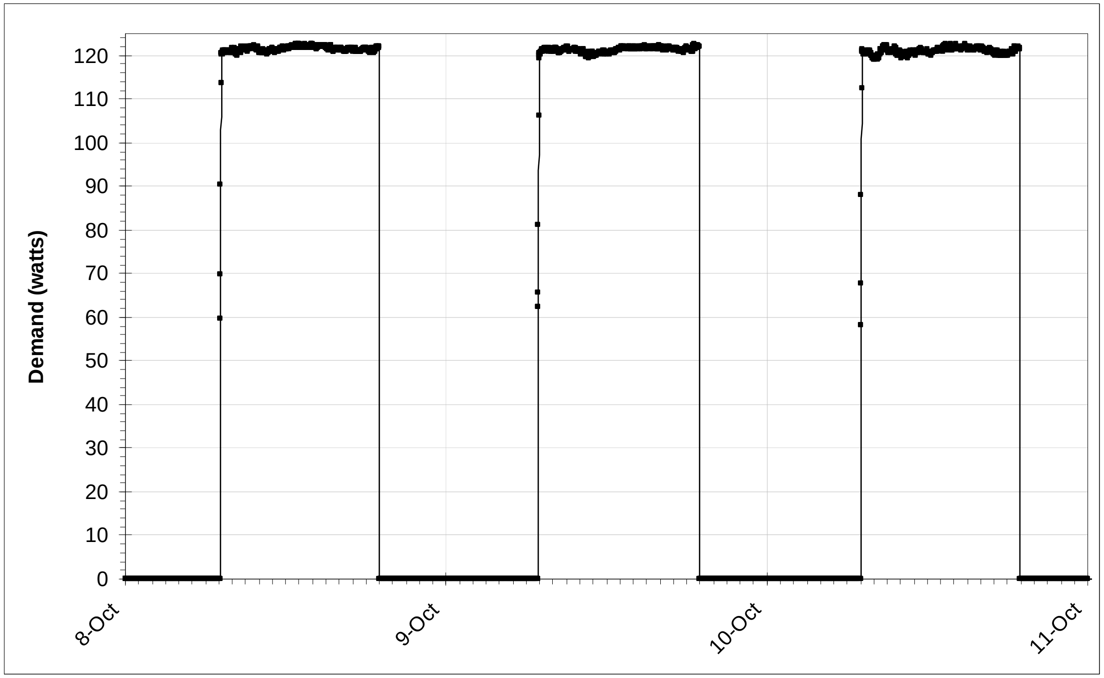


Figure A4.1: Detailed HPS Power Demand (Measured with DENT ElitePro Datalogger, 10/08/2007 to 10/11/2007)

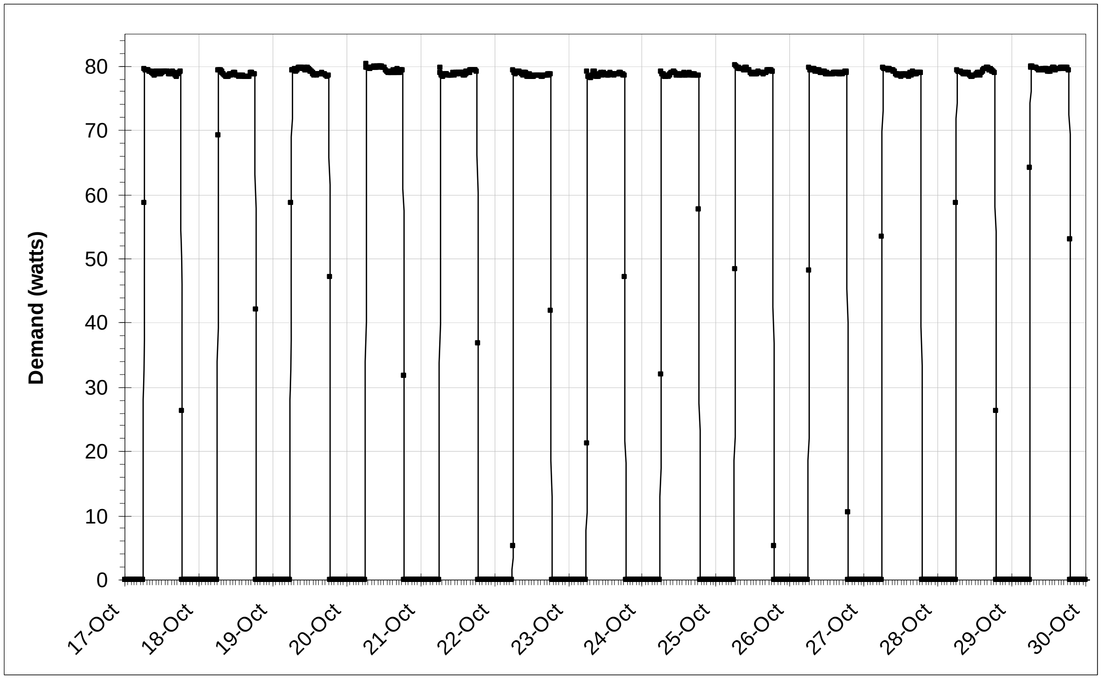


Figure A4.2: Detailed LED Power Demand (Measured with DENT ElitePro Datalogger, 10/17/2007 to 10/30/2007)

APPENDIX A5: RAW ILLUMINATION DATA

APPENDIX A5.1: HPS LUMINAIRE DATA

Highlighted values indicate measurements taken directly underneath luminaires.

Table A5.1: Photopic Illumination over HPS Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

Reference Coordinates (ft)	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	
1	18	14	7	4	3	2	3	4	8	13	14	10	6	3	2	1	0	0	0	0	0	1	2	4	9	15	8	4	2	1	1	2	3	6	13	17	0'
2	38	31	10	6	4	4	5	6	11	28	30	16	7	4	2	1	0	0	0	0	1	2	4	6	13	25	19	6	4	3	3	3	4	8	25	40	12'
3	27	19	10	6	5	4	4	6	9	20	21	13	7	4	2	1	1	0	1	1	2	2	3	7	12	17	11	6	4	4	3	3	4	8	18	30	24'
4	11	10	6	7	6	6	6	5	6	9	9	7	5	4	2	1	1	0	0	0	1	3	4	4	5	7	6	4	4	5	3	3	4	6	8	11	36'
	0'	11'	22'	33'	44'	55'	66'	77'	88'	99'	110'	121'	132'	143'	154'	165'	176'	187'	198'	209'	220'	231'	242'	253'	264'	275'	287'	299'	311'	323'	335'	347'	359'	371'	383'	395'	

Table A5.2: Scotopic Illumination over HPS Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

Reference Coordinates (ft)	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	
1	15	10	5	3	2	1	2	3	6	10	11	8	4	2	1	0	0	0	0	0	0	1	1	3	6	10	5	3	1	1	1	1	3	5	10	13	0'
2	29	24	7	4	3	3	4	5	9	22	23	12	5	3	1	1	0	0	0	0	0	1	3	4	12	18	14	4	3	2	2	2	3	6	20	31	12'
3	21	15	7	5	4	3	3	4	7	15	16	10	6	3	1	1	0	0	0	0	1	1	2	5	9	13	8	4	3	3	2	2	3	6	14	23	24'
4	8	7	5	5	5	5	5	4	5	8	7	6	4	3	2	1	0	0	0	0	1	2	3	3	4	5	4	3	3	3	1	2	3	5	6	9	36'
	0'	11'	22'	33'	44'	55'	66'	77'	88'	99'	110'	121'	132'	143'	154'	165'	176'	187'	198'	209'	220'	231'	242'	253'	264'	275'	287'	299'	311'	323'	335'	347'	359'	371'	383'	395'	

APPENDIX A5.2: LED LUMINAIRE DATA

Table A5.3: Photopic Illumination over LED Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

Reference Coordinates (ft)	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	
1	9	10	5	3	2	2	2	3	7	10	8	9	4	2	1	0	0	0	0	0	1	1	2	4	7	10	9	5	2	1	1	1	2	4	7	10	0'
2	13	11	8	5	4	4	5	5	7	10	11	10	7	3	2	1	0	0	*0*	0	1	*2*	3	*7*	12	13	11	7	*3*	3	2	2	3	7	16	13	12'
3	9	7	6	9	5	4	5	6	4	7	8	6	5	6	3	1	1	0	0	0	1	3	6	5	7	9	7	5	7	3	2	3	6	6	8	10	24'
4	5	5	8	5	5	4	5	5	8	5	5	6	7	*4*	3	2	1	1	1	1	1	3	4	*7*	*6*	5	5	7	*5*	*3*	1	3	5	8	5	5	36'
	0'	11'	22'	33'	44'	55'	66'	77'	88'	99'	110'	121'	132'	143'	154'	165'	176'	187'	198'	209'	220'	231'	242'	253'	264'	275'	287'	299'	311'	323'	335'	347'	359'	371'	383'	395'	

Table A5.4: Scotopic Illumination over LED Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

Reference Coordinates (ft)	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	
1	20	20	11	6	4	3	4	7	15	22	17	18	8	3	1	0	0	0	0	0	1	2	4	8	14	19	18	9	4	2	2	1	4	7	13	17	0'
2	25	23	17	10	9	7	10	9	15	19	22	20	14	5	3	1	0	0	*0*	0	1	*3*	6	*14*	24	25	23	14	*5*	5	3	3	5	15	33	26	12'
3	18	15	10	18	9	8	9	11	8	13	15	11	10	12	5	2	1	0	0	0	2	5	11	10	15	19	14	10	13	7	5	6	11	11	15	21	24'
4	10	10	17	11	9	9	9	10	15	10	10	11	15	*8*	5	3	2	1	1	2	2	5	8	*15*	*11*	10	9	14	*9*	*6*	2	6	9	16	10	10	36'
	0'	11'	22'	33'	44'	55'	66'	77'	88'	99'	110'	121'	132'	143'	154'	165'	176'	187'	198'	209'	220'	231'	242'	253'	264'	275'	287'	299'	311'	323'	335'	347'	359'	371'	383'	395'	

APPENDIX A6: CALCULATED MESOPIC ILLUMINANCE

Table A6.1: Mesopic Illumination over HPS Test Area. (In lux; calculated using MOVE model)

Reference Coordinates (ft)	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	
1	17.27	12.91	6.28	3.56	2.50	1.38	2.50	3.56	7.32	12.16	13.19	9.38	5.23	2.50	1.38	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.38	3.56	8.02	13.67	6.97	3.56	1.38	1.00	1.00	1.38	3.00	5.63	12.16	16.00	0'
2	36.44	29.66	9.06	5.23	3.56	3.56	4.60	5.63	10.41	26.80	28.64	14.97	6.28	3.56	1.38	1.00	0.00	*0.00*	*0.00*	0.00	0.00	*1.38*	*3.56*	5.23	12.73	23.51	17.81	5.23	*3.56*	2.50	2.50	2.50	3.56	7.32	23.95	38.48	12'
3	25.78	18.05	9.06	5.63	4.60	3.56	3.56	5.23	8.36	18.83	19.86	12.16	6.65	3.56	1.38	1.00	0.00	0.00	0.00	0.00	1.38	1.38	2.50	6.28	11.13	16.00	10.10	5.23	3.56	3.56	2.50	2.50	3.56	7.32	17.03	28.64	24'
4	10.10	9.06	5.63	6.28	*5.63*	*5.63*	5.63	4.60	5.63	8.68	8.36	6.65	4.60	*3.56*	2.00	1.00	0.00	0.00	0.00	0.00	1.00	2.50	3.56	3.56	4.60	6.28	5.23	3.56	3.56	4.17	1.89	2.50	*3.56*	5.63	7.32	10.41	36'
	0'	**11'**	**22'**	**33'**	**44'**	**55'**	**66'**	**77'**	**88'**	**99'**	**110'**	**121'**	**132'**	**143'**	**154'**	**165'**	**176'**	**187'**	**198'**	**209'**	**220'**	**231'**	**242'**	**253'**	**264'**	**275'**	**287'**	**299'**	**311'**	**323'**	**335'**	**347'**	**359'**	**371'**	**383'**	**395'**	

Table A6.2: Mesopic Illumination over LED Test Area. (In lux; calculated using MOVE model)

Reference Coordinates (ft)	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	
1	12.07	12.74	7.06	4.24	2.94	2.50	2.94	4.61	9.46	13.23	10.64	11.56	5.50	2.50	1.00	0.00	0.00	0.00	0.00	0.00	1.00	1.59	2.94	5.50	9.18	12.48	11.56	6.42	2.94	1.59	1.59	1.00	2.94	5.16	8.89	11.96	0'
2	16.00	14.15	10.64	6.74	5.84	5.16	6.74	6.42	9.46	12.48	13.91	12.74	9.18	3.86	2.50	1.00	0.00	*0.00*	*0.00*	0.00	1.00	*2.50*	*4.24*	9.18	15.07	16.00	14.15	9.18	*3.86*	3.86	2.50	2.50	3.86	9.46	19.88	16.23	12'
3	11.56	9.46	7.35	11.56	6.42	5.50	6.42	7.66	5.50	8.89	10.10	7.66	6.74	7.97	3.86	1.59	1.00	0.00	0.00	0.00	1.59	3.86	7.66	6.74	9.46	11.82	9.18	6.74	8.89	4.61	3.35	4.24	7.66	7.66	10.10	12.99	24'
4	6.74	6.74	10.64	7.06	*6.42*	*5.84*	6.42	6.74	10.10	6.74	6.74	7.66	9.46	*5.50*	3.86	2.50	1.59	1.00	1.00	1.59	1.59	3.86	5.50	9.46	7.66	6.74	6.42	9.18	6.42	4.24	1.59	4.24	*6.42*	10.37	6.74	6.74	36'
	0'	**11'**	**22'**	**33'**	**44'**	**55'**	**66'**	**77'**	**88'**	**99'**	**110'**	**121'**	**132'**	**143'**	**154'**	**165'**	**176'**	**187'**	**198'**	**209'**	**220'**	**231'**	**242'**	**253'**	**264'**	**275'**	**287'**	**299'**	**311'**	**323'**	**335'**	**347'**	**359'**	**371'**	**383'**	**395'**	

APPENDIX A7: CORRELATED COLOR TEMPERATURE

HPS Luminaires	Correlated Color Temperature
1	1851
2	1965
3	2156
Avg	1990.67

LED Luminaires	
1	6284
2	6212
3	6269
Avg	6255.00

Appendix B: Monitoring Layout

APPENDIX B1: FACILITY AND MONITORING LAYOUT

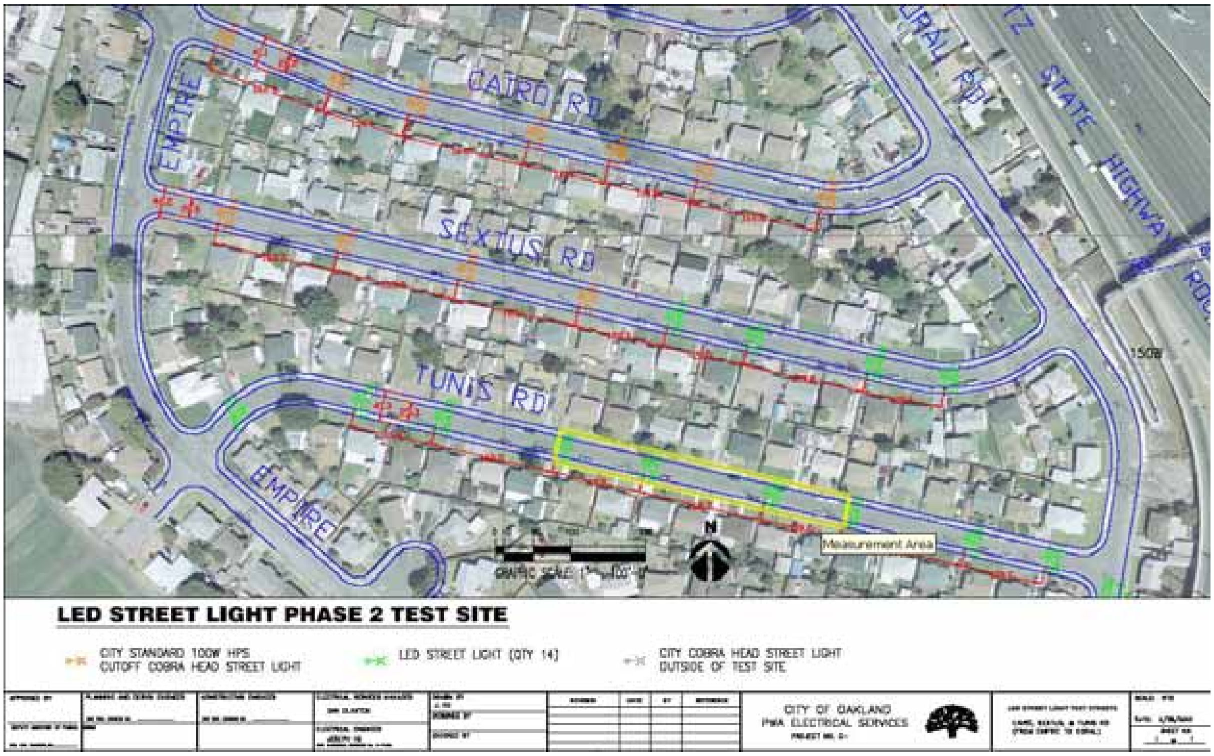


Figure B1: Image of Test Site and Measurement Area

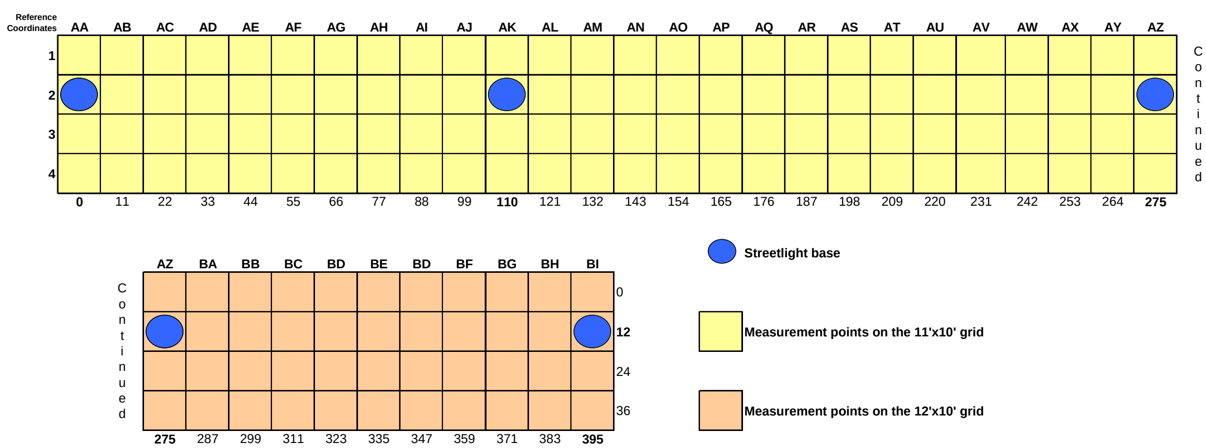


Figure B4.2: Schematic of Measurement Area and Grid

APPENDIX B2: DATA COLLECTION FORM

LED Street Light Fixture - PHASE 2 — **Page:** 1 of 3

Field Collection Form

Initial Visit Date ________

Second Visit Date ________

Location:	Tunis Road, Oakland, CA	**Meter 1** **Type:**		**Model:**
Initial Visit Team:		**Meter 2** **Type:**		**Model:**
Second Visit Team:		**Meter 3** **Type:**		**Model:**

FIXTURE	Illumination	Color Temp	NOTES
Type	At Ground on Grid (Attached)	Of Light In Space (midway)	
Circuit 1: ______________	Page 1	N/A	
Circuit 2: ______________	Page 2	N/A	
Delta Value	N/A	N/A	

LIGHTING CIRCUIT	POWER	VOLTAGE	CURRENT	POWER FACTOR	NOTES
Circuit 1: ______________					
Pre-installation Value					
Post-installation Value					
Delta Value					
Circuit 2: ______________					
Pre-installation Value					
Post-installation Value					
Delta Value					

LIGHTING CIRCUIT	NUMBER OF FIXTURES				
Fixture Type					NOTES
Circuit 1: ______________					
Pre-installation Value					
Post-installation Value					
Delta Value					
Circuit 2: ______________					
Pre-installation Value					
Post-installation Value					
Delta Value					

OTHER MEASUREMENTS					

Appendix C: Additional Site Photographs

Appendix D: Consumer Survey

PACIFIC NORTHWEST NATIONAL LABORATORY LED STREETLIGHT QUESTIONNAIRE
JOB # 320-341

FINAL

UFT N=60

Hello, I'm __________ from FMMA, a public opinion research company. We're conducting a short public opinion survey about the new streetlights the City of Oakland installed in your neighborhood this past October. I am not trying to sell you anything and I will not ask you for a donation or contribution of any kind. May I please briefly speak about these streetlights with the adult in the household who is 18 years of age or older and that most recent celebrated a birthday? **(IF NOT AVAILABLE, ASK:)** "May I speak to another adult in the household about these streetlights?" **(VERIFY THAT THE PERSON LIVES AT THE ADDRESS LISTED; OTHERWISE, ASK TO SPEAK TO SOMEONE THAT LIVES AT THE ADDRESS LISTED AND RESTATE THE INTRODUCTION.)**

1. Have you noticed that new streetlights were installed in your neighborhood this past October?

Yes		33%
No	**(SKIP TO Q11)**	67%
(DON'T KNOW/NA)	**(SKIP TO Q11)**	0%

(ASK Q2-Q10 ONLY IF YES IN Q1)

2. Do you feel that the new streetlights installed this past October have improved or not improved visibility for you as a driver? **(IF IMPROVED/NOT IMPROVED, ASK:)** "Is that strongly or just somewhat?"

Strongly improved	70%
Somewhat improved	10%
Somewhat not improved	5%
Strongly not improved	0%
(DON'T READ) No change/about the same	5%
(DON'T READ) DK/NA	10%

3. Do you feel that the new streetlights installed this past October have improved or not improved visibility for you as a pedestrian? **(IF IMPROVED/NOT IMPROVED, ASK:)** "Is that strongly or just somewhat?"

Strongly improved	65%
Somewhat improved	10%
Somewhat not improved	10%
Strongly not improved	0%
(DON'T READ) No change/about the same	10%
(DON'T READ) DK/NA	5%

4. Do you feel that the new streetlights installed this past October have made it easier or more difficult to recognize people at night under the streetlights? **(IF EASIER/MORE DIFFICULT, ASK:)** "Is that much easier/more difficult or just somewhat easier/more difficult?"

Much easier	50%
Somewhat easier	15%
Somewhat more difficult	5%
Much more difficult	0%
(DON'T READ) No change/about the same	20%
(DON'T READ) DK/NA	10%

5. Do you feel that the new streetlights installed this past October create less glare or more glare? **(IF MORE/LESS, ASK:)** "Is that much or just somewhat less/more glare?"

Much less glare	25%
Somewhat less glare	25%
Somewhat more glare	5%
Much more glare	10%
(DON'T READ) About the same as old lights	25%
(DON'T READ) DK/NA	10%

6. Do you feel that the new streetlights installed this past October give off the right amount of light or are they too bright or too dim? **(IF TOO BRIGHT/DIM, ASK:)** "Is that much or just somewhat too bright/dim?"

Right amount of light	80%
Much too bright	0%
Somewhat too bright	0%

Somewhat too dim --------------------------------------5%
Much too dim-- 10%
(DON'T READ) DK/NA ----------------------------------5%

7. Do you feel that the new streetlights installed this past October create fewer or more shadows? **(IF FEWER/MORE, ASK:)** "Is that many or just somewhat fewer/more?"

Many fewer --0%
Somewhat fewer -- 30%
Somewhat more --5%
Many more---5%
(DON'T READ) No change/about the same ---- 25%
(DON'T READ) DK/NA ------------------------------- 35%

8. Next, I want to read you some specific ways that the new streetlights installed this past October may have affected different aspects of your neighborhood. In each case, please tell me whether you think the new streetlights have improved or not improved each aspect. **(IF IMPROVED/NOT IMPROVED, ASK:)** "Is that strongly or just somewhat?"

(ROTATE)	**STR. IMP.**	**S.W. IMP.**	**S.W. NOT IMP.**	**STR. NOT IMP.**	**(DON'T READ) NO CHANG**	**(DON'T READ) DK/NA**
[ ]a. Your neighborhood's overall appearance	55%	20%	0%	0%	20%	5%
[ ]b. Your neighborhood's nighttime safety	65%	5%	0%	0%	20%	10%
[ ]c. Your neighborhood's nighttime visibility	55%	25%	0%	0%	10%	10%

9. When all things are considered, do you prefer the new streetlights that were installed this past October or do you prefer the old streetlights they replaced? **(IF PREFER THE OLD/NEW TYPE OF STREETLIGHT, ASK:)** "Do you strongly or just somewhat prefer that type of streetlight?"

Strongly prefer new streetlights--------------------- 60%
Somewhat prefer new streetlights ----------------- 10%
Somewhat prefer old streetlights------------------- 15%
Strongly prefer old streetlights ------------------------0%
(DON'T READ) DK/NA ------------------------------- 15%

(ASK Q10 ONLY IF NEW/OLD PREFERRED IN Q9)

10. In a few words of your own, why do you prefer the **(NEW/OLD)** streetlights? **(OPEN-END; RECORD VERBATIM RESPONSE BELOW)**

a. New streetlights

Improves visibility	50%
Like the color/more natural	14%
Better vision at night	7%
Brighter	29%
Less glare/softer light/does not flicker	21%
Less energy/servicing	7%
Improved appearance of neighborhood	7%

b. Old streetlights

Old visibility was better	33%
Old was brighter	33%
New ones not changed/costing more money	33%

THESE QUESTIONS ARE FOR CLASSIFICATION PURPOSES ONLY.

11. Do you have any children under the age of 18 living at home?

Yes	23%
No	68%
(DON'T READ) DK/NA	8%

12. In what year were you born?

1989-1983 (18-24)	7%
1982-1978 (25-29)	2%
1977-1973 (30-34)	2%
1972-1968 (35-39)	5%
1967-1963 (40-44)	2%
1962-1958 (45-49)	7%
1957-1953 (50-54)	8%
1952-1948 (55-59)	5%
1947-1943 (60-64)	3%
1942-1933 (65-74)	10%
1932 or earlier (75 & over)	22%
(DON'T READ) Refused	28%

13. Do you have a driver's license and currently drive?

Yes	60%
No	23%
(DON'T READ) DK/NA	17%

THANK AND TERMINATE

GENDER (BY OBSERVATION):	Male	40%
	Female	60%

LIST (BY PHONE LIST):	List 1 (Light group)	27%
	List 2 (Non-light group)	73%

Appendix E: Additional Economic Data and Scenarios

Estimated Annual Energy Costs

Estimated Annual Savings:[1] **21.74 $ per Fixture**

100 Watt HPS		
Monthly Fixed Charge[2]	5.3290	$/fixture
Annual Cost[3]	63.95	$/yr

LED		
Demand	77.7	W
Usage[4]	318.57	kWh
Rate5	0.1253	$/kWh
Monthly Fixed Charge[6]	0.1904	$/fixture
Annual Cost[7]	42.21	$/yr

[1] 100W HPS Annual Cost - LED Annual Cost
[2] Based on PG&E LS-2 Rate Structure
[3] Monthly Fixed Charge x 12
[4] Assuming 4,100 hr/yr. From PG&E LS-2 Rate Structure
[5] Based on Linear Regression from PG&E LS-2 Rate Structure for HPS Luminaires
[6] Based on Linear Regression from PG&E LS-2 Rate Structure for HPS Luminaires
[7] Usage x Rate + Monthly Fixed Charge x 12

Estimated Group Relamping Normal Repair Costs (100 Watt Cobrahead HPS)

Total Average Annual Repairs:[1] **10.97 $ per Fixture**

Details					
Repair Period:	6	years			
Labor Rate:	100	$/hr			
Vehicle Cost:	13.1	$/hr			
<u>Repair Item:</u>	<u>Lamp</u>	<u>Photocell</u>	<u>Starter</u>	<u>Ballast</u>	<u>Fixture</u>
Item Repair Frequency:[2]	100.00%	75.00%	5.00%	5.00%	0.25%
Additional Field Time (Minutes):	19.2	0	10	15	70.8
Additional Shop Time (Minutes):	0	0	0	25	0
Material Cost ($):	9.25	8.00	38.00	75.00	145.00
Total Additional Labor Cost ($):[3]	36.19	0.00	18.85	69.94	133.46
Total Item Repair Cost($):[4]	48.61	8.00	58.50	151.06	290.14
Average Item Repair Cost ($):[5]	48.61	6.00	2.92	7.55	0.73
Average Annual Item Repair Cost ($):[6]	8.10	1.00	0.49	1.26	0.12

[1] Sum of Average Annual Item Repair Costs. Does not include administrative overhead, major repair, or energy costs; see Details
[2] Percentage of repairs requiring Repair Item
[3] Additional Field Time x (Labor Rate + Vehicle Cost) + Additional Shop Time x Labor Rate
[4] Material Cost x (100% + 8.75% Sales Tax) + Total Additional Labor Cost
[5] Total Item Repair Cost x Item Repair Frequency
[6] Average Item Repair Cost / Repair Period

Estimated Spot Relamping Normal Repair Costs (100 Watt Cobrahead HPS)

Total Average Annual Repairs:[1] **20.40 $ per Fixture**

Details					
Repair Period:[2]	30,000	hr			
Labor Rate:	100	$/hr			
Vehicle Cost:	13.1	$/hr			
Repair Item:	Lamp	Photocell	Starter	Ballast	Fixture
Item Repair Frequency:[3]	100.00%	75.00%	5.00%	5.00%	0.25%
Additional Field Time (Minutes):	60	0	10	15	30
Additional Shop Time (Minutes):	0	0	0	25	0
Material Cost ($):	9.25	8.00	38.00	75.00	145.00
Total Additional Labor Cost ($):[4]	113.10	0.00	18.85	69.94	56.55
Total Item Repair Cost($):[5]	132.25	8.00	58.50	151.06	206.50
Average Item Repair Cost ($):[6]	132.25	6.00	2.92	7.55	0.52
Average Annual Item Repair Cost ($):[7]	18.07	0.82	0.40	1.03	0.07

[1] Sum of Average Annual Item Repair Costs. Does not include administrative overhead, major repair, or energy costs; see Details
[2] Based on Lamp Rated Life; 7.23 years at 4,100 hr/yr
[3] Percentage of repairs requiring Repair Item; conservatively assumed to be same as group relamping
[4] Additional Field Time x (Labor Rate + Vehicle Cost) + Additional Shop Time x Labor Rate
[5] Material Cost x (100% + 8.75% Sales Tax) + Total Additional Labor Cost
[6] Total Item Repair Cost x Item Repair Frequency
[7] Average Item Repair Cost / (Repair Period / 4,100 hr/year)

Estimated Simple Payback for LED Fixtures (New Construction)

Simple Payback (Spot Replacement): **11.56 Years**
Simple Payback (Group Replacement): **14.89 Years**

Details				
Incremental Cost ($):	*486.93*	*$ per LED Luminaire*		
Annual Savings (Spot Replacement):	*42.13*	*$ per Year*		
Annual Savings (Group Replacement):	*32.71*	*$ per Year*		
Labor Rate:	100	$/hr		
Vehicle Cost:	13.1	$/hr		
Luminaire Type:	HPS	HPS	HPS	LED
Installation Item:	Fixture	Photocell	Lamp	Luminaire
Field Time (Minutes):	90	-	-	90
Material Cost ($):	145.00	8.00	9.25	610.00
Total Additional Labor Cost ($):[3]	169.65	-	-	169.65
Total Item Repair Cost($):[4]	327.34	8.70	10.06	833.03

[1] Sum of Average Annual Item Repair Costs. Does not include administrative overhead, major repair, or energy costs; see Details
[2] Percentage of repairs requiring Repair Item
[3] Additional Field Time x (Labor Rate + Vehicle Cost) + Additional Shop Time x Labor Rate
[4] Material Cost x (100% + 8.75% Sales Tax) + Total Additional Labor Cost

Estimated Simple Payback for LED Fixtures (Retrofit)

Simple Payback (Spot Replacement): **19.77 Years**
Simple Payback (Group Replacement): **25.47 Years**

Details				
Incremental Cost ($):	*833.03*	*$ per LED Luminaire*		
Annual Savings (Spot Replacement):	*42.13*	*$ per Year*		
Annual Savings (Group Replacement):	*32.71*	*$ per Year*		
Labor Rate:	100	$/hr		
Vehicle Cost:	13.1	$/hr		
Luminaire Type:	HPS	HPS	HPS	LED
Installation Item:	Fixture	Photocell	Lamp	Luminaire
Field Time (Minutes):	-	-	-	90
Material Cost ($):	-	-	-	610.00
Total Additional Labor Cost ($):[3]	-	-	-	169.65
Total Item Repair Cost($):[4]	-	-	-	833.03

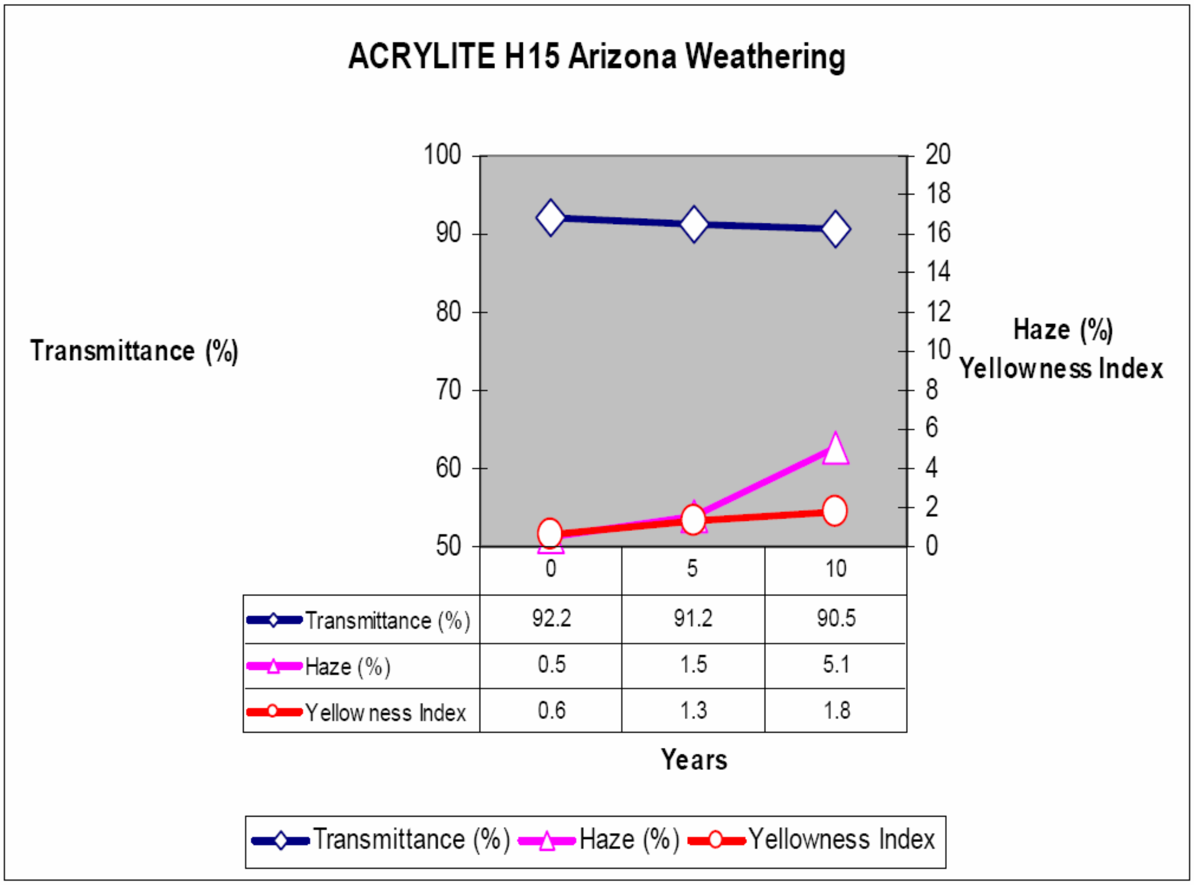
[1] Sum of Average Annual Item Repair Costs. Does not include administrative overhead, major repair, or energy costs; see Details

[2] Percentage of repairs requiring Repair Item

[3] Additional Field Time x (Labor Rate + Vehicle Cost) + Additional Shop Time x Labor Rate

[4] Material Cost x (100% + 8.75% Sales Tax) + Total Additional Labor Cost

Appendix F: Acrylic Weathering Information



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Appendix G: PG&E LS-2 Rate Schedule

Pacific Gas and Electric Company
San Francisco, California
U 39

	Revised	*Cal. P.U.C. Sheet No.*	26635-E
Cancelling	Revised	*Cal. P.U.C. Sheet No.*	26063-E

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

APPLICABILITY: This schedule is applicable service to lighting installations which illuminate streets, highways, and other publicly-dedicated outdoor ways and places where the Customer usually owns the lighting fixtures, poles and interconnecting circuits. The Customer's facilities must be of good construction acceptable to PG&E and in satisfactory condition to qualify for Class B or C rates. Class B and C are closed to new installations and additional lamps in existing accounts.

TERRITORY: The entire territory served.

RATES: Total bundled service charges are calculated using the total rates shown below. Direct Access (DA) and Community Choice Aggregation (CCA) charges shall be calculated in accordance with the paragraph in this rate schedule titled Billing.

Lamp rates include a Base Charge for the actual cost of operating and maintaining the various lamp sizes and types and an energy charge. The energy charge is included in the per lamp charges listed below. The Base Charge is assigned to distribution, and equals the difference between the total charge per lamp per month and the product of the energy charge per kWh and the kWh per month listed below.

CLASS:

A — PG&E supplies energy and service only.

B — PG&E supplies the energy and maintenance service for lamps and glassware.

C — PG&E supplies the energy and maintenance service as described in Special Condition 8

Nominal Lamp Rating:			Per Lamp Per Month			
LAMP WATTS	kWh PER MONTH	AVERAGE INITIAL LUMENS*	Class A All-Night	Class B*** All-Night	Class C*** All-Night	A, B, and C Half-Hour Adjustment
INCANDESCENT LAMPS:						
58	20	600	$2.697	–	–	$0.114
92	31	1,000	4.075 (R)	$5.275 (R)	$5.575 (R)	0.177
189	65	2,500	8.336 |	9.536 |	9.836 |	0.370
295	101	4,000 **	12.848 |	14.048 |	14.348 |	0.575 (R)
405	139	6,000 **	17.611 |	18.811 |	19.110 |	0.792
620	212	10,000 **	26.760 |	27.960 |	28.260 (R)	1.208
860	294	15,000 **	37.037 (R)	38.237 (R)	–	1.675
MERCURY VAPOR LAMPS:						
40	18	1,300	$2.446 (R)	–	–	$0.103
50	22	1,650	2.947 |	–	–	0.125
100	40	3,500	5.203 |	$6.403 (R)	$6.703 (R)	0.228
175	68	7,500	8.712 |	9.912 |	10.212 |	0.387 (R)
250	97	11,000	12.347 |	13.547 |	13.847 |	0.553
400	152	21,000	19.240 |	20.440 |	20.740 |	0.866
700	266	37,000	33.528 |	34.728 |	35.027 |	1.515 (R)
1,000	377	57,000	47.439 (R)	48.639 (R)	48.939 (R)	2.148
LIGHT EMITTING DIODE (LED) LAMPS: 120 VOLTS						
42	14	837	$1.945	–	–	$0.080

* Latest published information should be consulted on best available lumens.
** Service for incandescent lamps over 2,500 lumens will be closed to new installations after September 11, 1978.
*** Closed to new installations and new lamps on existing circuits, see condition 8A.

(Continued)

Advice Letter No. 3124-E	*Issued by*	*Date Filed*	September 21, 2007
Decision No.	*Brian K. Cherry*	*Effective*	November 1, 2007
	Vice President	*Resolution No.*	
107221	*Regulatory Relations*		

Pacific Gas and Electric Company
San Francisco, California
U 39

	Revised	Cal. P.U.C. Sheet No.	26636-E
Cancelling	Revised	Cal. P.U.C. Sheet No.	26064-E

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

RATES:
(Cont'd.)

CLASS:	A	B***	C***
	PG&E supplies energy and service only.	PG&E supplies the energy and maintenance service for lamps and glassware.	PG&E supplies the energy and maintenance service as described in Special Condition 8.

Nominal Lamp Rating:

LAMP WATTS	kWh PER MONTH	AVERAGE INITIAL LUMENS*	Class A All-Night	Class B All-Night	Class C All-Night	A, B, and C Half-Hour Adjustment
			Per Lamp Per Month			
HIGH PRESSURE SODIUM VAPOR LAMPS AT: 120 VOLTS						
35	15	2,150	$2.070 (R)	–	–	$0.085
50	21	3,800	2.822 |	–	–	0.120
70	29	5,800	3.825 |	$6.024 (R)	$5.324 (R)	0.165
100	41	9,500	5.329 |	6.528 |	6.828 |	0.234
150	60	16,000	7.710 |	8.910 (R)	9.209 (R)	0.342
200	80	22,000	10.216 (R)	–	–	0.456
HIGH PRESSURE SODIUM VAPOR LAMPS AT: 240 VOLTS						
50	24	3,800	$3.198 (R)	–	–	$0.137
70	34	5,800	4.451 |	$5.651 (R)	$5.951 (R)	0.194
100	47	9,500	6.080 |	7.280 |	7.580 |	0.268
150	69	16,000	8.838 |	10.037 |	10.337 |	0.393
200	81	22,000	10.342 |	11.541 |	11.841 |	0.461 (R)
250	100	25,500	12.723 |	13.923 (R)	14.223 (R)	0.570
310	119	37,000	15.104 |	–	–	0.678
360	144	45,000	18.238 |	–	–	0.820 (R)
400	154	46,000	19.491 (R)	20.691 (R)	20.990 (R)	0.877 (R)
LOW PRESSURE SODIUM VAPOR LAMPS:						
35	21	4,800	$2.822 (R)	–	–	$0.120
55	29	8,000	3.825 |	–	–	0.165
90	45	13,500	5.830 |	–	–	0.256
135	62	21,500	7.960 |	–	–	0.353
180	78	33,000	9.966 (R)	–	–	0.444

* Latest published information should be consulted on best available lumens.
*** Closed to new installations and new lamps on existing circuits, see condition 8A.

(Continued)

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Pacific Gas and Electric Company
San Francisco, California
U 39

Original Cal. P.U.C. Sheet No. 26667-E
Cancelling Cal. P.U.C. Sheet No. 26065-E

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

RATES:
(Cont'd.)

CLASS:	A	B***	C***
	PG&E supplies energy and service only.	PG&E supplies the energy and maintenance service for lamps and glassware.	PG&E supplies the energy and maintenance service as described in Special Condition 8.

Nominal Lamp Rating:

			Per Lamp Per Month			
LAMP WATTS	kWh PER MONTH	AVERAGE INITIAL LUMENS*	Class A All-Night	Class B All-Night	Class C All-Night	A, B, and C Half-Hour Adjustment
METAL HALIDE LAMPS:						
70	30	5,500	$3.950 (R)	–	–	$0.171
100	41	8,500	5.329 |	–	–	0.234
150	63	13,500	8.086 |	–	–	0.359
175	72	14,000	9.214 |			0.410
250	105	20,500	13.350 |			0.598
400	162	30,000	20.493 |	–	–	0.923
1,000	387	90,000	48.693 (R)	–	–	2.205
INDUCTION LAMPS:						
55	19	3,000	$2.571 (R)	–	–	$0.108
85	30	4,800	3.950 |	–	–	0.171
165	58	12,000	7.459 (R)	–	–	0.330 (R)

* Latest published information should be consulted on best available lumens.
*** Closed to new installations and new lamps on existing circuits, see condition 8A.

(Continued)

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Pacific Gas and Electric Company
San Francisco, California
U 39

	Revised	Cal. P.U.C. Sheet No.	26637-E
Cancelling	Revised	Cal. P.U.C. Sheet No.	26066-E

SCHEDULE LS-2–CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

RATES:
(Cont'd.)

TOTAL ENERGY RATES

Total Energy Charge Rate ($ per kWh)	$0.12533	(R)

UNBUNDLING OF TOTAL ENERGY CHARGES

The total energy charge is unbundled according to the component rates shown below.

Energy Rate by Components ($ per kWh)		
Generation	$0.05873	
Distribution	$0.04800	(I)
Transmission*	$0.00494	(R)
Transmission Rate Adjustments*	($0.00069)	
Reliability Services*	$0.00004	
Public Purpose Programs	$0.00596	
Nuclear Decommissioning	$0.00027	
Competition Transition Charge	$0.00002	
Energy Cost Recovery Amount	$0.00337	
DWR Bond	$0.00469	

* Transmission, Transmission Rate Adjustments, and Reliability Service charges are combined for presentation on customer bills.

(Continued)

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107195

Pacific Gas and Electric Company San Francisco, California		Revised	Cal. P.U.C. Sheet No.	24545-E
	Cancelling	Revised	Cal. P.U.C. Sheet No.	21409-E

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS:

1. TYPE OF SERVICE: This schedule is applicable to multiple lighting systems to which PG&E will deliver current at secondary voltage. Multiple current will normally be supplied at 120/240 Volt, single-phase. In certain localities PG&E may supply service from 120/208 Volt, wye-systems, polyphase lines in place of 240 Volt service. Unless otherwise agreed, existing series current will be delivered at 6.6 amperes. Single-phase service from 480 Volt sources and series circuits will be available in certain areas at the option of PG&E when this type of service is practical from PG&E's engineering standpoint. All currents and voltages stated herein are nominal, reasonable variations being permitted. (T)

   New lights will normally be supplied as multiple systems. Series service to new lights will be made only when it is practical from PG&E's engineering standpoint to supply them from existing series systems.

2. SERVICE REQUIREMENTS: (N)

   a) PHOTO CONTROLS

   This rate schedule is predicated on an electronic type photo controls meeting 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 for this rate schedule.

   b) LIGHT or POLE NUMBERING

   As agreed upon by the parties, pole number sequencing and coding for single lights or multiple lights on a single pole, shall be provided by either party and must conform to PG&E's billing system. Customer will provide physical numbering on lights or poles for LS-2 installations in order to facilitate accurate billing and inventory reporting. Numbering is required prior to energizing facilities. Numbering must be legible from the ground.

   c) SERVICE REQUESTS

   Service request shall include form 72-1007 for installation and energizing, and form 72-1008 for removing or de-energizing Customer's facilities. (N)

(L)

(Continued)

Advice Letter No. 2791-E	Issued by	Date Filed	February 24, 2006
Decision No.	Thomas E. Bottorff	Effective	March 1, 2006
	Senior Vice President	Resolution No.	
102509	Regulatory Relations		

Pacific Gas and Electric Company
San Francisco, California

	Original	Cal. P.U.C. Sheet No.	24546-E
Cancelling		Cal. P.U.C. Sheet No.	

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS: (Cont'd.)

3. **SERVICE INSTALLATION** (N)

PG&E will establish service delivery points within close proximity to its distribution system.

a) **Overhead:** In an overhead area, a single drop will be installed. For an overhead to underground system, service will be established in a PG&E box at the base of the riser pole or other agreed upon location within close proximity. PG&E will connect Customer's conductors at the service delivery point.

b) **Underground:** In an underground area, service will be established at the nearest existing secondary box. Where no secondary facilities exist, a new service, transformer and secondary splice box, as required, will be installed in the shortest most practical configuration from the connection on the distribution line source. Customer shall install and own all facilities from the service delivery point on PG&E's system.

c) **Customer Installation Responsibility:** Customer shall install, own and maintain all facilities beyond the service delivery point. For PG&E's serving facilities, Customer or Applicant, at its expense, shall perform all necessary trenching, backfill and paving, and shall furnish and install all necessary conduit and substructures (including substructures for transformer installations, if necessary, for street lights only) in accordance with PG&E's specifications. Riser material shall be installed by PG&E at the Customer's expense. Upon acceptance by PG&E, ownership of the conduit and substructures shall vest in PG&E. Customer shall provide rights of way as provided in electric Rule 16.

d) **PG&E Installation Responsibility:** PG&E shall furnish and install the underground or overhead service conductor, transformers and necessary facilities to complete the service to the distribution line source, subject to the payment provisions of Special Condition 4. Only duly authorized employees of PG&E shall connect Customer's loads to, or disconnect the same from, PG&E's electrical distribution facilities.

e) **Rearrangements:** Customer or Applicant shall pay, in advance, PG&E's estimated cost for any relocation, or rearrangement of PG&E's existing street light or service facilities requested by Customer or Applicant and agreed to by PG&E.

f) **Non-conforming Load:** Applicant or Customer must be a governmental agency. Only sprinkler control type loads or telecommunications type loads may be connected to LS-2 lamps or circuits, total load must not exceed 50 watts, and the installation must meet all GO 95 clearance requirements. All other non conforming load connected to unmetered LS-2 facilities beyond PG&E's service delivery point, requires metering of the Customer's system at PG&E's service delivery point and conversion to an applicable rate schedule absent any other Commission approved agreement. (N)

(Continued)

Advice Letter No. 2791-E	Issued by	Date Filed	February 24, 2006
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	Senior Vice President	Resolution No.	
102510	Regulatory Relations		

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS: (Cont'd.)

4. **NON REFUNDABLE PAYMENT FOR SERVICE INSTALLATION:** (N)

a) Customer or Applicant shall pay in advance the estimated installed cost necessary to establish a service delivery point. A one-time revenue allowance will be provided based on Customer's kWh usage and the distribution component of the energy rate posted in the Rate Schedule for the lamps installed. The total allowance shall be determined by taking the annual equivalent kWh times the Distribution component of this rate divided by the cost of service factor shown in Electric Rule 15.C.

b) The allowance will only be provided where PG&E must install capital assets to connect load. No allowance will be provided where a simple connection is required. Only lights on a minimum 11 hour All Night (AN) schedule for permanent service shall be granted an allowance. Where Applicant received allowances based upon 11 hour AN operation, no billing adjustments, as otherwise provided for in Special Condition 7, shall be made for the first three (3) years following commencement of service.

Line or service extensions in excess of the above shall be installed under special condition 9.

5. **TEMPORARY SERVICE:** Temporary services will be installed under electric Rule 13.

6. **ANNUAL OPERATING SCHEDULES:** The above rates for AN service assume 11 hours operation per night and apply to lamps which will be turned on and off once each night in accordance with a regular operating schedule selected by the Customer but not exceeding 4,100 hours per year. (N)

(Continued)

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS: (Cont'd.)

7. **OPERATING SCHEDULES OTHER THAN ALL-NIGHT**: Rates for regular operating schedules other than full all-night will be the AN rate, plus or minus, respectively, the half-hour adjustment for each half-hour more or less than an average of 11 hours per night. This adjustment will apply only to lamps on regular operating schedules of not less than 1,095 hours per year, or 3 hours per night, nor more than 4,500 hours per year. Photo control devices used for more or less than AN must be approved by PG&E prior to adjustments in billing. (T) (L) (T) (N) (N) (D) (D)

8. **MAINTENANCE, ACCESS, CLEARANCES:** (T)

   a) Maintenance (T)

   The Class B and C rates include all labor and material necessary for the inspection, cleaning, or replacement by PG&E of lamps and glassware. Replacement is limited to certain glassware such as is commonly used and manufactured in reasonably large quantities. A commensurate extra charge will be made for maintenance of glassware of a type entailing unusual expense. The Class C rate also includes all labor and material necessary for replacement by PG&E of photoelectric controls. Class B and C rates are closed to new installations and to additional lamps in existing accounts as of March 1, 2006. (T) (N) (N)

   b) Under the grand fathered Class B and C rates, the following shall apply: (T)

   1) At Customer's request, where PG&E's resources permit, PG&E will paint poles for Customer on a time and material basis. This service will only be offered for poles that have been designed to be painted. (N) (N)

   2) PG&E will Isolate any trouble in the Customer's system which has resulted in an outage or diminished light output. (T)

   3) PG&E will make necessary repairs which do not require wiring replacement on accessible wiring between poles and on equipment and wiring in and on poles to keep the system in operating condition. (T)

   4) PG&E will provide labor for the replacement of material such as ballasts, relays, fixtures, individual cable runs between poles where such runs are in conduit, and other individual parts of the system that are not capital items. (T)

   5) Customer shall compensate PG&E for any material furnished by PG&E not included in 8.A. above. The exception for Class B is that photo control replacement is not included in the rate. Customer must have been on Class C for this service.

   6) PG&E shall not be responsible for excavation or any major replacement of circuits, conduits, poles, or fixtures owned by the Customer. (T) (L)

   7) Tree trimming is the responsibility of the Customer for installation of new lights or for maintaining lighting patterns of existing lights. (N) (N)

(Continued)

Advice Letter No. 2791-E
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102512

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Resolution No.

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS: (Cont'd.)

8. **MAINTENANCE, ACCESS, CLEARANCES** (Cont'd.): (T)

c) Access (N)

Customer will maintain adequate access for PG&E's standard equipment used in maintaining facilities and for installation of its facilities. PG&E reserves the right to collect additional maintenance costs due to obstructed access or other conditions preventing PG&E from maintaining its equipment with standard operating procedures. Applicant or Customer shall be responsible for rearrangement charges as provided for in Special Condition 3.e.

d) Clearances

Customer applicant shall, at its expense, correct all access or clearance infractions, or pay PG&E its total estimated cost for PG&E to relocate facilities to a new location which is acceptable to PG&E. Failure to comply with corrective measures within a reasonable time may result in discontinuance of service in accordance with electric Rule 11. Applicant or Customer shall be responsible for tree trimming to maintain lighting patterns of existing lights. (N)

(D)
|
(D)

(Continued)

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS: (Cont'd.)

9. **LINE EXTENSIONS:** Where PG&E extends its electric lines to serve Customer's street lighting system, an Agreement for Installation or Allocation of Special Facilities, form 79-255, will be required. Should PG&E utilize the line to serve other metered load, an equitable adjustment will be made as provided in the Agreement. (T)

10. **STREET LIGHT LAMPS - STANDARD AND NONSTANDARD RATINGS:** The rates under Classes B and C are applicable to both standard and group replacement street lamps. Standard and group replacement street lamps have reference only to street lamps having wattage and operating life ratings within three percent of those specified in the EEI-NEMA Standards for Filament Lamps Used in Street Lighting. Where Class A service is supplied to lamps of other ratings than those specified in EEI-NEMA Standards an adjustment will be made in the lamp rates proportionate to the difference between the wattage of the lamps and the standard lamps of the same lumen rating. (T)

11. **CONTRACT:** Except as otherwise provided in this rate schedule, or where lighting service is installed in conjunction with facilities installed under the provisions of Rules 15 or 16, standard form contract 62-4527, Agreement to Perform Tariff Schedule Related Work shall be used for installations, rearrangements or relocations. (N)

12. **POLE CONTACT AGREEMENT:** Where Customer requests to have a portion or all Customer owned street lighting facilities in contact with PG&E's distribution poles, a Customer-Owned Streetlights PG&E Pole Contact Agreement (Form 79 938) will be required. (T)

(Continued)

SCHEDULE LS-2—CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING
(Continued)

SPECIAL CONDITIONS: (Cont'd.)

13. **BILLING**: This Rate Schedule is subject to PG&E's other rules governing billing issues, as may be applicable. Customer of record will provide, at a minimum an annual inventory and, if requested, maintenance record information to Company's billing department to reconcile streetlight billing similarly to how Company's Group Lamp Replacement program reconciles Company maintained lighting. Company reserves the right to audit customer facilities where information is not provided or is insufficient in nature to properly audit billing records. Company reserves the right to collect the cost of such audit from the customer.

Bundled Service Customers receive supply and delivery service solely from PG&E. The Customer's bill is based on the Total Rate set forth above.

Transitional Bundled Service Customers take transitional bundled service as prescribed in Rules 22.1 and 23.1, or take bundled service prior to the end of the six (6) month advance notice period required to elect bundled portfolio service as prescribed in Rules 22.1 and 23.1. These customers shall pay charges for transmission, transmission rate adjustments, reliability services, distribution, nuclear decommissioning, public purpose programs, the FTA (where applicable), the RRBMA (where applicable), the applicable Cost Responsibility Surcharge (CRS) pursuant to Schedule DA CRS or Schedule CCA CRS, and short-term commodity prices as set forth in Schedule TBCC.

Direct Access (DA) and Community Choice Aggregation (CCA) Customers purchase energy from their non-utility provider and continue receiving delivery services from PG&E. Bills are equal to the sum of charges for transmission, transmission rate adjustments, reliability services, distribution, public purpose programs, nuclear decommissioning, the FTA (where applicable), the RRBMA (where applicable), the franchise fee surcharge, and the applicable CRS. The CRS is equal to the sum of the individual charges set forth below. Exemptions to the CRS are set forth in Schedules DA CRS and CCA CRS.

	DA CRS	CCA CRS
Energy Cost Recovery Amount Charge (per kWh)	$0.00337 (R)	$0.00337 (R)
Power Charge Indifference Adjustment (per kWh)	$0.00002 (I)	$0.01998 (I)
DWR Bond Charge (per kWh)	$0.00469 (R)	$0.00469 (R)
CTC Charge (per kWh)	$0.00002 (R)	$0.00002 (R)
Total CRS (per kWh)	$0.00810 (R)	$0.02806 (R)

14. DWR BOND CHARGE: The Department of Water Resources (DWR) Bond Charge was imposed by California Public Utilities Commission Decision 02-10-063, as modified by Decision 02-12-082, and is property of DWR for all purposes under California law. The Bond Charge applies to all retail sales, excluding CARE and Medical Baseline sales. The DWR Bond Charge (where applicable) is included in customers' total billed amounts.

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