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LED Street Lighting and Network Controls
San Jose, CA

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Table of Contents

List of Tables

List of Figures

Preface

Energy Solutions provided monitoring, data collection, and data analysis services for this LED Street Lighting and Network Controls Assessment Project under contract to the Emerging Technologies Program of Pacific Gas and Electric Company (PG&E). The project was carried out in collaboration with the City of San Jose and the California Lighting Technology Center (CLTC). This project replaced 55W nominal low pressure sodium streetlights with dimmable networked LED luminaires (75W nominal at full power) in the demonstration area. This project also included functional testing and energy performance assessment of the streetlight network controls technology.

Acknowledgements

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Executive Summary

This report summarizes an assessment project conducted to study the performance of light-emitting diode (LED) luminaires with network controls in a street lighting application. The project included installation of LED streetlights with network controls on public roadways in San Jose, California. Quantitative light and electrical power measurements were taken, as well as surface and overhead photographs from a maintenance bucket truck to compare base case low pressure sodium (LPS) performance with that of the LED replacement luminaires. Network controls functionality was also tested and qualitative satisfaction with the system was gauged through a user survey. Estimated economic performance of the network-controlled LED street lighting system was compared to that of the incumbent non-networked LPS streetlights.

The pilot project replaced 118 55W nominal LPS fixtures (American Electric Lighting Roadway-Area-SRX Type II fixtures) with continuously dimmable BetaLED LEDway luminaires rated at 75W nominal at full output (BLD-STR-T2-HT LEDway™ Streetlight – Type II), but dimmed to 50% power setting as the default mode of operation per the City of San Jose's requirements. According to lab measurements, at the control system's 50% power setting, the LED luminaires draw 34.9W (47.4% of measured power), excluding network controls parasitic power. The LED street lighting pilot was located in the Cassell residential neighborhood of San Jose, California, between Leeward, Adrian, Amador, and Vistaglen streets. A 400 ft stretch of roadway under three consecutive streetlights on Adrian Way near the intersection of Newton Avenue was chosen as the test area where comparative lighting and energy performance data was collected.

The street lighting network controls system deployed for this demonstration was Echelon's LonWorks platform of power-line carrier (PLC) technology. The system is designed to offer more robust operations strategies than typical on/off photocell control, including capabilities such as streetlight scheduling, dimming, energy usage reporting, detection of failures, and asset management. The Echelon system used i.LON segment controllers installed on distribution circuits to communicate with connected LED streetlights, which were equipped with controls to send and receive PLC information and interact with the LED luminaires' 0-10v dimming drivers. The pilot system's 57 segment controllers were networked through three metro-class WiFi antennas that provided wireless communication between the segment controllers and an internet-connected gateway in the neighborhood. All connected street lighting assets were monitored and controlled through the third party web-based software interface Streetlight.vision.

Energy Performance

Energy savings potential from the replacement of the streetlights and from dimming and/or scheduling benefits allowed by the network controls was a key performance consideration for this study. The LED luminaire power was measured at 100%, 75%, and 50% power settings programmed through the network control system. Evaluation scenarios were then developed for hypothetical at-scale street lighting installations, comparing dimmed networked LED streetlights and non-networked LEDs to the LPS baseline (see Streetlight and Network Controls Economic Performance). The pilot LED luminaires were operated at the controls setting of 50% power as the default mode of operation; annual electrical energy savings for this setting is estimated below. The controls also offer adaptive scheduling features, so a hypothetical scenario for adaptive streetlight dimming to 25% power setting for half of the night was also evaluated. Annual hours of operation (4,100 hours) and energy costs are based on the PG&E rate schedule for these streetlights.[1]

Table I: Average Power and Savings per Streetlight for Evaluation Scenarios

Street Lighting Evaluation Scenarios	Power[2] (W)	Power Savings (W)	% Savings over Baseline LPS Power	Estimated Annual Energy Savings (4100 hr/yr, kWh)	Annual Energy Cost Savings[3]
LPS	92.5	--	0%	--	--
LEDs, 50% Power Setting	34.9	57.6	62%	236.2	$26.22
Hypothetical Adaptive Networked LEDs[4]	26.2	66.3	72%	271.8	$29.96

LPS is a less common technology for outdoor lighting, accounting for around 9% of the 31 TWh of annual electricity used nationwide by roadway lighting.[5] Even so, if energy usage by this fraction of streetlights could be cut in half with networked LED retrofits, 1,400 GWh of generation could be avoided: over 1 million metric tons of CO_2 emissions at average national electric generation emissions rates and the equivalent of savings 2.3 million barrels of oil. If similar results could be achieved for LPS and for all high intensity discharge street lighting sources (together totaling 92.4% of all roadway lighting electricity), the savings nationally would be over 14,300 GWh per year, roughly equal to 10.3 million metric tons of CO_2 or 23.9 million barrels of oil (See Potential Savings).

Lighting Performance

Illuminance measurements were taken to evaluate LPS and LED performance over a grid covering the roadway surface in the test area on Adrian Way. Comparative metrics included maximum, minimum and average illuminance, uniformity values (coefficient of variation, average-to-minimum uniformity ratio, and maximum-to-minimum uniformity ratio), and the percentage of test area grid points that were measurably illuminated, (.05 fc or greater for this study's meter, with a display resolution of .1 fc). Computer modeling of photometric performance was also carried out for a street lighting layout as close as possible to that of the test area.

Standards for roadway lighting are currently written for luminance and illuminance levels based on photopic sensitivity function levels, so photopic illuminance was the first basis for comparison. However, illuminance levels under nighttime roadway conditions typically fall in the mesopic range of visual perception, where both photopic and scotopic illuminance are important. LPS is a

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1 See Appendix E: PG&E Rate Schedule LS-2 for Customer Owned Streetlights

2 Power includes measured luminaire wattage only and does not include load from controls (smart drivers, segment controllers, system gateway), which varies based on installation parameters. See Network Controls Energy Performance section for a discussion of controls wattage.

3 Cost savings are based on PG&E's LS-2 rate schedule for LEDs, assuming dimmed LEDs will be charged at rates corresponding to dimmed wattages (see Streetlight and Network Controls Economic Performance).

4 The adaptive scenario assumes a schedule of 50% power setting half the night and 25% power setting half the night.

5 Navigant Consulting, Inc. (2002). "US Lighting Market Characterization, Volume I."

monochromatic source that peaks in the range of the photopic visual efficiency function, which is driven only by the cone photoreceptors. On the other hand, LEDs and other broad spectrum sources also emit in short wavelengths that excite the rod photoreceptors and are more heavily weighted by scotopic and mesopic efficiency functions (see Mesopic Illuminance Discussion). Research on the relative importance of mesopic performance and other broad spectrum light benefits is ongoing to determine if precisely equivalent photopic illuminance levels are necessary to provide adequate lighting performance with LEDs improvements in mesopic output, color rendering, and light distribution. Photopic and scotopic illuminance levels were measured for this study, and mesopic illuminance levels were calculated based on several models.

Results from field data show that at 100% and 75% power settings, the LED streetlights provided higher overall levels of photopic and scotopic illuminance than the incumbent LPS, with slightly less of the test area measurably illuminated. At the 50% power setting, which was set as the default level for the San Jose LED pilot, the average illuminance from the LEDs was slightly lower than from the LPS, though equivalent when rounded to the meter's accuracy. San Jose's lighting standard, based on the 1964 IESNA Standard Practice for Roadway Lighting, calls for minimum average illuminance of 0.2 fc for low pedestrian/vehicle conflict, residential areas and average-to-minimum uniformity of 6:1 or better. For both the LPS and the LED luminaires at 100%, 75%, and 50% power settings, average illuminance levels (rounded to the tenths place) and uniformity levels calculated from the field data met the San Jose standard. Under the current IESNA Standard (RP-8-00), both the LPS streetlights and the LED streetlights at all power settings meet uniformity criteria but fall short of the 0.4 fc average illuminance recommendation for low pedestrian/vehicle conflict, local roadways.

The computer model was used to simulate initial LPS and LED performance. The modeled LED average illuminance values in Table III are only slightly higher than the field data and equivalent when rounded to the tenths place, while the LPS average is somewhat higher than the field average, which was expected since field measurements were taken under existing (aged) fixtures and lenses. The modeled uniformity metrics show slightly greater uniformity for the LED luminaires than for the LPS, which do not meet the 6:1 average-to-minimum uniformity requirement, whereas field data in Table II show slightly better uniformity in most cases for the LPS luminaires. For uniformity calculations, especially the average-to-minimum ratios, the modeled results are a better comparative metric due to the limitations of the field data (see Project Results and Discussion).

Finally, the mesopic illuminance averages presented in Table IV, which were calculated with several models discussed in the Streetlight Performance Section and Appendix B, show higher mesopic performance for the LED luminaires at 50% power setting than the measured LED photopic illuminance. Mesopic illuminance for the LED luminaires was higher than mesopic illuminance calculated from the LPS data and as high as or higher than measured photopic illuminance for the LPS streetlights.

Table II: Comparison of Measured Photopic Performance, Entire Test Area

Luminaire	Grid Points Illuminated[6]	Average Illuminance (fc)	Coefficient Of Variation[7]	Average-to-Minimum Uniformity (Illuminated Points Only)[8]
LPS	99.03%	0.21	0.53	*2.15*
LED (100% Setting)	90.38%	0.29	0.83	*2.94*
LED (75% setting)	91.35%	0.25	0.75	*2.46*
LED (50% setting)	81.73%	0.16	0.77	*1.58*

Table III: Summary of Computer Modeled Photopic Performance, Entire Test Area

Luminaire	Grid Points Illuminated[9]	Average Illumination (fc)	Coefficient Of Variation	Average-to-Minimum Uniformity
LPS	100%	0.25	0.75	8.46
LED (100% Setting)	100%	0.32	0.60	4.60
LED (75% Setting)	100%	0.28	0.60	4.60
LED (50% Setting)	100%	0.19	0.59	4.64

Table IV: Average Illuminance Results from Mesopic Models, Entire Test Area

Luminaire	Measured Photopic	Measured Scotopic	MOVE Model Mesopic	Unified Photometry Mesopic	LEM Mesopic
LPS	0.21	0.08	0.15	0.10	0.14
LED (50% Setting)	0.16	0.27	0.21	0.24	0.33

Network Controls Performance

A test plan to evaluate the network controls system was prepared to collect information on system design, components, and set-up from the manufacturer, City of San Jose personnel, and hands-on experience. This plan included four evaluation categories:

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6 'Grid Points Illuminated' is the percentage of grid points that were measurably illuminated (.05 fc or greater for the meter used in this study, with a display resolution of .1 fc).

7 'Coefficient of Variation' is the standard deviation of the distribution, divided by the average illuminance. A lower Coefficient of Variation indicates increased uniformity. See Project Results and Discussion for more information.

8 Because there were points of zero measurable illuminance with the field detector (levels under .05 fc) in the test area for each case, uniformity ratios for field data were calculated only for measurably illuminated grid points; in other words, uniformity over the illuminated test area. The computer-modeled results were of a finer scale that generated non-zero illuminance values for all points in the simulated grid, allowing uniformity ratios to be calculated over the entire modeled area. These ratios are therefore a better comparative metric.

9 Meter limitations (which didn't allow measurement below .05 fc in the field) do not apply to the computer-modeled illumination values, which were above zero for all points; therefore all grid points could be included in analysis.

1. Technology overview and equipment description: network components, features, management system, and vendor specifications for performance, precision, durability, energy usage
2. User surveys and interviews: user feedback on control technology's installation and use, advantages and drawbacks, including satisfaction scales and qualitative comments
3. System functional testing: operation of web interface and network functions; observe input of scheduling and dimming commands; data queries; report production; streetlight mapping; etc. including field observations of system response and logged power data
4. System economics: cost estimates from manufacturer and potential cost savings due to system installation to provide system payback and present value analysis

Results from the network controls testing activities are summarized in Table V below. The Streetlight.vision interface for network management was found to be relatively straightforward to use and required minimal training for operators, who expressed that the tool provided useful benefits for system operation. Successful luminaire control and dimming from the web interface was observed in the field. However, some difficulties arose with luminaire grouping and scheduling features; operators were unable to save new setting for scheduling during system exercises.

The biggest challenge for the network controls system in the San Jose pilot was the layout of local distribution circuits and the small average number of streetlights fed by each circuit. The Echelon technology relies on power-line carried (PLC) communications, which must be issued downstream of residential transformers that step down line voltage to standard 120v. Therefore, many more segment controllers than expected had to be deployed to propagate the PLC signals to the network of streetlights. Fewer segment controllers would be required in a situation where a larger number of streetlights are fed by a single transformer. However, given the age and wide variety of the installed street lighting systems across PG&E territory and the nation, PLC systems are likely to encounter similar challenges in future installations. To address this challenge, Echelon is working on a next generation product that uses a hybrid communication network with both PLC and radio frequency (RF) components.

Energy monitoring and metering is one of the key benefits of advanced street lighting controls, particularly from a utility perspective. However, the Echelon technology tested in this demonstration was not capable of real-time power measurements in the field. Instead, before installation Echelon measured luminaire equipment power (LED luminaire, 0-10v continuous LED dimming driver, PLC transceiver) with a lab grade power analyzer at a range of power settings and programmed the system to report these pre-measured levels for each power setting. Later versions of the Echelon smart driver will include power measurement circuitry in order to provide real-time measurements as opposed to calibrated values, with anticipated accuracy of better than 2%.

Table V: Network Controls Performance Summary

Network Controls System Feature	Advantages	Drawbacks	Survey Ranking Most Satisfied 1 – 5 Least Satisfied
System Design and Compatibility	Power-line carrier designed to minimize hardware needs	Circuits not laid out favorably for PLC in pilot location, limited number of lights on each circuit, excessive network hardware required	4
System Installation	"Mounting, connecting [hardware] straightforward"	Required specially trained contractors to install	4
System Commissioning	"Contractor set up software and inventory…was fairly simple to connect with"	"Considerable time with contractor to make sure communication was working"	1 – 2
System Energy Benefits	Controls enabled 50% power and allow for adaptive dimming schedules. Dimming commands functioned properly in field	System components add some continuous un-metered load: 11.78 w / light for Pilot; 2.2 w / light for hypothetical larger scale deployments	1 – 2
Web-based System Interface	6 zone set-up helpful for grouping, managing. Pre-set dimming profiles available in system, operation "simple once you get the hang of it"	Problems creating new streetlight groups and schedules, "difficult …to schedule different wattages for specific lights, days"	2
Energy Metering	Reporting of avg. power and energy usage enabled for single streetlight or system-wide, based on pre-installation measurements	Not capable of real-time power monitoring, though future version should be	N / A
Outage Detection, Maintenance Planning	"Appeared to track outages and issues well, sent alerts to Echelon personnel for resolution"		1 - 3
Customer Support	"Any issues that came up were promptly addressed"		1

Economic Performance

Though still an emerging technology, LED streetlights are beginning to experience greater market adoption as costs decline and consumers become more familiar with the technology and more confident in performance and energy savings benefits. Recent announcements of LED street lighting plans by cities like Los Angeles (4,000 shipped, up to of 140,000 planned) and Pittsburg (proposal to replace 40,000+) demonstrate that LED streetlights are being taken seriously. Even so, this technology currently accounts for only a small fraction of the national installed base.

Networked streetlights are rarer; network control options represents a major shift from the traditional model of photocell controlled lights with no operator feedback. A few products are starting to make inroads in the U.S. street lighting market; the City of Glendale, AZ has just networked 18,500 streetlights with wireless RF controls, and Los Angeles has announced similar plans. European cities have demonstrated network controls as well, such as Oslo, Norway's deployment of over 15,000 power-line carrier linked "smart streetlights." Network controls provide operators various lighting and energy management benefits such as reduced runtimes and detection of outages and "day-burners," and controls with dimming capabilities like those tested in the pilot enable adaptive street lighting strategies to reduce lighting power as conditions change (i.e. periods of lower traffic or pedestrian volume).

In this evaluation, simple paybacks and net present values were calculated for LED luminaires with and without integrated network controls, based on estimated energy and maintenance savings compared to incumbent LPS and system costs for larger-scale installations than the pilot. Retrofit and new construction cases were both evaluated; retrofit economics consider the entire LED luminaire and controls cost and cost of installation, while new construction only includes the incremental cost of the LED luminaire and controls above the LPS luminaire and no labor cost since for new construction this would be roughly equivalent regardless of technology choice.

Economic estimates are sensitive to site-specific variables such as maintenance and energy costs, and to LED luminaire and network controls costs. The estimates below include a $50 incentive currently available in PG&E's service territory for this type of LED streetlight installation. Economic analyses without incentives are included later, though the impact on results is small. Results are also predicated on assumed maintenance savings from longer lasting LEDs and controls benefits; readers are advised to use cost estimates and equipment lifetime assumptions appropriate for location- and project-specific analyses. See the Streetlight and Network Controls Economic Performance section for more discussion.

Three economic scenarios were run for replacement of 55W LPS streetlights with the LEDs piloted in San Jose:

1. Non-networked LEDs at constant 50% power setting
2. Networked LEDs at constant 50% power setting (additional maintenance savings)
3. Hypothetical Adaptive Networked LEDs set at 50% power for half of each night and set at 25% power for half of each night (additional maintenance savings and highest energy savings)

Table VI: Summary New Construction and Retrofit Economics

Scenario	Annual Savings	New Construction			Retrofit		
		Initial Investment (after $50 incentive)	Simple Payback (Years)	15 Year NPV	Initial Investment (after $50 incentive)	Simple Payback (Years)	15 Year NPV
Non-networked LEDs, 50% Power	$46	$9	0.2	$613	$446	9.6	$176
Networked LEDs, 50% Power	$54	$128	2.4	$597	$565	10.4	$160
Hypothetical Adaptive Networked LEDs	$58	$128	2.2	$649	$565	9.8	$212

This study shows that energy savings potential from available LED streetlights and dimmable network controls is significant. LEDs alone can provide quality roadway lighting with proven energy-efficient performance. Controls that allow operators to adjust street lighting power to meet minimum performance criteria and even to adaptively alter light levels based on changing conditions offer even more energy savings potential. However, network controls systems are inherently more complex than traditional photocell controls. Evident in the pilot, current infrastructure layout can present challenges to the PLC communication strategy that need to be overcome for large-scale deployments.

In addition to lighting and energy performance, the cost / benefit case for networked LED streetlight projects will be a crucial consideration, subject to location specifics such as costs of equipment, labor, and maintenance and the longevity of the installed controls and luminaire components. The higher initial cost of LEDs and advanced controls is a challenge to market adoption but the energy and maintenance savings can provide real long term value.

The cost savings calculated in this study assume that a streetlight rate schedule is available to bill streetlights based on actual energy usage. Currently in PG&E territory and throughout most of the U.S., streetlights are not metered and are billed at flat monthly rates. For customers wishing to use network controls to institute adaptive dimming schedules or other energy saving options, cost savings will only be realized if new utility rate schedules are developed. Network controls products with metering functions will also need to be able to provide metered energy data in a useful format and at a level of accuracy acceptable to utilities for adaptive rate schedules to be feasible.

Incentive programs will increase LED streetlight adoption and are already available in some locations, such as PG&E service territory where the pilot was conducted. Incentive programs for LEDs and controls must continue to include performance standards for equipment to make sure that intended energy goals are achieved by the incented technologies while still meeting other key performance criteria (lighting quality, controls functionality and interoperability with local infrastructure, etc).

Project Background

Project Overview

This LED street lighting and network controls assessment project studied the viability of networked light-emitting diode (LED) luminaires as replacements for existing streetlights. Project partners included the City of San Jose, PG&E, and the California Lighting Technology Center (CLTC). Low pressure sodium (LPS) 55W nominal luminaires were replaced with new LED luminaires located in the Cassell residential neighborhood in San Jose, CA. The LED luminaires were evaluated for lighting and energy performance, and economic factors such as simple payback and net present value.[10] This project also included energy performance and functional testing of streetlight network controls. The assessment was conducted as part of the Emerging Technologies Program of PG&E. 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."[11]

Streetlight Technology and Market Overview

The most prevalent outdoor lighting technology today is high intensity discharge (HID), most commonly high pressure sodium (HPS), and less frequently mercury vapor and metal halide (MH). These sources account for over 80% of the estimated 58 TWh electricity used annually by outdoor stationary lighting and 31 TWh for roadway lighting specifically.[12] HPS is the most common source primarily because of its long rated life, low cost, and relatively high efficiency. An HPS drawback is low color rendition (typical CRI of 22) due to narrow spectral distribution.[13] LPS, a low intensity discharge source, makes up less than 10% of roadway lighting electricity usage, though in San Jose it is the predominant street lighting technology. LPS was selected by the City in the 1980s both because of its high efficacy (75 - 150 lamp lumens/W) and because the extremely narrow spectral distribution of the LPS source presents less interference than broader spectrum sources for research activities at the local Lick Astronomical Research Observatory located on Mt. Hamilton, east of San Jose. However, due its extremely narrow spectral distribution in the mid 500 nm range, LPS has a color rendering index (CRI) close to zero and a very low average correlated color temperature (CCT) of 1,700-1,800K.

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[10] Simple payback, in units of years, is defined as a project's initial cost divided by resulting annual savings. Net present value, or NPV, is the total current value of a project's future cash flows, discounted and/or escalated as appropriate, for *n* years (the term of the project or analysis), less the project's initial cost.

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

[12] Navigant Consulting, Inc. (2002). "US Lighting Market Characterization, Volume I." U.S. Lighting Market Characterization: National Lighting Inventory and Energy Consumption Estimate; prepared for Building Technologies Program of the Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Tables 5-7, 5-17, 5-20, and 8-7. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lmc_report_tables.pdf

[13] High-Intensity Discharge Lamps Analysis of Potential Energy Savings Docket #: EE-DET-03-001 USDOE Technical Support Document: Energy Efficiency Program For Commercial and Industrial Equipment. December 2004

Market penetration of LED street lighting is still relatively low, though the technology is continuing to attract attention for potential energy and maintenance savings and lighting performance benefits such as more uniform lighting distribution and enhanced nighttime visibility. The City of Los Angeles has announced large scale LED conversion plans, with 4,000 streetlights shipped, and up to 140,000 planned for retrofit.[14] The City estimates that LEDs will reduce street lighting energy consumption by 40% and save $10 million annually in combined maintenance and energy costs. Other locations leading the transition to LED street lighting include Pittsburg, Pennsylvania which has proposed replacing its streetlights (over 40,000) with LEDs for energy, environment, and economic benefits ($2.5 million annual savings estimated)[15] and Anchorage Alaska, which is installing 16,000 LED streetlights city-wide.

Municipal interest in LED streetlight conversions has grown to the point that the DOE in Fall 2009 announced the planned establishment of a Municipal Solid-State Street Lighting Consortium to "collect, analyze, and share technical information and experiences related to LED street lighting demonstrations" to leverage project results and information, particularly as American Reinvestment and Recovery Act of 2009 (ARRA) funding has become available to support efficient streetlight conversions.[16]

Recent PG&E Emerging Technologies studies have demonstrated significant LED luminaire cost reductions and energy savings for viable LED street lighting technologies of 50% to 70% over incumbent HPS technologies.[17] The US Department of Energy (DOE) has also been evaluating a variety of outdoor LED field demonstrations through its GATEWAY program and lab testing LED products through its CALiPER program.[18]

DEMONSTRATION STREETLIGHT INFORMATION

In the Cassell pilot demonstration location in San Jose, 118 55W nominal American Electric LPS luminaires (Roadway Series SRX, Phillips SOX Lamp 1SL) were replaced with BetaLED LEDway fully dimmable LED luminaires of 75W at full output (BLD-STR-T2-HT LEDway™ Streetlight – Type II) and dimmed to a 50% power setting as the default setting. Echelon network controls were integrated into the demonstration luminaires and network segment controllers, WiFi antennas, and an internet gateway to a web-based controls platform were installed and commissioned to allow for advanced control options such as remote scheduling, dimming and outage identification and energy

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14 See LEDs Magazine article *BetaLED streetlights included in Los Angeles retrofit program*. Sept 22, 2009 http://www.ledsmagazine.com/news/6/9/22

15 LEDs Magazine article Pittsburgh councilman releases plan to convert city street lights to LEDs. Dec. 17, 2008: http://www.ledsmagazine.com/news/5/12/12

16 See Program web page: http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_consortium.html

17 - Cook, et al. "PG&E Emerging Technologies Program Application Assessment Report #0726: LED Street Lighting, Phase III Continuation; Oakland, CA." November 2008.
- Cook, et al. "PG&E Emerging Technologies Program Application Assessment Report #0727: LED Street Lighting, San Francisco, CA." December 2008.
Available online through the Emerging Technologies Coordinating Council at http://www.etcc-ca.com and through the DOE at http://www.netl.doe.gov/ssl/techdemos.htm

18 DOE's GATEWAY Demonstration Programs support demonstrations of high-performance LED products to develop field data and experience for applications that save energy, are cost effective, and maintain or improve light levels. See http://www.netl.doe.gov/ssl/techdemos.htm.
DOE's Commercially Available LED Product Evaluation and Reporting (CALiPER) program supports testing of a wide array of SSL products available for general illumination. DOE allows its test results to be distributed in the public interest for noncommercial, educational purposes only. See http://www.netl.doe.gov/ssl/comm_testing.htm.

usage reporting. This assessment of the San Jose pilot results is only meant to characterize performance of the specific LED luminaire model and network controls technology evaluated under the demonstration conditions. Performance may be different in future generations of these products.

The table below provides luminaire-level performance metrics. LED luminaire results were provided by the CLTC. LPS results are based on luminaire and lamp performance as reported in manufacturer product cut sheets and .ies files.

Table VII: Luminaire Performance Summary

Luminaire	Luminaire Power[19]	Initial Lumens (luminaire)	Luminaire Efficacy (lm/W)	CCT (K)
LPS (based on .ies and cut-sheet info)	*80.0*	*5,171*	*64.6*	*1,800*
LED (100% power setting)	75.0	3,793	50.6	6,497
LED (75% power setting)	60.3	3,280	54.4	6,413
LED (50% power setting)	36.2	2,186	60.4	6,235

Note that though the reported LPS luminaire efficacy is 64.6 lumens / W, at the power measured in the field for the LPS luminaire (92.45W), the LPS luminaire efficacy would actually be 55.9 lumens / W. Also of note, the LPS .ies file included 33.7% "trapped light" from the 7,800 lumen lamp source in the luminaire.

The LPS luminaire manufacturer provides a six-year warranty (excluding lamp) according to product literature. The LPS lamp life is reported at 18,000 hours, or 4.4 years at 4,100 run hours per year. This is consistent with the San Jose's estimate of 5 years between 55W LPS lamp replacements. The LED luminaire manufacturer provides a five-year warranty for the LED luminaire. The manufacturer reports an LED chip lifetime of 70,000 to 170,000 hours depending on drive current and ambient temperature, or 17 to 40 years at 4,100 hours per year. The manufacturer provides a five-year warranty for the luminaire. Importantly, as an LED luminaire consists of multiple components (LEDs, driver, housing, coating, etc.), the expected useful life of the luminaire may not be the same as that of the LEDs, and standard methods to test and predict LED streetlight lifetimes are still in development.[20].

Network Controls Technology and Market Overview

Use of streetlight network controls is a major shift from the traditional controls approach of photocell-switched lights with no operator feedback. A networked system provides city-wide

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[19] LED luminaire power includes luminaire-level "Smart Driver" network control component. See Table XV: Measured Power Data for more information.

[20] IESNA's LM- 80-08 *Measuring Lumen Maintenance of LED Light Sources* is a standard for the measurement of LED chips, and does not provide guidance or make any recommendations regarding predictive estimations or extrapolation for lumen maintenance beyond that determined from actual measurement (6,000 hrs). IESNA's TM-21 is being developed to set a standard method for forecasting LED chip depreciation to L70 lifetimes based on heat management, drive currents, etc., but this may still not address total luminaire life.

management and monitoring of streetlight assets from a remote location. Network controls, especially those that include streetlight dimming, can also provide adaptive street lighting options for enhanced energy benefits, such as reducing lighting power as conditions change (i.e. lower traffic or pedestrian volume), along with benefits such as reduced runtimes and detection of outages and "day-burners" – malfunctioning luminaires that operate during daylight conditions.

Like LED streetlights, networked streetlights represent a very small fraction of the installed inventory, though a few products are making their way into the U.S. market at the pilot to mid-scale level. From April to December of 2008, the City of Glendale, AZ deployed a network for 18,500 of its streetlights using photocell-adapted ROAM (Remote Operations Asset Management) wireless RF transceivers. The system records and monitors individual streetlight activity and has helped achieve system-wide maintenance benefits for the City.[21] The City of Los Angeles has also previously demonstrated wireless network controls benefits for its street lighting system, deploying several 1,000 networked streetlights several years ago as part of a system trail for GE StreetSmarts,[22] now Tyco Lumawise. In conjunction with its current roll out of LED streetlights, the City is planning on installing network controls on all new street lights to allow the LA Bureau of Street Lighting to monitor system performance in real time, verifying LED energy savings and optimizing maintenance.[23] European cities have experimented with streetlight networking as well. Oslo, Norway began installation in 2006 of a system of 15,000 "smart streetlights" with Echelon power-line carrier controls, the same technology as demonstrated in San Jose.[24] Oslo has achieved 62% energy savings on retrofitted lights; two thirds due to changing over to electronic ballasts and the balance due to using the controls to reduce lamp burn hours.

DEMONSTRATION NETWORK CONTROLS SYSTEM INFORMATION

San Jose's motivation for piloting LED streetlights and network controls has been highlighted in recent Fortune and Wall Street Journal articles. [25] "The city hopes to cut down on energy use, and, hopefully, lower its utility costs, by tapping LED lighting's greater flexibility…[and will be] testing a concept called "adaptive lighting," in which streets can be made brighter, darker or even be illuminated with flashing strobes upon command."

The network controls vendor chosen for the 118 streetlight San Jose pilot was Echelon Corporation (Echelon), a $134 million public company that is a global supplier of control networking hardware and software. Echelon is headquartered in San Jose, California and offers two main product lines: the NES System for advanced metering infrastructure, and LonWorks infrastructure products for control networking. Echelon's streetlight network controls system is part of the LonWorks family of products.

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[21] LD+A, the magazine of the IESNA, Jan. 2009. Michael Sills-Trauch. http://www.roamservices.net/pdf/LDA_Article_ROAM_Glendale.pdf).

[22] www.geconsumerproducts.com/pressroom/press_releases/lighting/commercial_lighting/streetsmarts.htm

[23] City of Los Angeles Led Street Lighting Case Study. CCI, Feb, 2009. http://www.mwcog.org/environment/streetlights/downloads/CCI%20Case%20Study%20Los%20Angeles%20LED%20Retrofit.pdf

[24] Oslo Street Lighting System Slashes Energy Use with LonWorks® Technology: http://www.echelon.com/solutions/unique/appstories/Oslo.htm

[25] *The Old Streetlamp of the Past Gets Updated for the Green Future.* April 22, 2009. http://online.wsj.com/article/SB124035903357241327.html
San Jose street lights get smarter. April 24, 2009. .http://money.cnn.com/2009/04/24/technology/street_lights_echelon.fortune/

Echelon's streetlight networking technology uses power-line carrier (PLC) signaling to communicate between streetlight drivers equipped with LonWorks nodes installed inside the fixture and Echelon's i.LON SmartServers, or segment controllers. The system relies on existing power lines, which is intended to lower up-front costs associated with the system by lowering hardware and installation costs. PLC communication is accomplished using transceivers that send signals along the power line using the ANSI 709.2 standard (LonWorks, ISO/IEC 14908-3). LonWorks is an open, extensible architecture that allows control devices from multiple manufacturers to communicate with each other.[26] For projects using Echelon's street lighting technology, a third-party company, Streetlight.vision has been the most commonly used software provider. The Streelight.Vision M2M Data Collect software is used to collect, aggregate, transform, filter and store data from all controllers in a central, open database that is installed at an IT center in Paris.[27] The first large-scale implementation of Echelon's LonWorks technology for street lighting management was in the City of Oslo, Norway.[28] The project was implemented by Hafslund ASA, Norway's largest generator and supplier of electric power and security products. Benefits from the installation included reduced lamp downtime due to outage detection and significant energy savings from the ballast conversions and reduced lamp burn hour control strategies.

The Echelon network controls system installed for the San Jose pilot demonstration consists of "smart driver" controls integrated into each of the 118 dimmable LED luminaires and 57 i.LON SmartServer segment controllers that network the individual streetlights via PLC communication. The segment controllers are also equipped with Wifi antennas (802.11G wireless local area network protocol) to communicate to a system gateway. The gateway in San Jose includes three metro-class Tropos WiFi nodes, one of which is bridged to a DSL connection in the neighborhood's community center. The DSL connection ties the network to the internet, which provides San Jose Department of Transportation (San Jose DOT) operators access to the system through the third-party Streetlight.vision web interface and management tool. While Streetlight.vision acts in a supervisory role to collect system-wide data and provide real-time control for service purposes, the Echelon segment controllers perform scheduling and data logging functions on-board, and can operate independently.

Key system features for the San Jose pilot include:

- On/off scheduling based on virtual astronomical time-clock; no photocells required
- 50% power setting as default with other dimming options available
- Individual streetlight and system-wide average power and energy logging and reporting (based on assigned calibrated wattages; real-time monitoring circuitry not included in pilot version)
- Outage detection and maintenance tracking
- Adaptive dimming schedules available to increase energy savings in lower conflict zones or times
- Logging and scheduling functions are carried out on-board by segment controller hardware so that in the event of loss of network connectivity, streetlights continue to operate normally until communication is restored

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[26] http://www.echelon.com/solutions/unique/appstories/oslo.pdf

[27] Streetlight.vision is an independent "Streetlight Monitoring" and "City Monitoring" software solution provider, and is headquartered in Paris, France. http://www.streetlight-vision.com/content/solutions.htm

[28] Oslo Street Lighting System Slashes Energy Use with LonWorks® Technology: http://www.echelon.com/solutions/unique/appstories/Oslo.htm

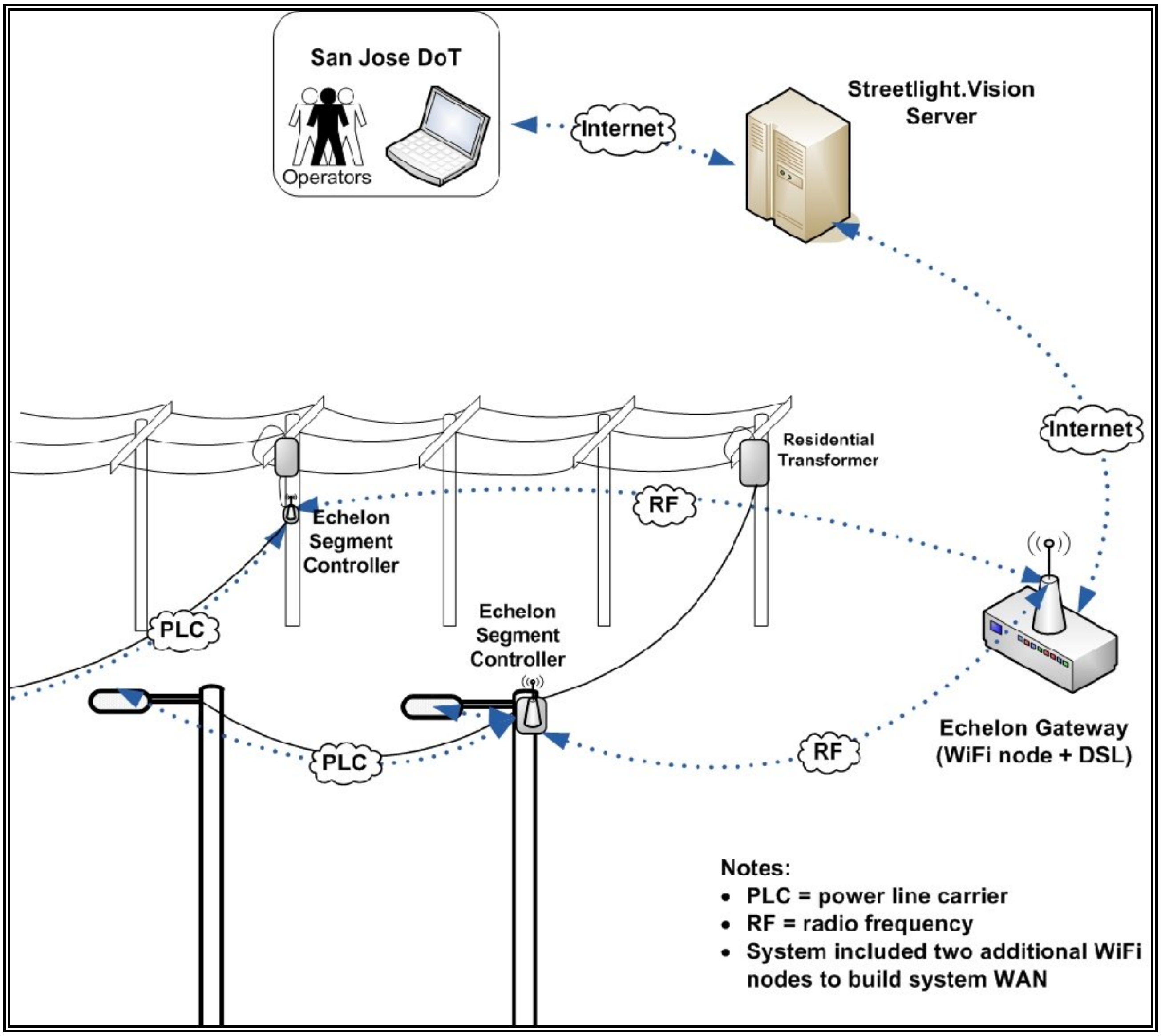

Figure 1: Basic System Architecture Diagram for Cassell Echelon Pilot

Project Objectives

The objectives of this study were to examine energy, lighting, and economic performance of dimmable, networked LED luminaires as compared to incumbent LPS Type II full cutoff luminaires. In addition, the project included functional testing of the piloted streetlight network controls technology. 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 (photopic, scotopic, and calculated mesopic), uniformity metrics, and by qualitative indicators such as before and after photographs. Correlated color temperature (in Kelvin) was also measured for both light sources. Economic performance was evaluated through simple payback and net present value analyses for substitution of LPS street lights with networked and non-networked LED luminaires in new installation and retrofit scenarios. Resident surveys are also being administered by the City in the pilot neighborhood to collect feedback on the new street lighting system.

Methodology

Host site information

The demonstration LED luminaires were installed in the Cassell residential neighborhood of San Jose, CA. The LED pilot area was bounded by Leeward, Adrian, Amador, and Vistaglen streets. For the test area where lighting and power measurements were taken, new LPS Type II full cutoff luminaires were installed before replacement with LED luminaires to establish a consistent baseline. Photometric measurements were taken over a test area grid laid out under three consecutive streetlights (one "cycle") on alternating sides of the street.

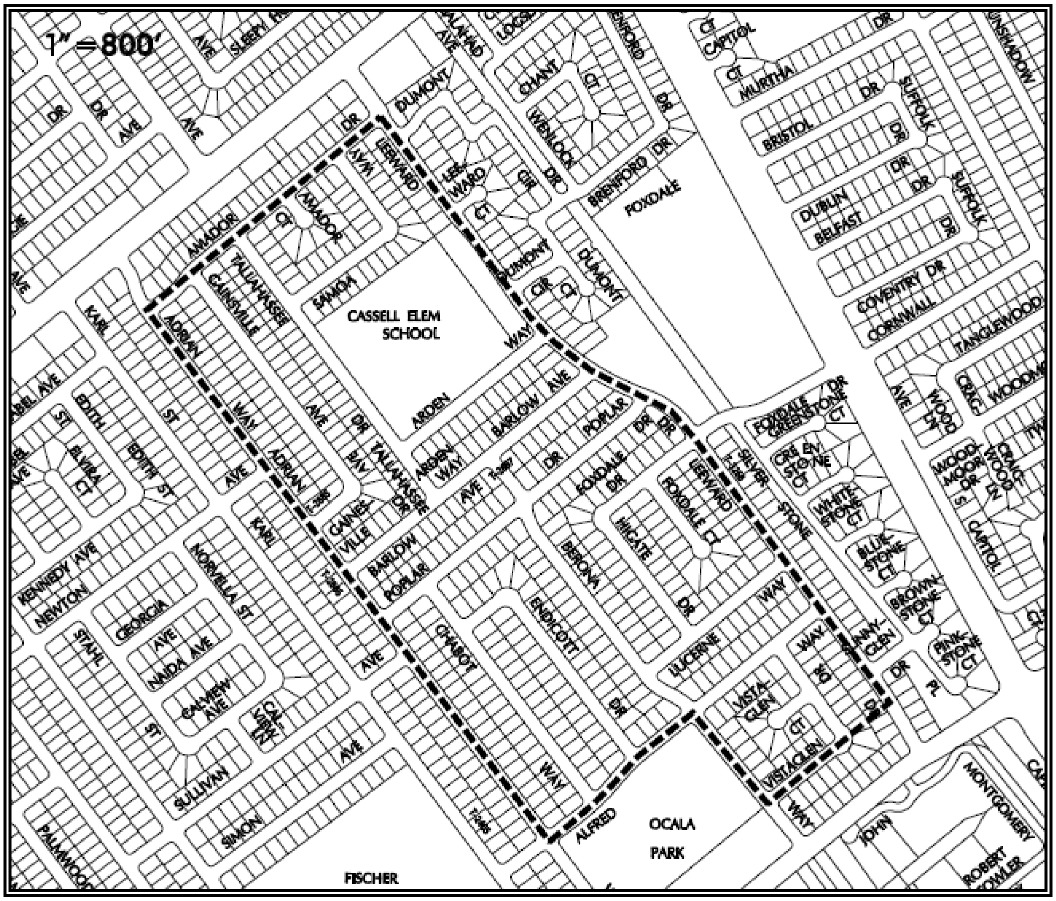

Figure 2: Demonstration Area Neighborhood

Figure 3: Aerial View of Test Area Location on Adrian Way

Streetlight Performance Monitoring Plan

The Streetlight Performance Monitoring Plan consisted primarily of illuminance measurements and time series power measurements. The measurements taken included: photopic illuminance, scotopic illuminance, correlated color temperature, RMS watts, amps, volts, and power factor. Estimated annual energy usage from the lighting systems was also calculated based on PG&E rate schedules and the estimated load from a single luminaire (network segment controllers and gateways are assumed to be un-metered load).

The streets in the demonstration area were 36' in width with one parking lane and one traffic lane in either direction. 104 measurement points were laid out on a 4.5' x 15' grid covering both traffic lanes in the test area. Measurements could not be taken in parking lanes due to the presence of vehicles. The monitoring grid followed as closely as possible IESNA guidance for photometric measurements of street lighting systems.[29] Both photopic and scotopic illuminance measurements were taken at a height of 18" above ground, after civil twilight, and when ambient light from the moon was at a minimum.

[29] See LM – 50 – 99; IESNA Guide for Photometric Measurement of Roadway Lighting Installations.

Measurements in the test area were taken under the LPS luminaires with new lamps and under the new LED luminaires (at 100%, 75%, and 50% power settings). Measurement points were located in the following arrangement:

- 4 points transverse to the street lanes (east-west) at 4.5' spacing, with two points per traffic lane beginning ½ point spacing (2.25') in from edge of traffic lane.
- 15' longitudinal (north-south) spacing between transverse points, beginning ½ point spacing (7.5') in from the first luminaire in the monitored cycle, and ending ½ point spacing before the last luminaire in the monitoring zone.

Correlated color temperature measurements were taken directly under test fixtures for both LPS and LEDs in the test area. Since instrument limitations did not allow on-board correlated color temperature calculations under the LPS luminaires, chromaticity coordinates were measured and later converted to correlated color temperature based on published equations.[30] The method for obtaining correlated color temperature values was identical for both LPS and LED luminaires.

Power measurements were 5 minute averaged recordings logged over several days, using a Dent ElitePro Datalogger. Time-series plots of luminaire power are included in Appendix A: Monitoring Data. Measurements included RMS watts, amps, volts, and power factor and were taken on one luminaire in the test area.

Field work activities required several visits to the sites. Monitoring equipment for power measurements was installed during the LPS lamp change out and was removed after power monitoring on the LED luminaire was complete.

FIELD VISITS

The first field visit took place the week of May 11, 2009 to verify demonstration site dimensions and establish the existing conditions of test location. The next visits were carried out to measure and record photopic and scotopic illuminance levels and chromaticity coordinates and to take photographs to provide qualitative indication of lighting performance. All light measurements were taken after civil twilight.

- June 19: LPS streetlights in their "As Restored" condition. Prior to this visit, five new LPS lamps were seasoned by 100+ hours of burn-in at a maintenance facility. These lamps were installed in the existing LPS fixtures and adjacent luminaires on either side of the monitoring area. While the lenses and reflectors in the existing LPS fixtures were cleaned, there was likely still some light loss from using existing, aged fixtures and lenses.
- July 22: New, dimmable BetaLED LEDway streetlights controlled by Echelon network controls. The plan allows for 100+ hours of burn-in time for the LED luminaires before monitoring. LED illuminance measurements were taken at three power settings (100%, 75%, and 50%), which were issued by San Jose DoT staff in the field during the visit.

Monitoring equipment used in the execution of the Monitoring Plan is detailed below:

ILLUMINANCE METER

Solar Light SnP Meter PMA 220

[30] McCamy, Calvin S. (April 1992). "Correlated color temperature as an explicit function of chromaticity coordinates". Color Research & Application 17 (2): 142–144.

Correlated Color Temperature Meter
Konica Minolta Chroma Meter

Power Meter
Dent ElitePro Datalogger

Digital Camera
Nikon D80

Laboratory Assessment

In addition to in-situ testing, this study included laboratory testing of the same LED luminaire type installed in San Jose, outfitted with Echelon network controls for dimming. Lab testing was performed by the CLTC and included measurement of electrical and lighting performance through a range of dimmed settings, from 10% to 100% in 10% increments and including 25% and 75%. Lab measurements included:

- True power and power factor of luminaire with respect to controls dimming setting
- Delivered photopic lumens with respect to controls dimming setting
- CRI and CCT of luminaire with respect to controls dimming setting
- Controls package signal voltage to dimmable LED driver with respect to controls dimming setting
- Off-State power demand of smart LED driver

Resident Survey

The City of San Jose is in the process of administering a survey throughout the pilot neighborhood to gather feedback from residents on the new street lighting system. Readers interested in resident survey results are advised to contact the City for more information.

Network Controls Test Plan

The test plan for the network controls system was developed to address all of the major functions of the controls technology, which is designed to provide smart control and monitoring of streetlight assets to improve management of operations and information, enhance maintenance planning, increase response time to faults, report system data such as energy usage, and provide energy-savings opportunities.

Most results from the test activities are qualitative in nature, including feedback from system users based on experience with system installation and operation, and observations during on site functional testing with San Jose DOT system operators. This involved testing functions such as on/off and dimming commands, pulling reports on energy data and streetlight outages, and setting up luminaire groups and schedules. Logged energy data from the controls system was pulled for comparison with the data logger installed in the field for streetlight energy analysis. The four categories of test information and activities are described below:

Technology Overview and Equipment Description

Information describing system design, components, and setup was collected from manufacturer contacts, product literature, and project managers and engineers. Information reviewed in this step included vendor specifications for component performance characteristics such as precision, durability, energy usage (reported, tested, or measured in-field), etc.

User Surveys and Interviews

A user-group survey document was prepared to collect user feedback on the control technology's advantages and drawbacks. Survey questions included both satisfaction scales and qualitative comment feedbacks. Surveys were submitted to primary host contacts. Additional feedback from communications with host personnel is also incorporated into test results.

Functional Testing and Web Interface Demonstration

The monitoring team collaborated with City of San Jose DOT personnel to test functionality of network controls system through dispatch of commands from the user interface to controlled lights and live observations and measurements at the monitoring area. Test engineers previewed the user interface with system operator and observed actions such input of scheduling commands, data queries, report production, streetlight mapping, etc. Actual controls commands were issued and system response was observed in conjunction with LED luminaire testing (dimming in the field to take illuminance measurements at lower light levels). Logged power data was compared with data recorded by the network system.

System Economics

System cost estimates were based on a larger scale order (1,000 to 10,000+ streetlights), with cost information provided by the manufacturer. These initial costs, along with estimated ongoing energy and maintenance savings, were considered in order to calculate system payback and present value for hypothetical large deployments.

Project Results and Discussion

Streetlight Performance

ILLUMINANCE

METRICS

Illuminance metrics were calculated for photopic and scotopic illuminance data, which was recorded for the baseline LPS luminaires and for the LEDs at 100% (full), 75% and at 50% power settings. For the wider pole spacing (210'), neither the LPS nor the LED output was sufficient to illuminate all points in the test area to a level detectable by the photometer (0.05 fc or greater, with a display resolution of .1 fc). The numbers of measurement points with light levels above that threshold, as a percentage of the total numbers of measurement points, are shown below as 'Grid Points Illuminated.' This, combined with the average illumination, provides some indication of the amount of light provided by the luminaires.

Average illuminance levels were calculated based on all measurement points in the traffic lanes, as described in the Methodology section, and rounded to the nearest hundredth fc. The uniformity of the light provided by the luminaires was compared using three metrics: coefficient of variation (CV), average-to-minimum uniformity ratio (AMU), and maximum-to-minimum uniformity ratio (MMU).

CV, also known as relative standard deviation, is a measure of the disparity between the actual values of all measured points and the average of those values. It is calculated as the standard deviation of the distribution, divided by the average illuminance. It is useful because it provides an indication of the uniformity of all points across the test entire area. A lower CV is indicative of a more uniform distribution.

AMU provides an indication of how low the minimum measured level is compared to the average of all measured values. It is calculated by dividing the average of all measured values by the single lowest value measured. MMU provides indication of the largest disparity in illuminance level between any two points in the area of interest – the minimum measured value compared to the maximum measured value. It is calculated by dividing the single highest of all measured values by the single lowest level measured. When there were points in the measurement area of undetectable illuminance, neither AMU of MMU could be calculated, as it would require dividing by zero. In this case, AMU and MMU can be calculated **for the illuminated area only** if the lowest detected level within the "Grid Points Illuminated" is used as the minimum. This gives an indication of uniformity within the illuminated space.

Though computer modeling cannot account for all the variables of actual streetlight installations, computer simulations provide illuminance values at a finer scale than measured in the field. The model returned values above zero for every point in the simulated illuminance grid (all spacings and lighting scenarios). This removed the problem of calculating AMU and MMU ratios when points of zero detected illuminance were measured, so uniformity ratios from the model results represent a better comparative metric for uniformity over the test area.

MEASUREMENT POINTS

Photopic and scotopic illuminance measurements were taken over a 390' x 15' area covering both traffic lanes between 3 streetlights at spacings of 180' and 210' as described in the Monitoring Plan. As can be expected in any field test, there was slight variation in the test area for parameters such as orientation of the luminaire arms, ambient light from surrounding houses, etc. Every attempt was made to minimize impacts of field variables on data collection, and modeled results provide a useful point of comparison for a controlled simulation environment.

Consolidated illuminance values based on field measurements for the LPS and LED luminaires are shown below, followed by surface plots generated to provide further qualitative understanding.

MEASURED LPS AND LED PERFORMANCE

Table VIII: Photopic Illuminance

Luminaire	Spacing	Grid Points Illuminated[I]	Average Illuminance (fc)	Coefficient of Variation	Average-to-Minimum Uniformity[II] (Illuminated Points Only)	Maximum-to-Minimum Uniformity[II] (Illuminated Points Only)
LPS	**180'**	100.00%	0.24	0.51	2.40	6.00
LED (100% Power)		100.00%	0.33	0.74	3.31	10.00
LED (75% Power)		95.83%	0.27	0.68	*2.69*	*7.00*
LED (50% Power)		95.83%	0.19	0.59	*1.85*	*5.00*
LPS	**210'**	98.21%	0.20	0.52	*1.93*	*5.00*
LED (100% Power)		82.14%	0.26	0.93	*2.63*	*9.00*
LED (75% Power)		87.50%	0.23	0.81	*2.27*	*7.00*
LED (50% Power)		69.64%	0.13	0.95	*1.34*	*5.00*
LPS	**Entire Area**	99.03%	0.21	0.53	*2.15*	*6.00*
LED (100% Power)		90.38%	0.29	0.83	*2.94*	*10.00*
LED (75% Power)		91.35%	0.25	0.75	*2.46*	*7.00*
LED (50% Power)		81.73%	0.16	0.77	*1.58*	*5.00*

I. Grid Points Illuminated refers to all points within measurement grid that were illuminated to within the meter's lowest detection level (.05 fc or greater, with a display resolution of .1 fc)
II. Ratios in italics are calculated for Grid Points Illuminated only, because test area minima were zero, so full grid ratios could not be calculated

The LEDs at 50% provided slightly less average illuminance than the LPS and noticeably more at 75% and 100% power settings. Coverage in terms of grid points illuminated decreased significantly from the LED 100% power setting to 50%. The field data uniformity ratios for the LPS and LEDs cannot be adequately compared, because for most spacings neither light source illuminated all grid points. In the one instance where they both did (the 180' spacing, LEDs at 100%), the LPS show slightly better uniformity. For uniformity of illuminated points, the LED streetlights provided slightly less uniformity in terms of CV and equivalent or better performance in terms of uniformity ratios. Because of the limitations of the field data sets, in that illuminance was lower for some points than could be measured with the detector and uniformity ratios could not therefore be calculated, the uniformity metrics from modeled results are a better means of evaluation.

San Jose's adopted standard for roadway lighting levels is IESNA's 1964 Standard Practice for Roadway Lighting[31] which calls for a minimum average illuminance level of 0.2 fc for local residential areas and average-to-minimum uniformity of 6:1 or better.[32] Both the LPS and LEDs at all power settings (rounded to the tenths place) meet the minimum residential average and uniformity criteria from the 1964 standard. Under IESNA's more current Standard Practice for Roadway Lighting (RP-8-00)[33] the pilot location would likely be classified as a low conflict local roadway in which case the guidelines call for a minimum average photopic illuminance of 0.4 (at pavement class R2) and the same average-to-minimum uniformity as the 1964 standard. According to the field data, the incumbent lighting system would not meet the current standard for average illuminance for the wider spacing, nor would the LED retrofit, though both would meet the standard for uniformity.

It is again important to emphasize that these standards do not differentiate in any way mesopic or scotopic performance or spectral power distribution and color diversity for different light sources. Qualitative evaluation of the pilot photographs later in this section does clearly demonstrate the difference in lighting characteristics between the LPS and the LEDs, but any enhanced visibility from a broad spectrum source like LED is not taken into account in current recommended practices that consider only photopic illuminance.

The following table highlights the difference in scotopic performance of the two sources, with the LEDs showing considerably higher average scotopic illuminance than the LPS baseline. Again, the uniformity ratios are of limited use in cases where the grid points illuminated is less than 100%. The difference in scotopic illuminance levels becomes important later when mesopic levels are calculated.

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[31] Journal of the Illuminating Engineering Society of North America. Vol. LIX, Feb. 1964. Page 73

[32] If the test area were classified as an intermediate local roadway however (the definitions are somewhat vague), the standard increases to 0.6 fc.

[33] American National Standard Practice for Roadway Lighting. ANSI / IESNA RP-8-00, Approved 6/27/2000 Reaffirmed 2005. (Table 2: Recommended Values). Page 8

Table IX: Scotopic Illuminance

Luminaire	Spacing	Grid Points Illuminated[I]	Average Illuminance (All Measured Points, fc)	Coefficient of Variation	Average-to-Minimum Uniformity[II] (Illuminated Points Only)	Maximum-to-Minimum Uniformity[II] (Illuminated Points Only)
LPS	**180'**	78.72%	0.10	0.65	*0.96*	*2.00*
LED (100% Power)		100.00%	0.72	0.72	7.19	22.00
LED (75% Power)		100.00%	0.59	0.68	5.92	16.00
LED (50% Power)		100.00%	0.33	0.63	3.25	10.00
LPS	**210'**	62.50%	0.08	0.89	*0.75*	*2.00*
LED (100% Power)		100.00%	0.58	0.88	5.79	21.00
LED (75% Power)		98.21%	0.51	0.77	*5.11*	*16.00*
LED (50% Power)		69.64%	0.22	1.01	*2.20*	*9.00*
LPS	**Entire Area**	69.90%	0.08	0.77	*0.84*	*2.00*
LED (100% Power)		100.00%	0.64	0.80	6.43	22.00
LED (75% Power)		99.04%	0.55	0.73	*5.48*	*16.00*
LED (50% Power)		83.65%	0.27	0.82	*2.68*	*10.00*

I. Grid Points Illuminated refers to all points within measurement grid that were illuminated to within the meter's lowest detection level (.05 fc or greater, with a display resolution of .1 fc)

II. Ratios in italics are calculated for Grid Points Illuminated only, because test area minima were zero, so full grid ratios could not be calculated

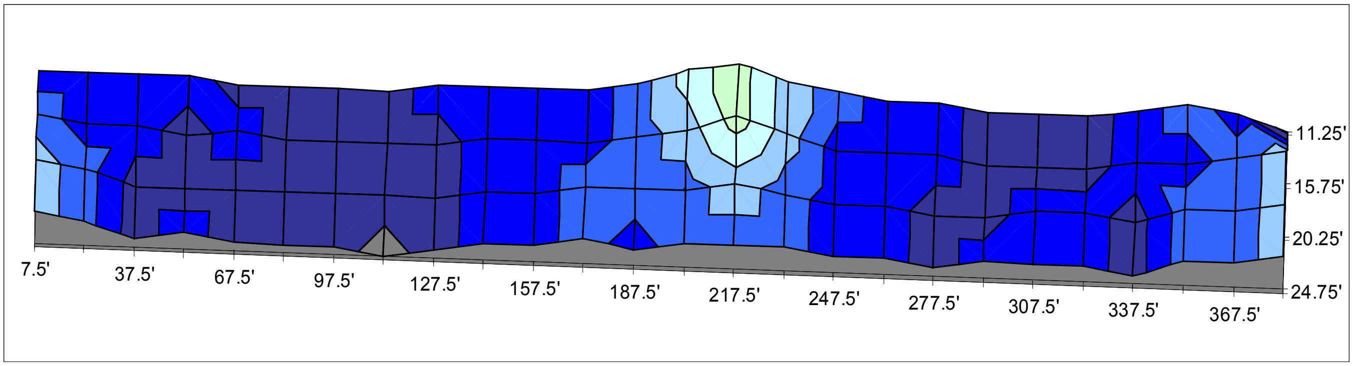


Figure 4: LPS Photopic Surface Plot

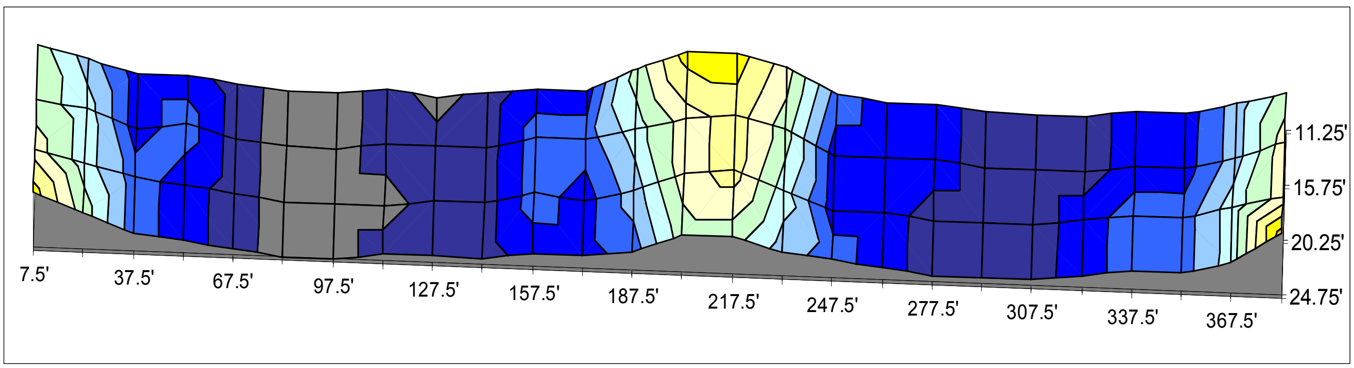


Figure 5: LED 100% Power Photopic Surface Plot

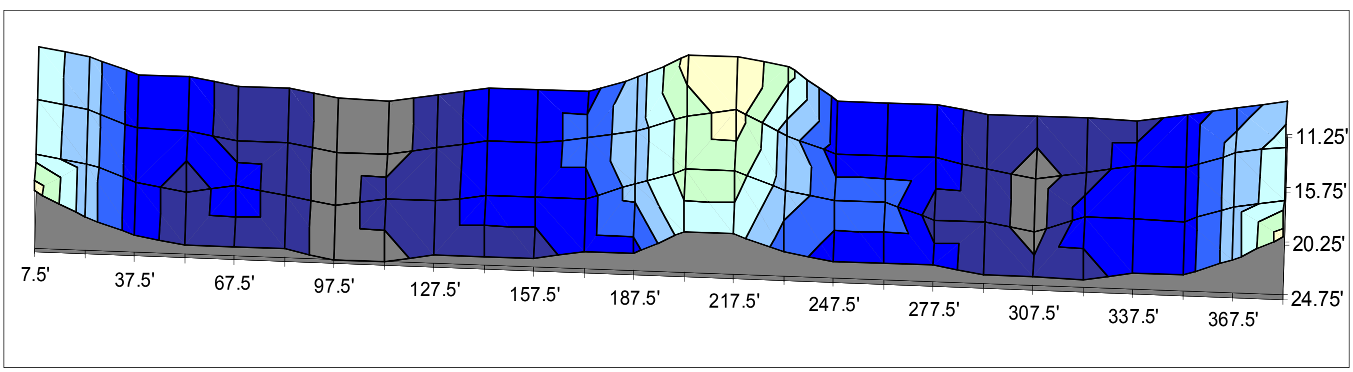


Figure 6: LED 75% Power Photopic Surface Plot

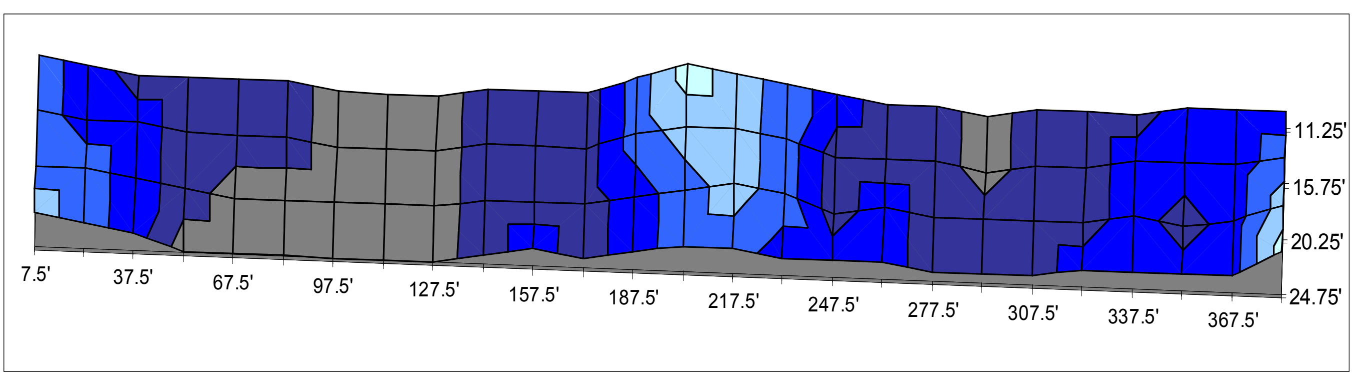


Figure 7: LED 50% Power Photopic Surface Plot

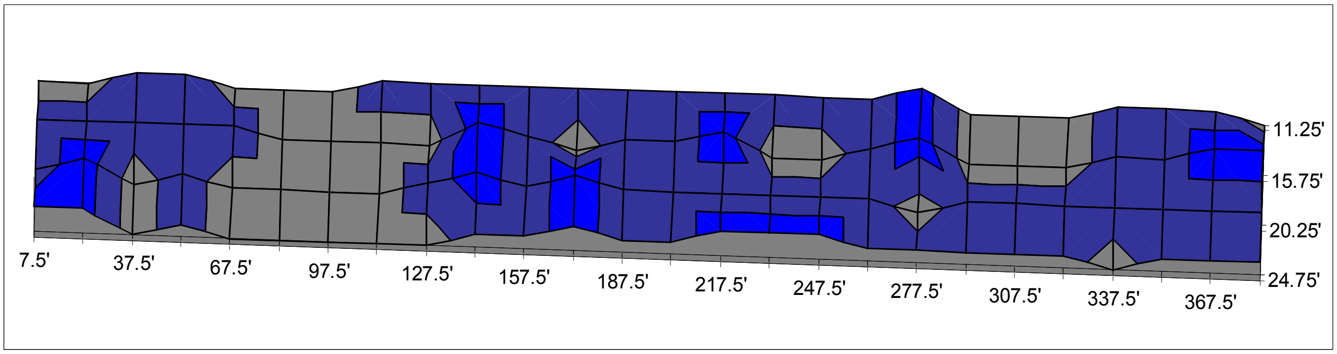
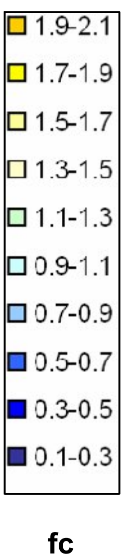


Figure 8: LPS Scotopic Surface Plot



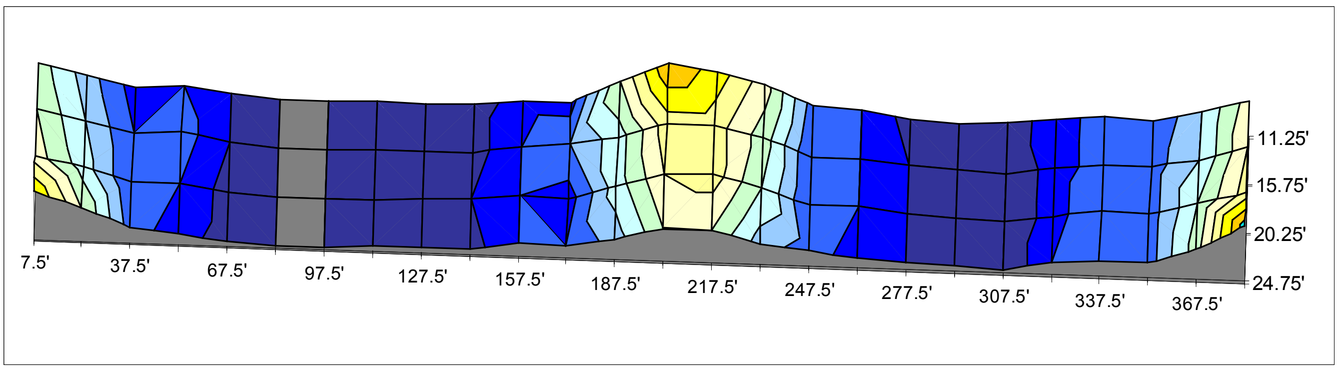


Figure 9: LED 100% Power Scotopic Surface Plot

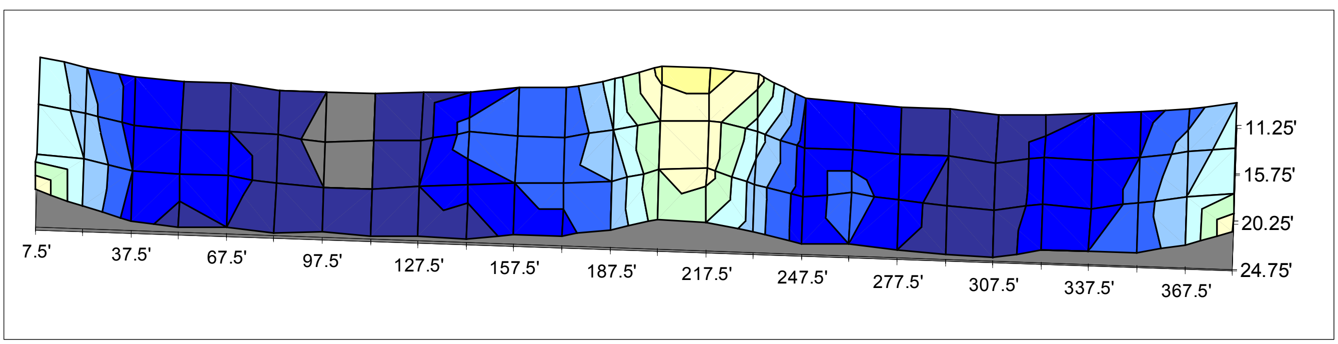


Figure 10: LED 75% Power Scotopic Surface Plot

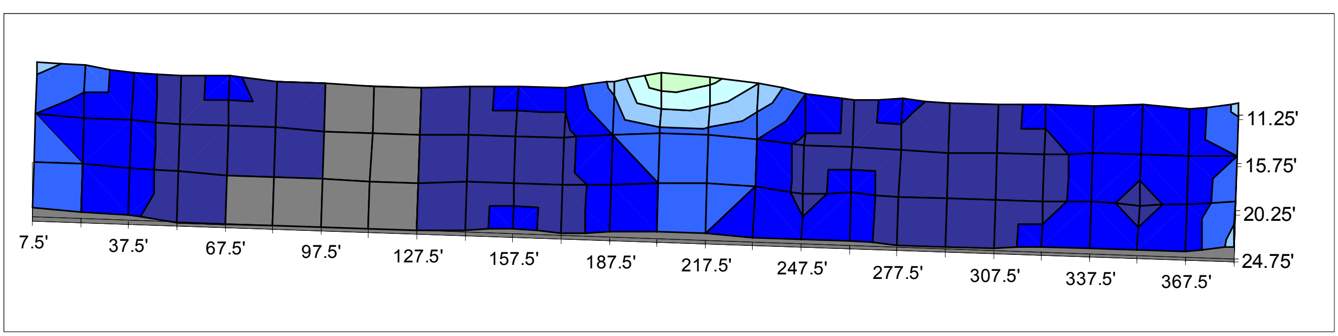


Figure 11: LED 50% Power Scotopic Surface Plot

MODELED ILLUMINANCE PERFORMANCE

In addition to field measurements, computer simulations were run to model photopic illuminance for a theoretical street of similar dimensions to the demonstration area street. This modeling provides useful data for comparison that eliminates field measurement variables. Additionally, greater precision can be achieved using computer simulations than is possible for data gathered in the field.

Modeling was done using the manufacturer .ies files for a hypothetical 390' long street with luminaire spacings of 180' and 210' (luminaires at 0', 180', and 390', with buffer luminaires of the same type on either side, 200' distant from the test cycle). The width of the modeled street was 36', and the modeling resolution was 4.5' X 15' in the same grid layout over traffic lanes as described for field measurements. Computer model results were compared to field data and found to be in close agreement. Total lumen output for the modeled LED luminaires was based on results from CLTC lab testing of lumen output at the 100% and dimmed settings. Note that the model scenarios were for initial performance, while in the field the LPS measurements were taken under used luminaires with new lamps, so more fixture losses would be expected in the field due to aged lenses and reflectors.

Metrics for the modeled data were calculated identically to those for the measured data with the exception of the uniformity ratios. Since the modeled illuminance values were not subject to the same minimum illuminance limitations as the measured data, the uniformity ratios in the modeled results were calculated using all grid points. Uniformity ratios and CV from the computer model should be taken as a better comparative metric for performance than the field results, which could not be effectively calculated for most scenarios due to points of zero measurable illuminance (see previous discussion). Consolidated illuminance values for all luminaires are shown below, followed by surface plots generated to provide further qualitative understanding.

Modeled results again show that the LPS luminaires and the LED luminaires at 100%, 75%, and 50% power settings meet San Jose's residential average illuminance standard, though the LPS initial performance as modeled does not meet the average-to-minimum uniformity requirement of 6:1 or better. Modeled initial average photopic illuminance for the LPS is .06 fc higher than the average illuminance for the LED streetlights at 50% power but lower than the averages for the LEDs at 75% and 100%. The modeled results also show greater uniformity for the LEDs than the LPS by all metrics (CV and uniformity ratios). Averaged over the entire grid area, the LEDs meet the current IESNA RP-8-00 recommended average-to-minimum uniformity ratio, while the LPS do not.

Table X: Modeled Initial Photopic Illuminance

Luminaire	Spacing	Grid Points Illuminated[I]	Average Illuminance (fc)	Coefficient of Variation	Average-to-Minimum Uniformity	Maximum-to-Minimum Uniformity
LPS	**180’**	100%	0.27	0.67	5.49	13.40
LED (100% Power)		100%	0.35	0.52	2.33	4.60
LED (75% Power)		100%	0.30	0.52	2.30	4.54
LED (50% Power)		100%	0.20	0.52	2.23	4.33
LPS	**210’**	100%	0.24	0.82	7.87	22.00
LED (100% Power)		100%	0.30	0.67	4.27	9.86
LED (75% Power)		100%	0.26	0.67	4.28	9.83
LED (50% Power)		100%	0.17	0.66	4.33	9.75
LPS	**Entire Area**	100%	0.25	0.75	8.46	22.33
LED (100% Power)		100%	0.32	0.60	4.60	9.86
LED (75% Power)		100%	0.28	0.60	4.60	9.83
LED (50% Power)		100%	0.19	0.59	4.64	9.75

I. Refers to points within simulated measurement grid. The model calculates to a finer resolution than was measurable in the field with the actual detector (.05 fc or greater, with a display resolution of .1 fc) and illuminance levels above zero were calculated for 100% of grid points in all instances.

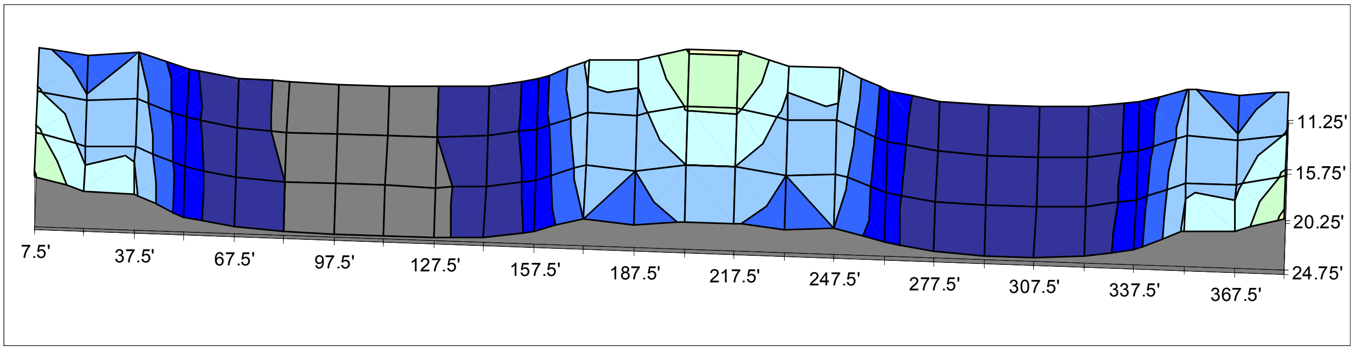
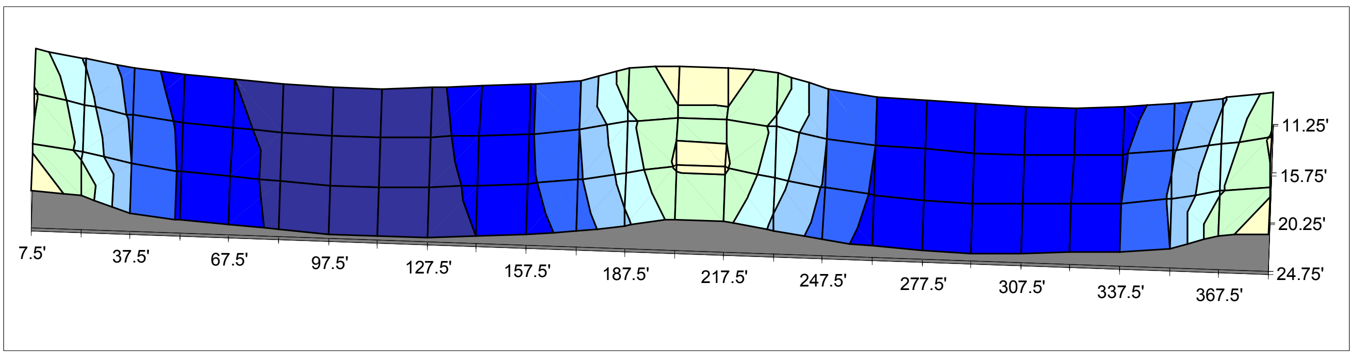


Figure 12: LPS Photopic Surface Plot, Computer Model



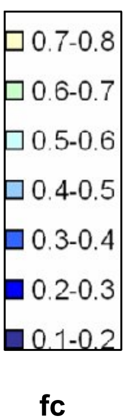


Figure 13: LED 100% Power Photopic Surface Plot, Computer Model

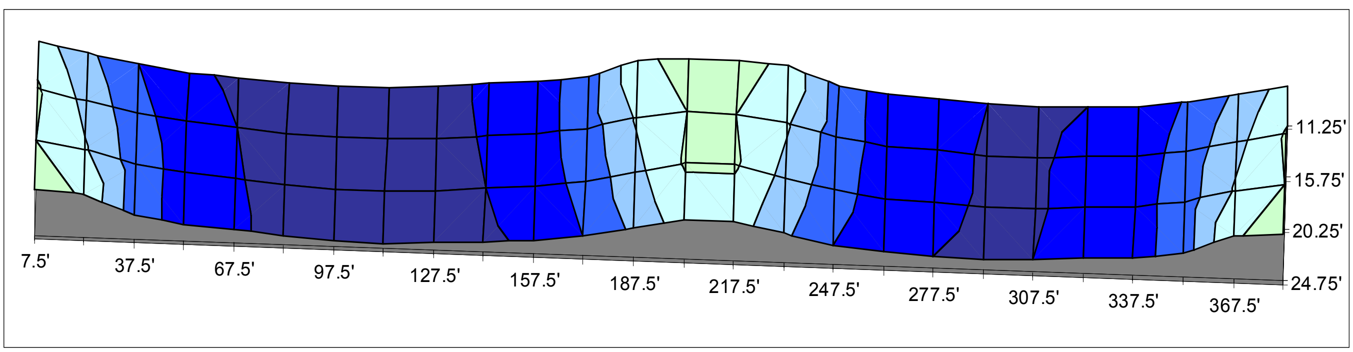


Figure 14: LED 75% Power Photopic Surface Plot, Computer Model

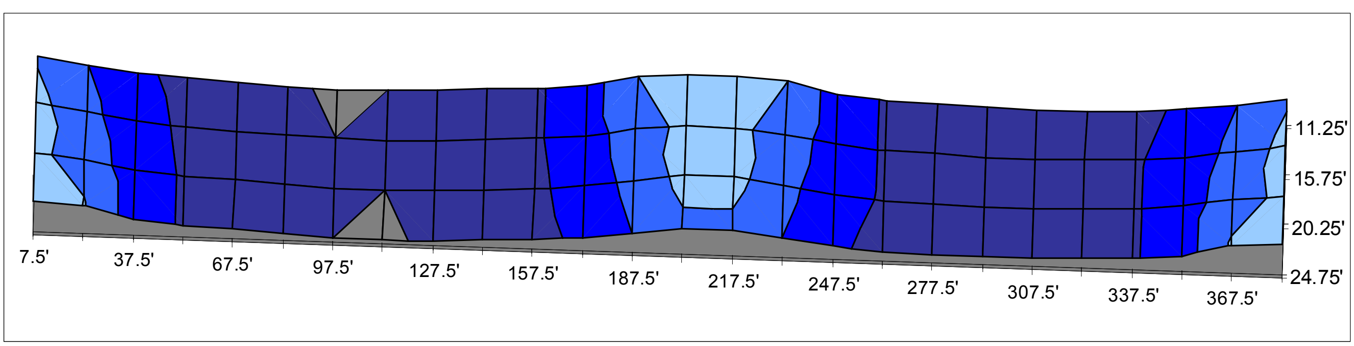


Figure 15: LED 50% Power Photopic Surface Plot, Computer Model

MESOPIC ILLUMINANCE DISCUSSION

Commercial photometry traditionally measures light levels based on the photopic luminous efficiency function (Vλ). This is a well established response function that weights the visual effectiveness of wavelengths in the electromagnetic spectrum according to the human eye's response in levels of adaption over 3 cd/m^2 (e.g., daylight conditions), which are dominated by the eye's cone photoreceptors. However, under the lowest light conditions (adaption less than 0.001 cd/m^2), when the eye's rods are the active photoreceptors, human perception of light follows a different response curve; the scotopic luminous efficiency function (V' λ). At intermediate levels between daylight and darkness (ambient photopic luminance in the 0.001 to 3 cd/m^2 range) typical of nighttime roadway lighting levels, rods and cones both provide levels of spectral sensitivity, with rods' importance diminishing and cones' increasing as light levels increase. In these intermediate levels, the photopic response curve and the scotopic response curve are both important. This is known as the mesopic range.

Light sources differ in their spectral power distribution, which influences their effectiveness at different light levels. Light sources considered "white" (e.g., metal halide, LED, induction) emit energy broadly across the visible spectrum. These broad spectrum sources appear white and excite multiple photoreceptors (e.g., short, medium, and long-wavelength cones and rods depending on the adaptation state). In contrast, narrow spectrum sources (e.g., HPS, LPS, and color-specific LEDs) do not appear white and may only excite a specific type of photoreceptor. Narrow spectrum sources may provide little or no energy at wavelengths sensed by the rods or short or medium-wavelength cones. Visual performance and apparent brightness at mesopic light levels can therefore be enhanced by light sources emitting light in the low to mid section of the visible light spectrum. Mesopic lighting is the subject of ongoing research, and the proper methods for including photopic and scotopic illumination in outdoor lighting analyses are under debate in the lighting community. Both the IESNA and CIE have formed technical committees to define and investigate mesopic performance, underscoring its increasing importance in the lighting discussion.[34] The IESNA has published a technical memorandum on the subject, TM-12-06, Spectral Effects of Lighting on Visual Performance at Mesopic Light Levels. This technical memorandum is currently undergoing revision to provide more specific recommendations for incorporating lamp spectral distribution effects under mesopic conditions into street lighting design.

As traditional photometry relies only on photopic performance and does not account for the scotopic or mesopic characteristics of a light source, and due to the importance of scotopic and mesopic vision for roadway lighting levels, methods for calculating mesopic light levels were used in this study's analyses to more accurately represent nighttime performance. Over the past several years, several models have been developed, and three were used here to compare performance of the LPS and LED streetlights.

Mesopic Optimization of Visual Efficiency (MOVE) Model: The MOVE model is a performance-based model developed for the European Community by the Lighting Laboratory of Helsinki University of Technology.[35] The model is based on 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.

[34] CIE Technical Committee 1-58: "Visual Performance in the Mesopic Range"
http://www.lightinglab.fi/CIETC1-58/index.html#
IESNA Mesopic Technical / Research Committee:
http://www.ies.org/about/committees/committees_view_action.cfm?committeeid=306

[35] Mesopic Optimisation for Visual Efficacy. Performance Based Model for Mesopic Photometry. Helsinki University of Technology Lighting Laboratory. Report 35. Espoo, Finland. 2005

The photopic and scotopic illuminance data from this study were converted into luminance, assuming that the roadway surface had a reflectance value of 0.07 and lambertian reflectance. 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 based on the MOVE equations discussed in Appendix B: Mesopic Illuminance Calculations. Mesopic luminance values were then converted to mesopic illuminance values by the same formula.

Unified System of Photometry: The Lighting Research Center at Rennselaer Polytechnic Institute recently published an article on outdoor lighting visual efficacy through its ASSIST program (Alliance for Solid-State Illumination Systems and Technologies) that describes the unified system of photometry proposed by Rea et al in 2004.[36]

> "The unified system of photometry integrates both the scotopic and photopic luminous efficiency functions into a complete system that can be used across the entire range of light levels available to the human visual system. The system differentially weighs the scotopic and photopic luminous efficiency functions depending upon light level.[37]

The Lighting Research Center article published Rea's closed-form expression for combining photopic and scotopic luminance levels to calculate unified luminance. This approach, which is also detailed in Appendix B, was used with the field data and the unified luminance values were converted to illuminance values for comparison.

Lumen Effectiveness Multipliers (LEMs): LEMs are another approach for quantifying the effectiveness of white light sources under low light conditions. They are light source – specific multipliers designed to be used with photopic luminance levels to calculate "effective" light levels produced by various light sources in night conditions. In 2001, Lewin proposed LEMs for four light sources[38] (HPS, LPS, Mercury, Metal Halide) based on previous studies of apparent brightness and visual performance in the mesopic range (Adrian, 1998;[39] He et al, 1998;[40] and Rea, 1999[41]). More recently Lewin has developed multipliers for four additional light sources (warm and cool-white LEDs, warm and cool-white Induction). LEMs trend toward higher values as the spectral distribution of the light source shifts to blue/green wavelengths and as luminance levels decrease. The LEMs used here for LPS and cool-white LEDs (CCT of 5,500K) are based on those reported

[36] A proposed unified system of photometry. MS Rea PhD, FIES FSLL LC, JD Bullough MS, JP Freyssinier-Nova ,MS LC MSLL, and A Bierman MS. Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, USA. Lighting Research and Technology. 362 (2004) pp. 85-111

[37] Outdoor Lighting: Visual Efficacy. ASSIST Recommends… Vol 6, Issue 2. Jan. 2009. Lighting Research Center.

[38] Lewin, Ian. "Lumen Effectiveness Multipliers for Outdoor Lighting Design." Journal of the Illuminating Engineering Society, JIES, Summer 2001. Illuminating Engineering Society of North America, New York, NY.

[39] Adrian, Werner. "The Influence of Spectral Power Distribution for Equal Visual Performance in Roadway Lighting Levels." Proceedings: Vision at Low Light Levels. EPRI/LRO Fourth International Lighting Research Symposium. TR-110738. Lighting Research Office of the Electrical Producers' Research Institute, Palo Alto, California. 1999

[40] He, Junjian; Bierman, Andrew; Rea, Mark. "A System of Mesopic Photometry." International Journal of Lighting Research and Technology. Vol. 30, no. 4. Chartered Institution of Building Services Engineers, London, UK. 1998

[41] Rea, Mark. "A Unified System of Photometry for Lighting Applications." Proceedings of the CIE Symposium: 75 years of CIE Photometry, Budapest, 1999

by Lewin for brightness matching mesopic data developed by Adrian. While the LED luminaires in this study did not have precisely the same spectral distribution as those used to determine these LEMs, they can be assumed to be close enough to still be informative.

Table XI: LEMs for Evaluated Light Sources and Photopic Luminance Ranges

Photopic Luminance Level (cd/sq.m.)	.001	.01	.10	1.00
Cool White LED (5,500K CCT) LEM	2.75	2.57	2.09	1.47
LPS LEM	0.47	0.51	0.61	0.82

The following table and plot of results from the various models show variation in the way the different methods weight the mesopic advantages of the LED light source, but in each case average mesopic illuminance is lower for the LPS luminaires and higher for the LED luminaires compared with measured photopic levels. In fact, for all models, the mesopic illuminance levels for the LEDs are equal to or greater than the measured photopic illuminance levels for the LPS. The uniformity as measured by CV shows little change for the LEDs or LPS with the exception of the unified luminance method, for which LPS CV increased somewhat (lower uniformity).

Table XII: Comparison of Mesopic Illuminance Values

Luminaire Type		Average Illuminance (footcandles)	Coefficient of Variation
LPS	Measured Photopic Values	0.21	0.53
LED (50% Power)		0.16	0.77
LPS	MOVE Mesopic Values	0.15	0.58
LED (50% Power)		0.21	0.84
LPS	Unified Luminance Method Values	0.10	0.78
LED (50% Power)		0.24	0.75
LPS	LEM Values	0.14	0.59
LED (50% Power)		0.33	0.72

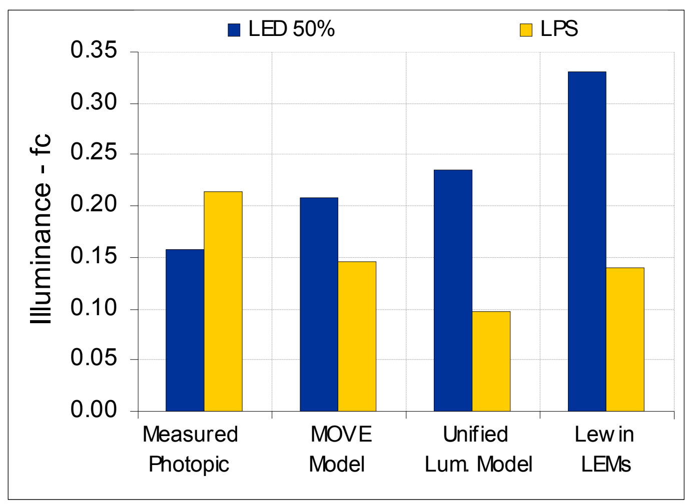


Figure 16: Mesopic Illuminance Plot

For more information on mesopic illuminance calculations and values, please see Appendix B: Mesopic Illuminance Calculations.

COLOR TEMPERATURE

CCT parameters were measured using a Konica Minolta Chromameter under three LPS Type II full-cutoff luminaires in the test area and under three LED luminaires. CCT was calculated from measured tristimulus coordinates. The average CCTs for the LPS and LED luminaires are provided below; all recorded values are given in Appendix A: Monitoring Data.

Table XIII: Average Measured Correlated Color Temperature

Luminaire	CCT (K)
LPS	1,697
LED (100% Power)	6,497
LED (75% Power)	6,384
LED (50% Power)	6,106

ILLUMINANCE AND CCT REDUCTIONS RELATIVE TO LED POWER

The effects of LED dimming on measured power (LED luminaire power minus controls power), average illuminance, and color temperature are presented in Table XIV.

Table XIV: Changes in Illuminance and CCT at Dimmed LED Power Settings

Control System Power Setting for LED Streetlight	Average Power	Average Photopic Illuminance	Average Scotopic Illuminance	Change in CCT
100%	100.0%	100.0%	100.0%	-
75%	80.1%	83.7%	85.2%	-113K
50%	47.4%	53.6%	41.7%	-391K

It is evident from these results that the controls-programmed power levels do not reflect actual LED luminaire power levels (as a percent of full power) with complete accuracy. The reason for the 3-5% discrepancy is not clear. Recall that the pilot controls system is not capable of real-time power metering; if the system were able to read luminaire power in real time it would likely be able to adjust dimmed power to reflect the intended setting. Reductions in light output also do not follow reductions in power demand in a linear fashion, nor is the relationship between power level and photopic and scotopic performance the same. As LED power decreases there is a greater reduction in scotopic performance and a small but measurable reduction in CCT.

PHOTOGRAPHIC COMPARISONS

To provide further qualitative indication of lighting performance, various ground level and overhead photographs were taken of the LPS luminaires and the LED luminaires at 100%, 75%, and 50% power. These photographs were taken with a Nikon D80 digital camera, with identical settings under LPS and LED luminaires.

Ground Level Camera Settings
Flash: No
Focal Length: 18 mm
F-Number: F/8
Exposure Time: 8 sec.
White Balance: Automatic

Overhead Camera Settings
Flash: No
Focal Length: 18 mm
F-Number: F/5.6
Exposure Time: 5 sec.

White Balance: Automatic

Figure 17: Overhead Shot, LPS

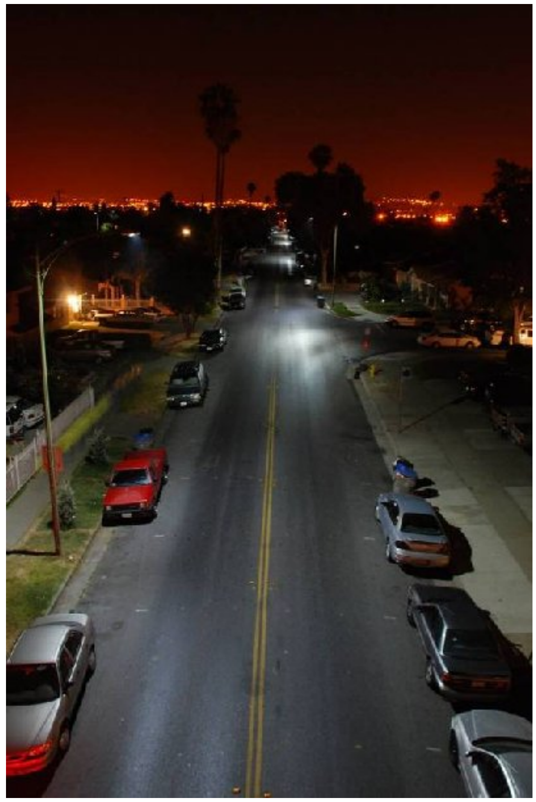


Figure 19: Overhead Shot, LED 75%

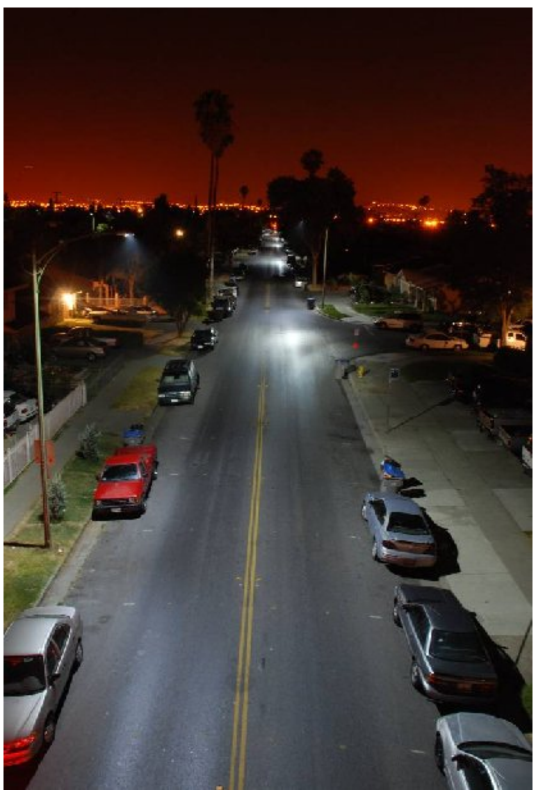


Figure 18: Overhead Shot, LED 100%

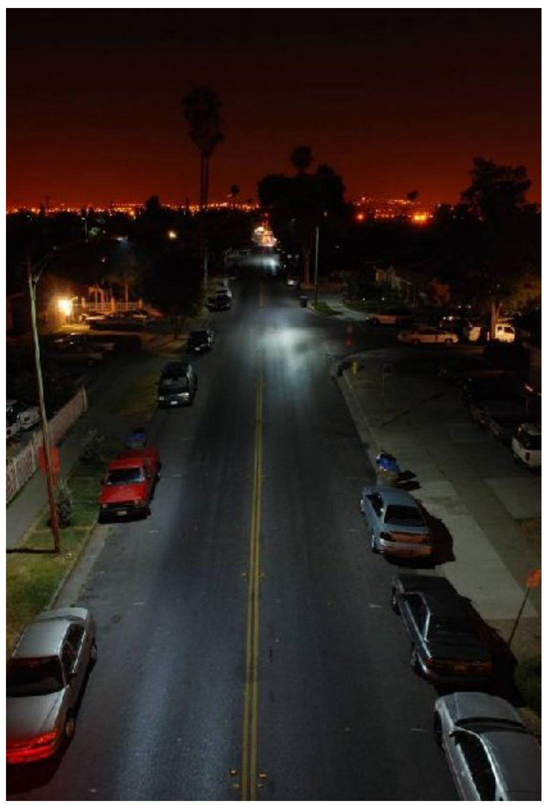


Figure 20: Overhead Shot, LED 50%

Figure 21: Street Level Shot, LPS

Figure 22: Street Level Shot, LED 100%

Figure 23: Street Level Shot, LED 75%

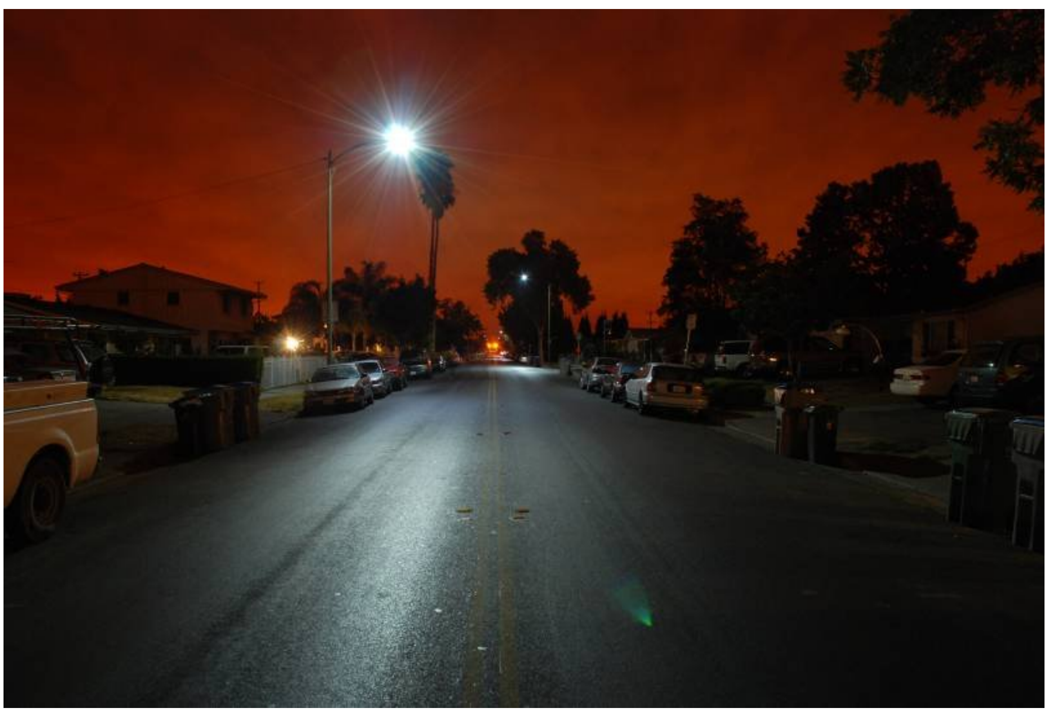


Figure 24: Street Level Shot, LED 50%

ENERGY PERFORMANCE

Power data for the baseline LPS luminaires and the LED luminaires were recorded in the field for one of each streetlight type using a DENT ElitePro weather proof data logger. The measurements were taken for a period of two weeks or more each. For the LED power readings in the field, the monitored circuit included one LED luminaire with Echelon smart driver and an Echelon smart segment controller. The LED luminaire was set to 100% and 75% for a shorter period of time for monitoring purposes and was otherwise set to 50%. The monitoring team relied upon San Jose DOT personnel to install and remove the power meter.

LED luminaire power was also measured under lab conditions by the CLTC, using the Echelon controls package to set luminaire power level to 100%, 75%, and 50%. The lab readings did not include a segment controller. The Echelon system recorded and reported calibrated power data at these settings and Echelon provided average controls power information as well.

Table XV: Measured Power Data

<table>
<tr><th>Luminaire Type</th><th>Field Measured Power (W)</th><th>Echelon Reported Power (W)</th><th>CLTC Measured Power (W)</th></tr>
<tr><td>LPS</td><td>92.5</td><td>n/a</td><td>n/a</td></tr>
<tr><td>LED 100% Power Setting
(Not Including Controls)</td><td>75.6</td><td>76.0</td><td>73.7</td></tr>
<tr><td>LED 75% Power Setting
(Not Including Controls)</td><td>52.4</td><td>59.9</td><td>59.0</td></tr>
<tr><td>LED 50% Power Setting
(Not Including Controls)</td><td>31.1</td><td>35.8</td><td>34.9</td></tr>
<tr><td>Smart Driver</td><td rowspan="2">9.7</td><td>0.9</td><td>1.3</td></tr>
<tr><td>Segment Controller</td><td>10.0</td><td>n/a</td></tr>
<tr><td>System gateway + Antennas</td><td>n/a</td><td>41.3</td><td>n/a</td></tr>
</table>

While the average LED power draw at 100% is similar for each data set, average power from field data at the 75% and 50% settings is several watts lower than the CLTC and Echelon-reported values and several watts lower than values corresponding to 75% and 50% of full measured power. The field data does confirm that the monitored luminaire dimmed according to system commands, but since field measurements also included variable controls power that had to be subtracted from total power to estimate luminaire power, the lab data may be more representative of actual dimmed luminaire power levels. Variations in each dimming driver's response to controls signals and conditions such as ambient temperature may also explain differences in power readings. Conservatively, the CLTC power data at each LED setting is used for further energy savings analysis. Note that, with on-board power monitoring circuitry in each luminaire, reporting actual power draw per streetlight or for an entire system of streetlights would be possible.

The base case LPS luminaire drew an average of 92.5 watts per luminaire over the monitored period. The estimated annual energy consumption for this load, assuming 4,100 hours of operation, is 379 kWh. Average power for the LED luminaire only (not including controls), according to lab readings was 73.7W at 100% power setting, 59.0W at 75% power setting, and 34.9W at 50% power setting. The LED luminaire alone at 50% power setting represents a savings of 62% versus the base case LPS luminaire. System wide savings should consider the load added by the controls components; the Network Controls Performance section evaluates controls load for the pilot scenario and for hypothetical larger scale deployments.

Table XVI: Potential Demand and Energy Savings for LED (excluding controls load)

Luminaire Type	**Power** (W)	**Power Savings** (W)	**% Power Savings**	**Estimated Annual Energy** (kWh/yr)	**Estimated Annual Savings** (kWh/yr)
LPS	92.5	-	0%	379	-
LED 100% Power Setting (Not Including Controls)	73.7	18.8	20.3%	302	77
LED 75% Power Setting (Not Including Controls)	59.0	33.5	36.2%	242	137
LED 50% Power Setting (Not Including Controls)	34.9	57.6	62.3%	143	236

Network Controls Performance

FUNCTIONAL TESTING AND WEB INTERFACE DEMONSTRATION

Through street lighting field work and visits to San Jose DOT, the network controls system design, operation and many of its functions were observed. System operators demonstrated the web interface used to manage network streetlights on August 26, 2009. The 118 streetlight system in Cassell was set up in the Streetlight.vision web interface as a six-zone system. Each zone is independently controllable, and schedulable.

- Hillview NE
- Hillview CE
- Hillview SE
- Hillview NW
- Hillview CW
- Hillview SW

The screenshot below shows the layout of the Hillview NW pilot zone. The chip icons represent the 11 segment controllers in the zone, while the grey and yellow buttons represent the 18 luminaires controlled by the segment controllers. The system user can click on any of the icons on the zone map for detailed information and manual command options, such as on/off or dimming. The six page menu on the left allows the user to select the zone of interest.

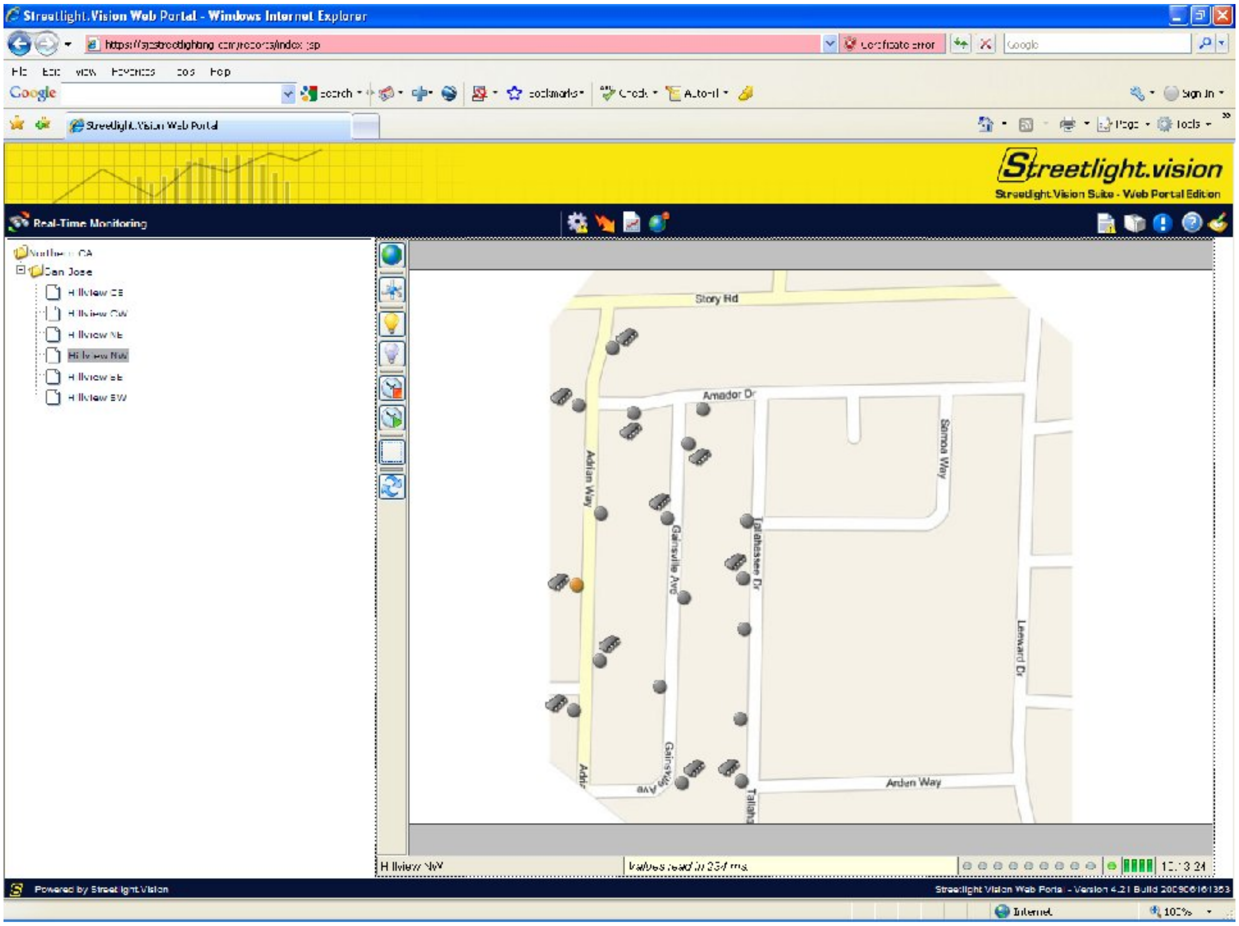


Figure 25: Streetlight.vision Zone Map for Hillview NW Pilot

ON / OFF AND DIMMING CONTROLS:

The controls system schedules on and off commands by virtual astronomical time clock logic in the segment controllers and through Streetlight.vision; in fact, there are no photocells on the luminaires in the pilot. If a networked streetlight loses communication with the segment controller for over 15 minutes, it defaults to on. If a segment controller or the system gateway loses IP connectivity, streetlight schedules are maintained by a battery-backed clock on board the segment controller until IP connectivity is restored.

The luminaires are continuously dimmable with the Echelon smart controller and dimmable driver integrated into each luminaire. The system dashboard offers power setting options of 100%, 75%, 50%, and 25%, rather than giving the user an entire dimming range, though the range of dimming options is customizable based on users' wishes. Real-time observations of dimming commands and luminaire response were made in the field on the night of July 22 when photometric field work required that the demonstration area luminaires be dimmed for measurements. The system operator brought a wireless-enabled laptop to the field and dimmed five streetlights on command. There was some lag in the time between dimming commands and actual dimming (under one minute), and the operator had to command each luminaire individually, rather than dimming the entire group at once. Otherwise, the dimming exercise successfully demonstrated this system capability.

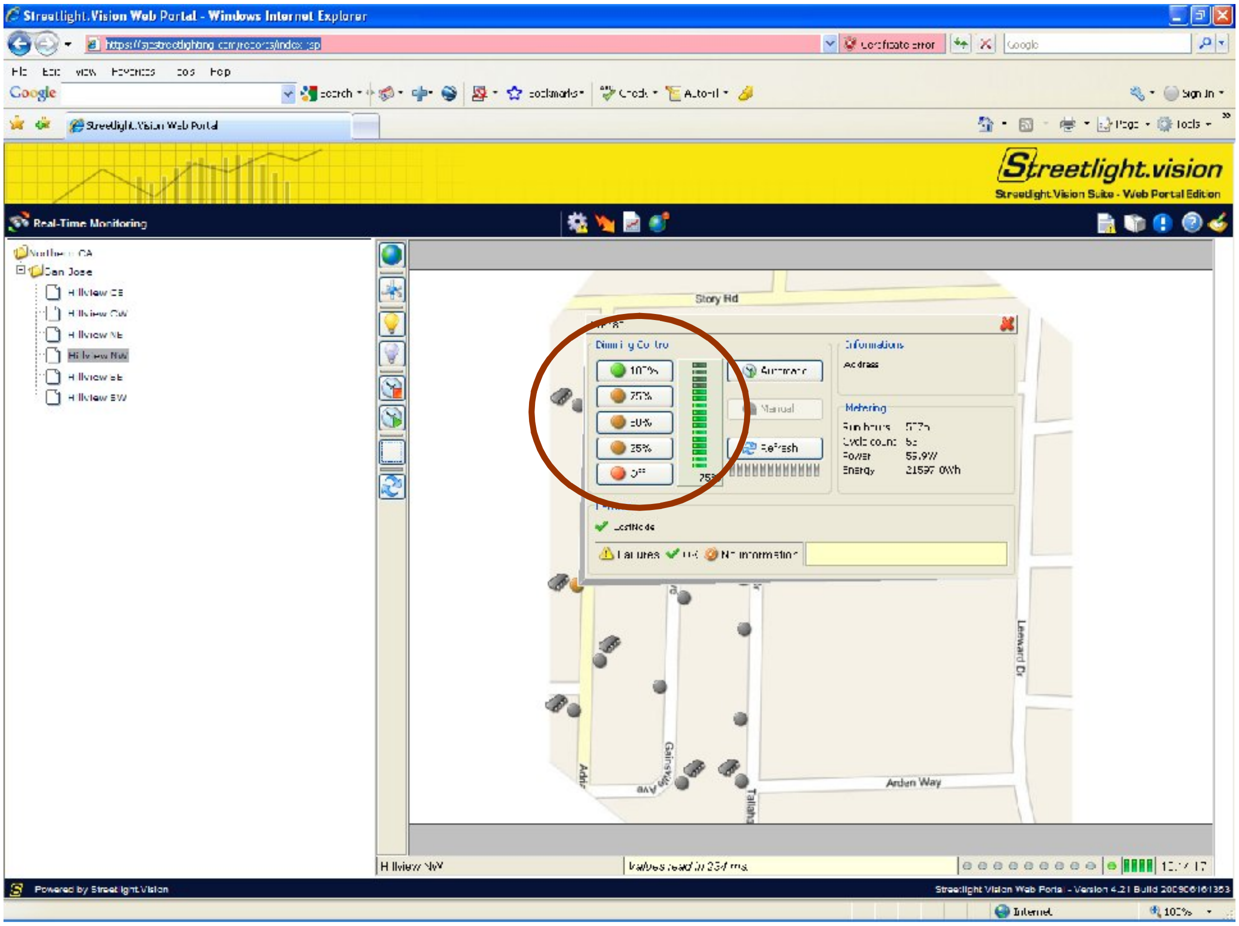


Figure 26: Streetlight.vision Dimming Controls Interface

Outages, Maintenance Work Orders and Tracking System

The system interface had many functions for identifying and tracking luminaire outages, and reporting these to operators through text or email messages. Maintenance alarms are sent to Echelon support when they are triggered. For example, the system will report issues such as a loss of communication to a luminaire to Echelon support, which then troubleshoots and resolves the issue.

Power Measurement, Data collection and reporting

For luminaire runtime and on/off reporting, lamp-burn hours and calculated cumulative energy consumption are recorded in the system for each luminaire. The system allows queries of power demand for individual luminaires, and data tables and graphs can also be generated. System-wide power and energy reporting was also available. Unfortunately the system does not appear to allow for export of data, such as in .csv format, which would be helpful for data analysis and sharing. A data export feature could be customized for the system and would need to be developed to share energy metering data for adaptive rate schedule purposes.

For luminaire power reporting, it is clear from the data tables and graphs that the power values reported by the system are assumed wattages and not real-time measurements, as the values are identical in each instance. For this pilot, the smart controller and LED driver combination did not include actual power monitoring circuitry and devices; rather, wattages at each power level

(100%, 50%, etc.) were programmed into the system based on pre-installation measurements at each the power setting:

- 100%: 76.0W
- 75%: 59.9W
- 50%: 35.8W

Future versions of this system are planned to include an integrated controller / driver package that does include actual power monitoring devices that should be capable of real time power metering and logging, accurate to 2%.

Luminaire grouping and scheduling

The system's scheduling and grouping functions include a full range of options, but operators had difficulty grouping and scheduling luminaires. Several attempts to activate test grouping and scheduling scenarios were made, but the changes did not save in the system. It appeared that in order to change schedules, one would have to visit each luminaire's page, rather than being able to command a schedule to an entire group. The method for grouping streetlights was not clear; there was a page for creating groups, but adding devices like luminaires and saving settings was not intuitive. Like the schedule pages, after navigating away from the group creation interface, the group was lost. However, the software engineers had already grouped the streetlights into zones during the system set-up, which has proven helpful for operations.

The system also includes pre-set nightly dimming schedules; a dimming profile was previewed that steps luminaire power down in 10% increments as the night progresses and then back up before dawn. The user should also be able to create new dimming schedules. For example, a simple 50% dimmed level after midnight, or an incremental ramp down from start to finish of a nightly luminaire cycle.

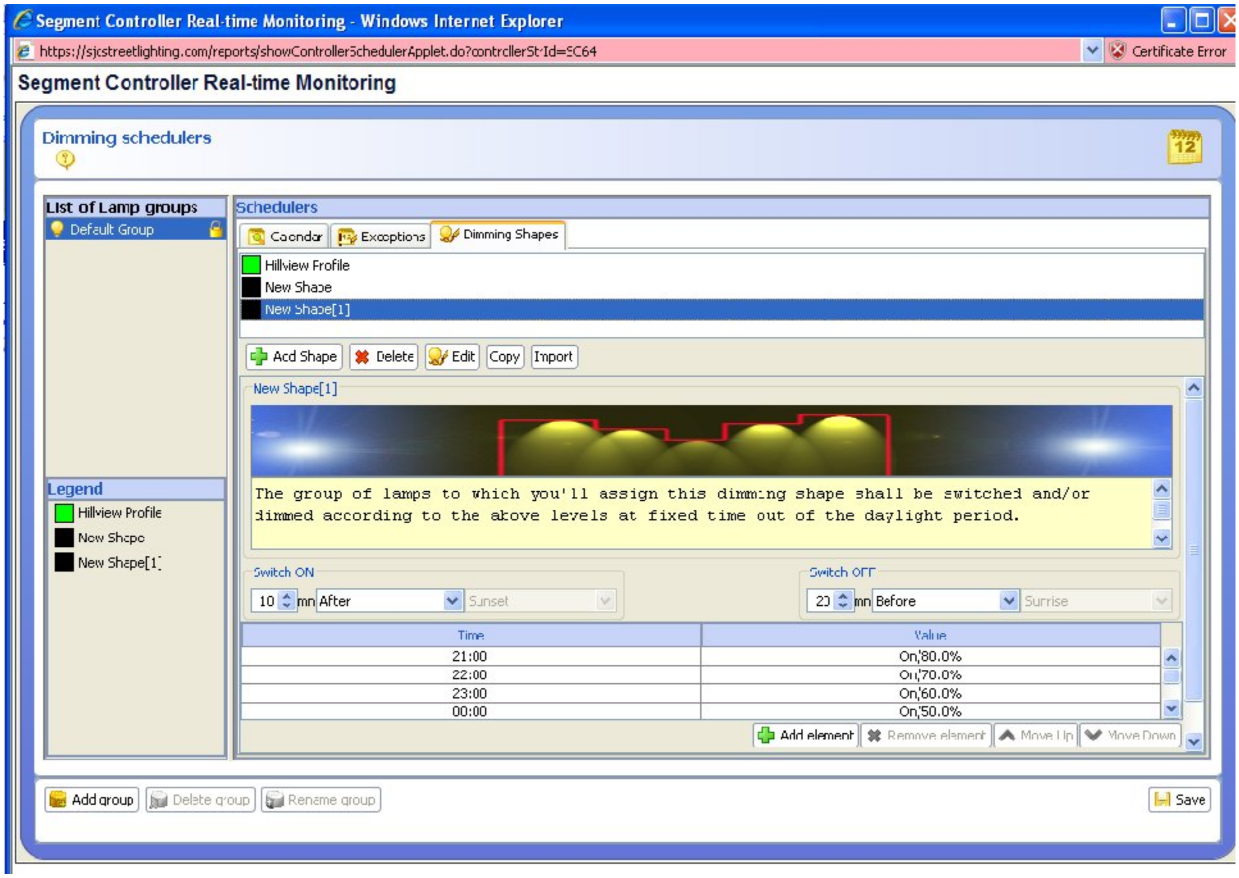


Figure 27: Streetlight.vision Adaptive Dimming Profile Schedule

User Interface Functionality and Ease of Use

Overall, system operators commented that the interface was fairly straightforward to navigate and use. The system allows a full array of scheduling options, but as mentioned above the method for saving and verifying new schedules and groups was not intuitive and it appeared that the test schedules did not take effect. The operator was planning on following up with Echelon customer support to investigate this issue.

The system included extra features such as graphics for cumulative luminaire operating hours and operating hours relative to expected luminaire life in a pie chart form and a comparative energy and economic graph option to demonstrate savings from the dimmable LED system relative to a hypothetical LPS base case.

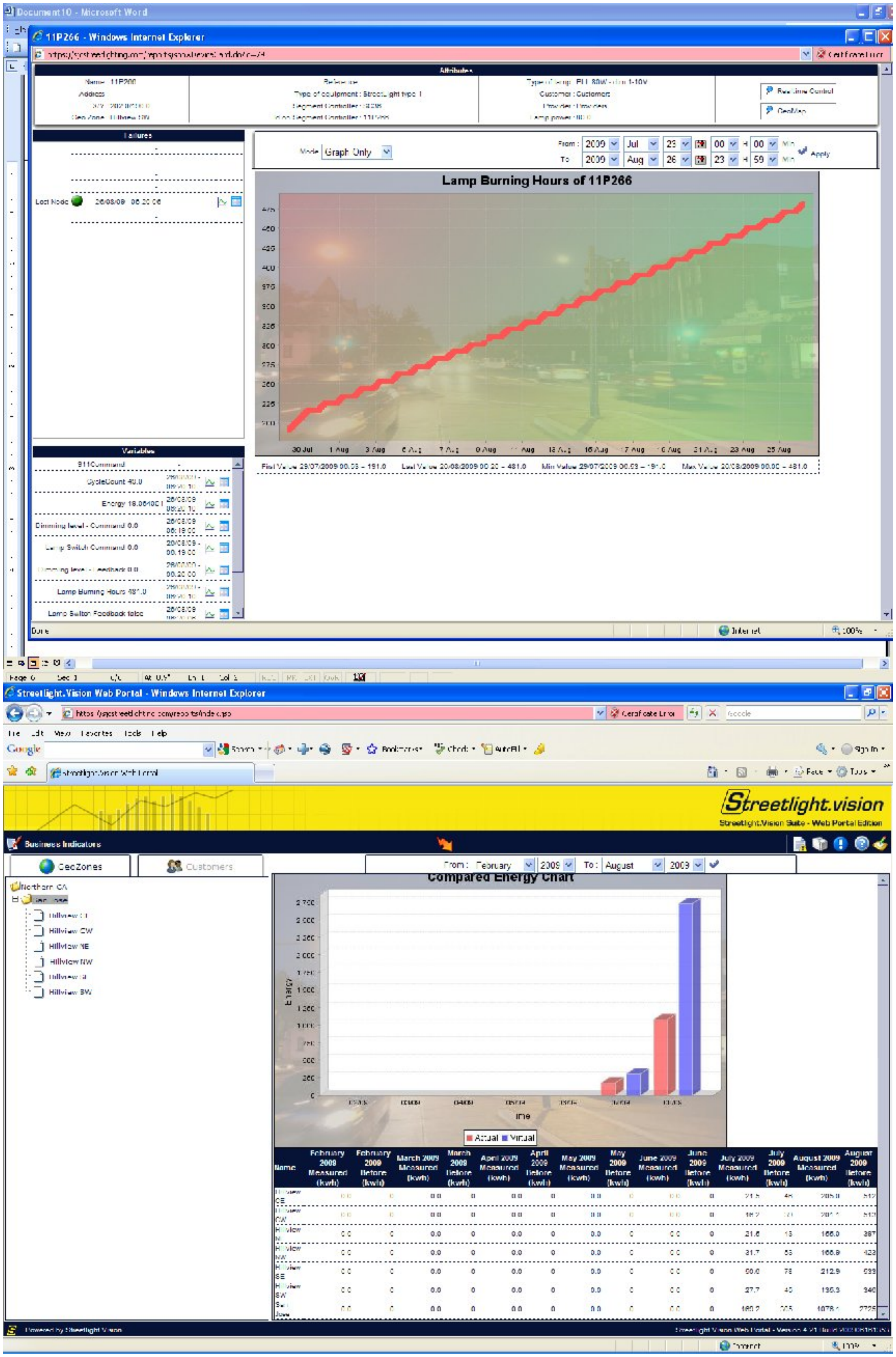


Figure 28: Streetlight.vision Burn Hours and System Energy Comparison Screens

INSTALLATION AND COMMISSIONING ISSUES

The PLC communication technology is designed to minimize hardware costs by using each segment controller to command multiple luminaires (up to 200), instead of requiring expensive hardware for each luminaire. This strategy works well when many streetlights are serviced by the same circuit so that control signals can travel uninterrupted between one segment controller and many streetlights. However, when voltage is transformed; for example, when line voltage is stepped down for residential distribution, any PLC signal is lost. Unfortunately, due to the layout and wiring of the streetlights in the pilot location, it was not feasible to control large numbers of streetlights with each segment controller. Overhead service in the neighborhood only powers one to several streetlights downstream of each residential transformer. Therefore it was not possible to communicate between each segment controller and large numbers of LEDs via PLC signals. To build out the network with the least equipment, it would have been necessary to rewire several circuits to increase the number of streetlights on each. Large-scale electrical changes like these would be cost prohibitive and impractical. Given the age of the installed street lighting base and the wide variation in electrical distribution wiring, this situation may be fairly common for existing street lights and present a challenge for PLC systems. To resolve these challenges, Echelon is working on a hybrid communication network (PLC/wireless RF) solution that may provide easier installation and robust communications for large-scale deployments.

CUSTOMER ACCEPTANCE

A user survey document was prepared to collect customer feedback on various aspects of the owner / operator experience. The survey was given to the primary system users; the San Jose DOT Streetlight Section Senior Civil Engineer, Streetlight Supervisor, and Senior Office Specialist. Survey questions covered installation and commissioning, operation and functionality, customer support, and overall satisfaction. Respondents were asked for comments and numeric satisfaction responses on a scale of 1 (most satisfied) to 5 (least satisfied). Feedback from the three surveyed parties is compiled below; where numeric responses differed, the range of responses is highlighted.

SYSTEM INSTALLATION AND COMMISSIONING

Ease of installation:

Most Satisfied : 1 2 3 **4** 5 : Least Satisfied

The streetlight installation went in without any issues [but] the segment controllers [were] a major challenge requiring a redesign of the originally proposed communication system

Compatibility with existing lighting system:

Most Satisfied : 1 2 3 **4** 5 : Least Satisfied

Challenges due to power line communication system… additional segment controllers needed to be added… in lieu of having PG&E modify their circuits

Training for system installation:

Most Satisfied : **1** 2 3 4 5 : Least Satisfied

Installation was straight forward on mounting and connection…considerable time spent with contractor to make sure communication was working

Commissioning:

Most Satisfied : 1 **2** 3 4 5 : Least Satisfied

Contractor set up the software and populated it with the City streetlight inventory…web based program was fairly simple to connect with, and navigate through

OPERATION AND FUNCTIONALITY

System interface ease of use:

Most Satisfied : 1 **2** 3 4 5 : Least Satisfied

Control and monitoring is self explanatory… simple once you get the hang of the system, but until then a little difficult to understand…difficult to figure out how to schedule different wattages for specific lights on certain days

Training and experience required to operate:

Most Satisfied : **1** 2 3 4 5 : Least Satisfied

Training was simple, but would have liked hands on to fully grasp all aspects of program

Operations, management, and maintenance functions:

Most Satisfied : **1 2 3** 4 5 : Least Satisfied

Provides option of adaptive dimming… real time command of the streetlights…eliminates photocells, reducing the number of complaints… all functions are useful once you get the hang of the program

Energy benefits:

Most Satisfied : **1 2** 3 4 5 : Least Satisfied

Using the network controls to operate the streetlights at 50% dimmed level… have the capability of dimming the lights even further in the early morning…using about half the energy as the LPS lights did

Data and reporting capabilities:

Most Satisfied : **1** 2 3 4 5 : Least Satisfied

Network reports are valuable in determining the system efficiency

CUSTOMER SUPPORT

Most Satisfied : **1** 2 3 4 5 : Least Satisfied

Any questions or issues that have come up were promptly addressed

OVERALL SATISFACTION

Most Satisfied : 1 **2 3** 4 5 : Least Satisfied

With some of the deficiencies [noted] above the City is proving feedback to the contractor in order to address some of the issues

ENERGY PERFORMANCE

Traditional photocell control would not allow the City to take advantage of the energy benefits of dimming LED streetlights such as those installed for the San Jose pilot. A more robust controls system, such as the Echelon option, that is capable of communicating with the 0-10v dimmable LED driver is necessary to send dimming commands to the lights to reduce power level as desired. The Echelon smart driver and segment controller package allowed the City to achieve significant energy benefits by setting neighborhood LED streetlights to 50% full power as the default setting. Further energy savings strategies have also been discussed, such as an adaptive schedule that would reduce streetlight power even further during the early morning hours when vehicle and pedestrian activity is at a minimum. Again, cost savings for these approaches can only be realized if adaptive street lighting rate schedules are available and energy metering data can be shared between the network system and the electric utility.

While the network controls offer important energy benefits, the components of the system require some power to operate. The smart-driver setup in the luminaire represents a small continuous load in order to remain in communication with the system, and the segment controllers and the system gateway must also be continuously powered. The power used by the smart drivers, segment controllers and the system gateway can be divided across the networked streetlight inventory to represent controls power on a per streetlight basis.

Since controls components run continuously, to represent controls load on a per-streetlight basis for the period of time during which the streetlights are on, controls power must be multiplied by a factor of 24 hours (controls runtime) / 11.23 hours (average nightly streetlight runtime)[42] = 2.14. Dividing the number of controls components by the number of streetlights and multiplying this by the load per controls component times the runtime factor of 2.14 gives total controls power per operating streetlight.

Tables of network controls power and annual energy use are given below based on CLTC lab-measured power for the LED luminaire and smart driver and Echelon-reported segment controller and gateway power. Total controls power and controls power as a percent of luminaire power is presented for the demonstration scenario and for a larger scale deployment using the same LED luminaires at the same power setting, but with a network optimized for controls equipment ratios (fewer segment controllers per streetlight).

[42] Assuming annual operation of 4,100 hours, per PG&E LS2 rate schedule; 4,100 hours / 365.25 days = 11.23

Table XVII: Weighted Controls Power per Streetlight for San Jose Pilot Scenario (118 lights)

System Component	Measured Power (W)	System Inventory	Component : Streetlight Ratio	Runtime Factor (Component Hours / Streetlight Hours)	Weighted Power (W) per Streetlight
LED Streetlight	34.9	118	1:1	1	34.9
LED Smart Driver (CLTC measured)	1.3	118	1:1	2.14	2.8
Segment Controller (Echelon reported)	10.0	57	57:118	2.14	10.3
Gateway + WAN Antennas (Echelon reported)	41.3	1	1:118	2.14	0.7

Total Power per Streetlight	48.7 W
Annual Energy (per Streetlight)	199.7 kWh
Controls Power Only	13.8 W
% Power due to Controls	28.3%
Annual Energy Used by Controls Alone (per streetlight)	56.6 kWh

Table XVIII: Weighted Controls Power per Streetlight for Larger Optimized Scenario (1000 Lights)

System Component	Measured Power	System Inventory	Component : Streetlight Ratio	Runtime Factor (Component Hours / Streetlight Hours)	Weighted Power per Streetlight
LED Streetlight	34.9	1000	1:1	1	34.9
LED Smart Driver (CLTC measured)	1.3	1000	1:1	2.14	2.8
Segment Controller (Echelon reported)	10.0	10	1:100	2.14	0.2
Gateway + WAN Antennas (Echelon reported)	41.3	1	1:1000	2.14	0.1

Total Power per Streetlight	38.0 W
Annual Energy (per Streetlight)	155.8 kWh
Controls Power Only	3.1 W
% Power due to Controls	8.2%
Annual Energy Used by Controls Alone (per streetlight)	12.7 kWh

Streetlight and Network Controls Economic Performance

Advanced streetlights and controls offer cost savings advantages over time but require significant upfront investment. The San Jose demonstration was a pilot installation of 118 networked streetlights, but the City is continuing to evaluate LED and controls technologies for possible wider deployment. Along with roughly 30,500 LPS 55W streetlights, the City also has 19,000 LPS streetlights in the 95 – 135W nominal range, and 3,500 185W LPS. Higher volume replacement scenarios make more sense for economic projections, as unit costs for the streetlights and controls would be lower and more realistic for larger scale installations than the pilot. The streetlight and controls manufacturers were asked to provide cost information for installations of 1,000+ streetlights. For the network controls, the projected costs also assume lower density of segment controllers to streetlights (1:100), which could be achieved if the streetlight circuits were more favorable for power-line carrier or with wireless bridges between circuits to propagate control signals. To be clear, the proposed costs here are not meant to reflect actual costs for the San Jose pilot, where the density of controls equipment to streetlights was very high.

ECONOMIC ANALYSIS SCENARIOS

Longer lasting LED streetlights operating at 50% power due to network controls settings should result in lower energy and maintenance costs. The network controls may also streamline maintenance practices such as outage identification, further reducing costs. If adaptive street lighting strategies are adopted, such as dimming the lights beyond 50% power at low-conflict hours, even more energy savings could accrue.

Based on estimated equipment and installation costs and energy and maintenance savings, economic performance was evaluated through simple payback[43] and net present value (NPV) analyses[44] for LED luminaires with (or without) network controls relative to incumbent LPS luminaires on photocell controls. Several deployment scenarios were constructed.

1. Non-networked LEDs at 50% Power: Replacement of 55W LPS streetlights with photocell-controlled LED streetlights of constant 34.9W (equal to demonstration streetlights at 50% power setting)
2. Networked LEDs at 50% Power: Replacement of 55W LPS streetlights with networked LED streetlights set at 50% power
3. Hypothetical Adaptive Networked LED Scenario: Replacement of 55W LPS streetlights with networked LED streetlights set at 50% power for half of the night and dimmed to 25% power for half of the night

It is not suggested here that the outlined adaptive scenario will necessarily work for or be applied at the pilot location in San Jose. For example the test area roadway is already in the lowest average illuminance category according to standards, so it may not be acceptable to dim the lights beyond the LEDs' 50% power setting. The example is meant only to be illustrative of what is possible with the networked LED streetlights and may be more applicable to roadways with higher, but more variable, vehicle and pedestrian volumes (see Discussion section).

Economic estimates are sensitive to site-specific variables such as maintenance and energy costs and material costs such as the LPS and LED luminaires and controls equipment. San Jose provided streetlight maintenance schedule and budget information. Assumptions were made about maintenance savings from LED streetlights and network controls based on available information. Savings estimates also depend upon assumptions for LED luminaire lifetime, which is a function of the life of all parts of the luminaire (LEDs, driver, housing, coating, etc.). Manufacturers' claims for luminaire lifetimes are highly variable. Readers are advised to use their own cost estimates and assumptions when possible.

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[43] Simple payback, in units of years, is defined as a project's initial cost divided by resulting annual savings.

[44] NPV calculations were based on a project analysis term of 15 years, an annual escalation rate for energy of 3% and 2% for labor and maintenance, and a cost of capital of 4%. Readers are advised to use their own rates and assumptions. See Appendix D: Economic Data and Calculations.

ESTIMATED ENERGY COSTS

Since San Jose owns and maintains its street lighting system, its streetlights are currently billed by PG&E under the LS-2 rate schedule for customer-owned street and highway lighting under Class A rates, which include a small monthly "facilities" charge ($.187) and monthly fixed-rate energy charges. PG&E released a new LS-2 electric rate in May of 2009 that includes rates for LED streetlights of various wattages. The LS-2 rate is un-metered, with flat monthly energy charges listed for various lamp types (HPS, LPS, MH, MV, induction, and LED), wattage bins, and voltage service. These charges are calculated based on an energy rate of $0.12206 / kWh, assumed ballast losses for each lamp type and wattage bin, and annual hours of operation.

(Lamp wattage + ballast losses) x 4,100 hours/12 months/1000 x streetlight kWh rate

LPS 55W nominal streetlights are assumed to represent 83.5W load each (including ballast losses) in the rate schedule, and are charged a total monthly fee of **$3.727**. For energy cost savings it is assumed that San Jose would be charged for the programmed LED wattage rather than the LED wattage at full power. The LED rate bin corresponding to San Jose's pilot LED streetlights at 50% is the 30 – 35W bin, with a charge of **$1.542** monthly. For an adaptive schedule, it is assumed that half of the monthly charge will be in the 30 – 35W bin, and half the charge would be in the 15 – 20W bin, **$0.919** monthly, corresponding to the LED streetlights at 25% power setting. This represents a combined monthly adaptive rate of **$1.231** per streetlight.

Note that the energy consumed by the luminaire controls, the segment controllers and the system gateway are assumed to be un-metered load for this paper's analysis. With advanced network communications that metered and shared all system energy data, controls energy could be reported to the utility and billed at an adaptive street lighting rate as well. In this case there would be additional incentive to design the controls network with a low density of segment controllers to streetlights.

The adaptive rate outlined above, and used for this study's economic analysis, is purely hypothetical because currently the utility's rate schedule options for street lighting do not include schedules applicable to adaptive lighting strategies. A metered rate schedule that bills streetlights based on actual energy usage as opposed to fixed monthly rates for assumed usage would be necessary for a customer to realize cost savings from reduced streetlight energy use. The rate schedule issue will need to be addressed for streetlight network controls technology to achieve widespread adoption.

STREETLIGHT AND NETWORK CONTROLS COSTS

From communications with the LED streetlight vendor, the bulk purchase rate per LED luminaire used in the pilot (1000+ units), including the 0-10v dimmable driver, is roughly **$375**. A version of the product is available that does not use a continuously dimmable driver, but has three pre-wired driver settings for different output levels (350mA, 525mA, 700 mA). The 350mA level is roughly equivalent to the 50% power setting. The estimated bulk purchase rate for this luminaire is **$360**. Without network controls, the LED system would have to include a photocell (quoted at $6 each for San Jose) so a luminaire cost of **$366** was used for a non-networked installation. The cost of a 55W LPS luminaire, including photocell, was quoted at **$312**. It should be noted that the LPS baseline cost in San Jose is considerably more expensive than typical HPS streetlight costs. For example, last year's street lighting studies in San Francisco and Oakland, CA listed costs of $107 to $145 for HPS streetlights in similar applications.

The estimated cost for an at-scale deployment of the piloted network controls technology is a little more complicated to determine because it depends on assumptions regarding the number of segment controllers deployed per streetlight, and any additional costs such as set up of a local WAN if one is not already available for communications between the system gateway and the segment controllers. Remember also that for the pilot, the density of segment controllers to streetlights was much higher than expected (almost 1:2) whereas the intended system design is for each segment controller to command 100 – 200 streetlights. This could be achieved in locations with more ideal street lighting circuits for power-line carrier technology, or through wireless bridges that could leap circuit interruptions to propagate segment controller signals to multiple circuits.

For the purposes of the economic evaluation here, the manufacturer assumed a deployment of 10,000 networked streetlights, at a segment controller-to-streetlight ratio of 1:100 and with no WAN antennas and subscriptions needed, which would be the case if an accessible public wireless network were already available in the deployment area. The network system cost was estimated to add roughly **$100** per streetlight, including installation and hardware. This estimate therefore represents close to a "best-case" (lowest cost) scenario.

The San Jose pilot is within PG&E service territory, where a recent incentive program for LED streetlights has been launched. This program pays $50 - $125 per qualifying LED streetlight installed, depending on the wattage of the streetlight replaced.[45] For this analysis, it is assumed that the incentives would be available at a rate of **$50**/per replaced LPS streetlight. Costs, including state and local sales tax, are summarized below:

Table XIX: Streetlight and Network Controls Costs Summary

Streetlight Option	Luminaire Cost	Controls Cost	Total Cost (incl. 9.5% sales tax)	Incentive Value	Total Cost	Cost Difference (Vs. LPS Baseline)
LPS	$306	$6	$342	---	$342	---
Non-networked LEDs	$360	$6	$401	($50)	$351	$9
Networked LEDs	$375	$100	$520	($50)	$470	$128

ESTIMATED INSTALLATION AND MAINTENANCE COSTS AND SAVINGS

Costs used in this analysis are estimates based on available data; due to uncertainties on reported costs and maintenance totals, these estimates should not be considered absolute. Readers are advised to use appropriate cost assumptions for their particular application.

San Jose provided information on the City's total streetlight inventory and average annual repairs and replacements. From the City's reported inventory size and annual repair visits, it is estimated that 20% of streetlights are serviced every year, representing a 5 year repair and replacement cycle. This agrees with available data on expected lifetimes for the range of LPS streetlight wattages in the inventory. The City's standard streetlight maintenance practice is spot, or 'burn-out," replacement based on complaints and observed outages, rather than rolling group replacements.

Based on the City's reported annual maintenance budget for streetlights and the total number of streetlights, an average annual cost of maintenance (labor and materials) per light was estimated at **$40**. The City's cost for installation of a streetlight on an existing pole was estimated at **$95**, which also agrees with data from previous studies. This installation cost is assumed to be the same for LPS and LED luminaires, whether networked or not, since at the luminaire level, controls components are integrated into the unit itself.

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[45] Follow the LED Streetlights link at http://pge.com/led/ for more program info.

The manufacturer of the LED streetlights assessed in this study publishes a predicted life for the LEDs used in the luminaires of 70,000 to over 170,000 hours (17 to 40+ years at 4,100 hours per year), depending on drive current. These lifetimes are far longer than the LPS rated lamp life of 18,000 hours, or roughly 4.4 years. While LED streetlights are expected to outlast LPS lamps, it seems likely that LED luminaires will still require some level of maintenance for occasional catastrophic failure and periodic routine visits for cleaning, inspection, and so forth.

As an emerging technology, LED streetlights have been operating in field installations only for a relatively short period of time and there is no historical data for real, long-term performance and maintenance costs. As a result, calculating the expected maintenance cost for an LED street lighting system is difficult, requiring assumptions about the annual probability of luminaire failure, before and after warranty, etc. Furthermore, the industry standard method for measuring LED chip lumen maintenance (LM-80-08) does not provide a method for measuring lifetime of the whole luminaire, which includes multiple components (LEDs, driver, housing, coating, etc.).[46] The expected useful life of the luminaire will likely not be the same as that of the LED package.

In general, it is expected that there will be significant maintenance savings due to longer LED luminaire lifetimes. Recent reports on LED streetlight retrofit demonstrations in Oakland and San Francisco, CA have based economic calculations on maintenance savings ranging from 59 to 100%.[47] Because of the many uncertainties inherent in attempting to quantify maintenance savings, for this report a simplifying and conservative assumption of 50% savings is used. No data was available on maintenance savings due to networked streetlights installed to-date. Remote outage detection and automated maintenance orders and tracking should have cost savings benefits, but without hard data, a broad assumption of 20% additional maintenance savings (above LED streetlight savings only) is made here. Again, readers should use their own estimates for maintenance savings when evaluating these technologies for their specific applications.

Table XX: Estimated Annual Costs and Savings per Streetlight

Scenario	Maintenance Cost	Maintenance Savings	Energy Cost	Energy Savings	Total Cost	Total Savings
LPS	$40.00	---	$44.72	---	$84.72	---
1) Non-networked LEDs, 50% Power	$20.00	$20.00	$18.50	$26.22	$38.50	$46.22
2) Networked LEDs, 50% Power	$12.00	$28.00	$18.50	$26.22	$30.50	$54.22
3) Adaptive Networked LEDs	$12.00	$28.00	$14.77	$29.96	$26.77	$57.96

Comparison between the networked and non-networked LED scenarios and the baseline LPS options were made for new construction economics in which LED luminaires with network controls are installed instead of the standard 55W LPS luminaires, and 'retrofit' economics in which LED luminaires are installed in place of existing and fully functional 55W LPS luminaires.

[46] The current industry-standard testing procedure for LED lumen depreciation, IESNA LM-80-08, does not include a method for extrapolating beyond the required 6,000 hours of testing. The IESNA is currently working on development of a standardized method (TM-21) for extrapolation of LM-80 data, but this has not been finalized. As a result, there is no industry standard methodology to properly verify manufacturers' claims for lumen maintenance.

[47] See Cook, et. al. PG&E Emerging Technologies Reports referenced previously.

NEW CONSTRUCTION / REPLACEMENT-AT-FAILURE ECONOMICS

For new construction or replacement of LPS luminaires at time of failure, the cost of luminaire installation is assumed to be the same for either LEDs or LPS. The incremental cost of the project is therefore only the difference in material costs between the LEDs and the LPS. For networked streetlights, this cost includes the material and installation costs of the controls components ($100 / light).

Table XXI: New Construction Economics (per Streetlight)

With Incentives

Scenario	Initial Investment	Annual Energy Savings	Annual Maintenance Savings	Simple Payback (Years)	15-Year NPV	15-Year IRR
1) Non-networked LEDs, 50% Power	$9	$26	$20	0.2	$613	521.8%
2) Networked LEDs, 50% Power	$128	$26	$28	2.4	$597	45.5%
3) Adaptive Networked LEDs	$128	$30	$28	2.2	$649	48.6%

Without Incentives

Scenario	Initial Investment	Annual Energy Savings	Annual Maintenance Savings	Simple Payback (Years)	15-Year NPV	15-Year IRR
1) Non-networked LEDs, 50% Power	$59	$26	$20	1.3	$563	82.7%
2) Networked LEDs, 50% Power	$178	$26	$28	3.3	$547	33.0%
3) Adaptive Networked LEDs	$178	$30	$28	3.1	$599	35.3%

As this table demonstrates, for new construction or replacement of LPS at time of luminaire failure, the savings achieved by LED luminaires alone is enough to pay for the incremental cost very quickly and the internal rate of return (IRR) for this investment is very high. This is a result of the projects' high annual savings relative to the small incremental cost for the LED streetlights over a new LPS streetlight. For new construction projects such as major subdivisions, networked LEDs are also a good investment in terms of short payback and high net-present value (NPV).

RETROFIT ECONOMICS

For retrofit economics, the cost of deploying LEDs and network controls is the full material and installation cost of the LED luminaires and controls. This necessarily increases the payback on investment and reduces net present value.

Table XXII: Retrofit Economics (per Streetlight)

With Incentives

Scenario	Initial Investment	Annual Energy Savings	Annual Maintenance Savings	Simple Payback (Years)	15-Year NPV	15-Year IRR
1) Non-networked LEDs, 50% Power	$446	$26	$20	9.6	$176	8.8%
2) Networked LEDs, 50% Power	$565	$26	$28	10.4	$160	7.6%
3) Adaptive Networked LEDs	$565	$30	$28	9.8	$212	8.6%

Without Incentives

Scenario	Initial Investment	Annual Energy Savings	Annual Maintenance Savings	Simple Payback (Years)	15-Year NPV	15-Year IRR
1) Non-networked LEDs, 50% Power	$496	$26	$20	10.7	$126	7.2%
2) Networked LEDs, 50% Power	$615	$26	$28	11.3	$110	6.3%
3) Adaptive Networked LEDs	$565	$30	$28	10.6	$162	7.3%

For the retrofit scenario, it is interesting to consider the costs and benefits of replacing the entire San Jose inventory of 55W LPS (30,500 units) with the piloted LEDs. The project simple payback and IRR remain the same as long as the costs per unit are the same. While the total investment (including incentives) would be quite large, project NPV would also be high.

Table XXIII: Retrofit Economics

Scenario	Initial Investment	Annual Energy Savings	Annual Maintenance Savings	15-Year NPV
1) Non-networked LEDs, 50% Power	$13,595,985	$799,710	$610,000	$5,378,158
2) Networked LEDs, 50% Power	$17,236,313	$799,710	$854,000	$4,882,269
3) Adaptive Networked LEDs	$17,236,313	$913,719	$854,000	$6,466,578

Calculated simple payback periods and net present values for each LED option are sensitive to estimated energy and maintenance cost savings, as well as cost of capital and cost escalator assumptions, which will vary for each customer. To demonstrate the effect of maintenance savings on project payback periods, the following figures plot paybacks for each project scenario through a range of assumed maintenance savings.

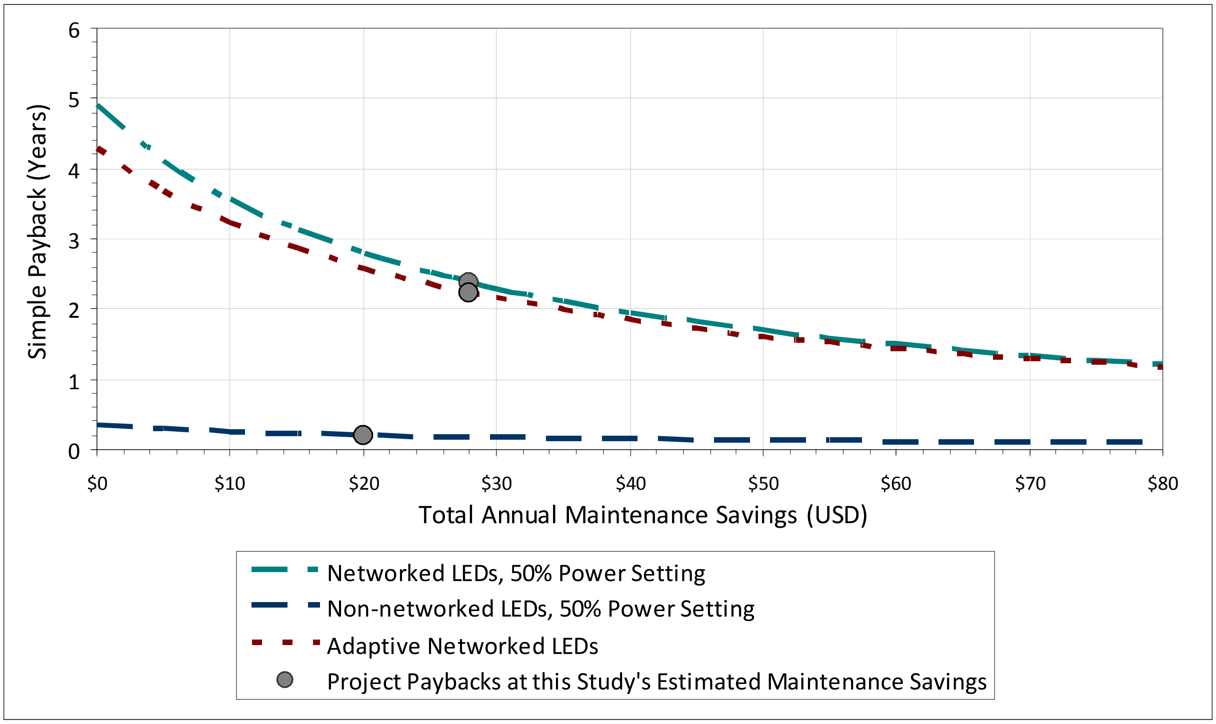

Figure 29: Project Payback Sensitivity to Assumed Maintenance Savings: New Construction

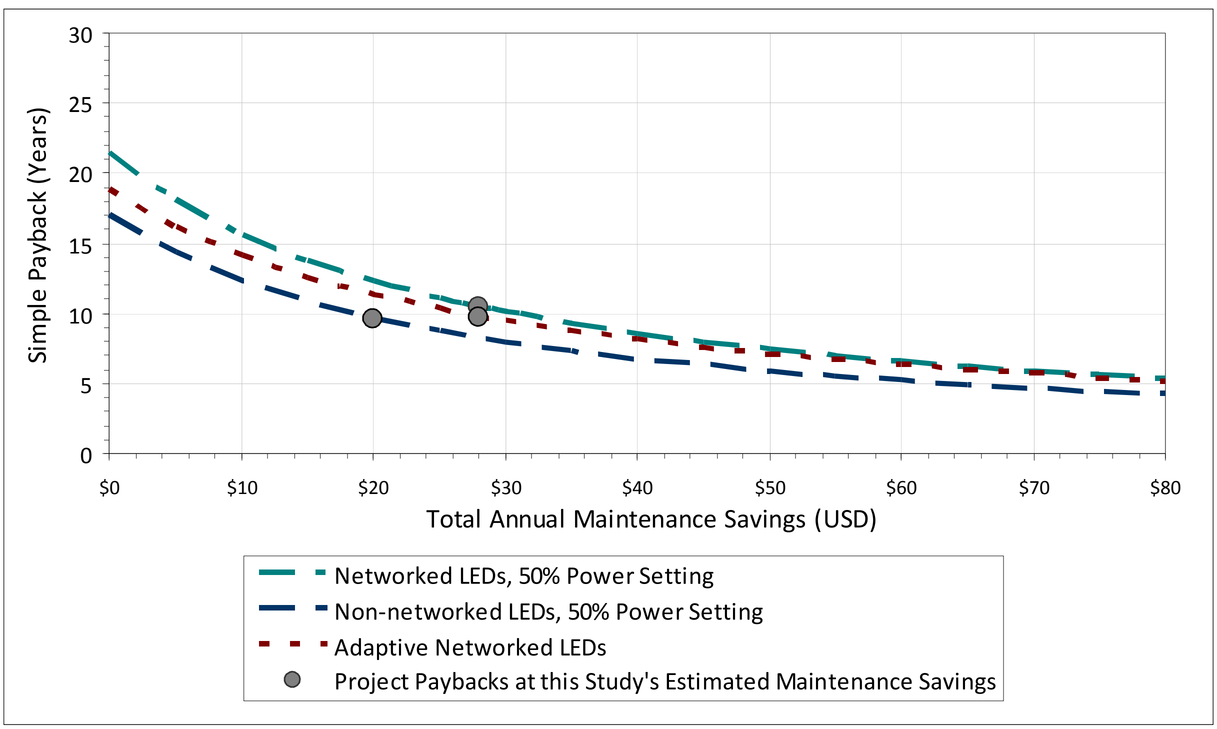

Figure 30: Project Payback Sensitivity to Assumed Maintenance Savings: Retrofit

Discussion

At the current state of the technology, LED streetlights can be a viable, cost effective replacement for HID and LPS streetlights and have the potential to deliver significant energy savings. Network controls technologies can also provide enhanced energy benefits, especially with dimmable streetlights that allow operators to set lighting power to meet efficiency and performance goals and even adjust lighting power adaptively. However, new streetlight energy rate structures and billing methods would be required for customers to realize many of the potential economic benefits.

The demonstrated streetlight and controls technologies both showed promise in terms of wider scale adoption, though the network communications design was challenged by local infrastructure characteristics (few streetlights per transformer) that may be typical of similar residential neighborhoods. Nonetheless, the dimmable luminaires and controls did demonstrate that remote monitoring, scheduling and dimming of LED streetlights is possible.

A variety of LED street lighting options are now available for a range of roadway layouts. Consider the numerous models of streetlights that have qualified for PG&E's incentive program, which requires independent lab testing according to standard IESNA test procedures of all products and sets performance requirements for minimum efficacy, CRI and CCT. The qualified list has grown to over 70 luminaire models from five manufacturers. The DOE acknowledges that streetlights are an active area of the LED market that is capturing the interest of efficiency programs and municipalities, and though demonstrations are proving savings, testing has also shown wide performance ranges.[48] The DOE and Environmental Protection Agency are in the process of finalizing, with stakeholder input, ENERGY STAR® solid-state outdoor lighting criteria including new performance metrics such as Fitted Target Efficacy to help customers better differentiate between LED options in the growing market.

Along with lighting performance considerations such as efficacy, distribution, spectral power distribution, etc, other technical features of LED replacement options must be proven for this lighting option to succeed. Well-designed luminaires compatible with existing infrastructure (wiring, mounting, etc.) and that will withstand environmental factors over time will emerge as winners in the competitive marketplace.

Several qualities will be expected of advanced controls options if they are to become more prevalent also. Compatibility with the power grid as well as emerging street lighting options, durability, reliability, and performance all need to be guaranteed before large and costly street lighting networks are rolled out. Experiences in early adopter locations like Glendale, LA, and San Jose should help planners understand the potential and limitations of network options and designs.

LED LUMINAIRE PERFORMANCE CONSIDERATIONS

Lighting quality, product reliability, energy usage, and cost are the key performance factors for LED streetlights. If LED streetlights can perform as well or better than incumbent technologies from a lighting quality perspective, and can do so using less energy, it is likely that the LED streetlight market will continue to grow. However, LED streetlights will also need to live up to lifetime claims to maintain momentum, and costs, which have been decreasing steadily, may still need to come more in line with those of other options.

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[48] Hitting the Target: ENERGY STAR SSL Outdoor Lighting Criteria. Jason Tuenge, LC, LEED AP Pacific Northwest National Laboratory DOE Webcast October 8, 2009

Photometric results from this study show that average photopic illuminance from the LED streetlights fulfilled San Jose's standard and was similar to the photometric performance of the existing LPS streetlights. Other light source characteristics like color rendering and spectral power distribution, which do not necessarily directly affect illuminance levels, can at least qualitatively be said to have enhanced visual perception and information in the pilot area (see field photos). It is important to note that the measured photometric performance is specific to the LED product evaluated in this test. As with traditional lighting sources, performance varies widely between manufacturers and should be evaluated independently for specific products under consideration.

It was also noted that the illuminance provided by the LPS and LED streetlights likely would not meet the higher illuminance requirements of more current IESNA guidelines. On the other hand, with dimming drivers and network controls, the LED streetlight output could be increased considerably and the City would still save some energy over the base case LPS streetlight. Again most lighting guidelines are currently written only for photopic lighting performance and do not yet account for the mesopic advantages that LED streetlights clearly demonstrate. The IESNA Technical Memo dealing with mesopic lighting, TM-12, is currently undergoing revisions to provide more specific recommendations for incorporating lamp spectral distribution effects under mesopic conditions into street lighting design.

NETWORK CONTROLS PERFORMANCE CONSIDERATIONS

The features that network controls systems offer streetlight managers will vary, but are almost certain to represent improvement over basic photocell control. It is important that the functions promised by the technology, such as flexible scheduling, system energy reporting, outage detection, and maintenance tracking deliver once systems are installed. Testing and verification of system operation will be critical, especially given that these systems are much more complex than the controls technology they are replacing. In the case of the pilot, further development and testing of modules such as grouping and scheduling needs to be carried out so that users can easily program desired luminaire power levels and operation schedules to maximize the system's effectiveness. Pilots demonstrating these technologies in real world applications, and underscoring challenges that manufacturers need to address, will help cities understand the value of controls for street lighting inventories and project their benefits for future installations.

San Jose's energy savings in the pilot were enabled by the advanced network controls, which allowed operators to experiment with different light outputs before settling on the 50% power setting as the neighborhood default. This approach could be applied at future networked dimmable streetlight installations as well to maximize energy savings while maintaining acceptable light levels. Adaptive scheduling, such as the hypothetical 50%/25% power scenario evaluated here, could improve savings even further, though as stated previously, a 25% LED power setting may not be realistic at the pilot location as it is already classified in the lowest tier of average illuminance requirements. However, since roadways are classified according to levels of traffic volume and pedestrian conflict by most standards, it is conceivable that roadways move through these classifications nightly based on cyclical changes in the level of traffic and pedestrian activity.

Standards such as RP-8-00 do not currently specifically address adaptive strategies, which have only recently become possible with the advent of easily dimmable light sources like LEDs. As an example of how an adaptive schedule might be implemented, consider the following abridged version of the RP-8-00 standard, showing recommended illuminance levels for collector and local roadways based on pedestrian conflict levels. From high to low pedestrian conflict in the local roadway classification, the recommended illuminance drops over 50%, from 0.9 to 0.4 fc. Similarly, recommended illuminance levels vary depending upon the volume of traffic expected on the street. For streets classified as roadways with low traffic volume, lower illuminance levels are recommended, as compared to street classified as collectors with higher traffic volume.

Roadway lighting systems are designed for the conditions of highest anticipated traffic volume and highest anticipated pedestrian activity (see RP-8-00 roadway classifications and design criteria). An adaptive lighting strategy would recognize that for many hours of the evening and early morning, the actual traffic and pedestrian activity is much lower, and recommended light levels under these lower activity conditions would be lower, per the RP-8-00 standard. For example, if a street lighting system was designed for the anticipated early evening activity level of a collector with high pedestrian activity, the recommended illuminance would be 1.2 fc. If the actual traffic and pedestrian volumes dropped to the levels classified by a local roadway with low pedestrian activity during late evening and early morning hours, the recommended illuminance would be only 0.4 fc. Obviously the savings implications are significant if lighting levels can be lowered to match this lower recommended level, and are predicated on controls options that allow dimming schedules. Future standards guidelines would help clarify acceptable adaptive street lighting strategies by directly addressing this point.

Table XXIV: Hypothetical Use of RP-8-00 Road and Pedestrian Conflict Classifications to Implement Adaptive Lighting Strategies

Road and Pedestrian Conflict Area		Pavement Classification			Uniformity E_{avg}/E_{min}
Road	Pedestrian Conflict Area	R1 fc	R2 & R3 fc	R4 fc	
Collector	High	0.8	1.2	1.0	4.0
	Medium	0.6	0.9	0.8	4.0
	Low	0.4	0.6	0.5	4.0
Local	High	0.6	0.9	0.8	6.0
	Medium	0.5	0.7	0.6	6.0
	Low	0.3	0.4	0.4	6.0

Another key point of interest, and a highly touted feature of network controls, is the ability to monitor and meter streetlight energy usage. This is an improvement from the city and utility perspective because currently streetlights operate as un-metered load and it is not always known when they are not operating properly; i.e. lamp failures or day burning lights. How the energy data from these systems is going to be used is another question. Ideally, some form of communication with utility information systems would be available to transfer data collected by the streetlight network for monitoring and billing purposes. For example, if San Jose is to be billed at the LED rate corresponding to the luminaire power level at the 50% setting, the utility must know that this is the effective load from the streetlights. Otherwise they would likely be billed at the LED rate for the luminaires at full power. This will be even more important for adaptive lighting scenarios, where the luminaire wattage is not a fixed point. Similarly, there will need to be some standardization in terms of the frequency and accuracy of power measurements recorded by network controls systems. Utilities such as PG&E maintain strict requirements for revenue-grade metering, such as accuracy of ±2%, compliance with ANSI C12.1-2008 American National Standard for Code for Electricity Metering, programmability for rolling interval demand calculations, etc. Some of these standards may not apply to streetlight controls system, but key elements like accuracy would not be met by the pilot version of the controls technology, for which pre-measured power levels were programmed for luminaire states rather than measuring power demand with on-board circuitry. Future versions need to be more robust in their energy measurements and a clear pathway for data transfer should be developed between cities, controls designers, and utilities.

POTENTIAL SAVINGS

In the case of this study, LPS streetlights were replaced with LED streetlights of similar wattage when operating at full power. In terms of total photopic lumen output, LPS is a highly efficient technology; LED streetlights are just beginning to compete with the photopic efficacy (lumen/W) ranges achievable by LPS. In fact, while the LED streetlight at the low power setting had lower total lumen output than the LPS, its efficacy was actually higher. It was found in San Jose that satisfactory lighting performance could be achieved at a controls setting of 50% power. The LED streetlight power savings at this level over the LPS baseline were over 62%. Including the parasitic power of all of the controls in the pilot (on a per-streetlight basis), the savings were still over 47% for the pilot. In more typical HPS street lighting inventories, LEDs are showing similar competitiveness and savings.[49]

A 2002 DOE report estimated annual energy usage of 31 TWh in the US from streetlights alone for an inventory of approximately 38 million luminaires.[50] Less than 10% of the national street lighting load is LPS. However, as previous studies have shown, LED streetlights can be effective replacements for HPS streetlights as well, a much larger percent of the national street lighting load (59%). LPS, HPS and other HID sources account for 92.4% of all roadway lighting electricity use in the U.S. Based on findings, it could be assumed that LEDs are technically capable of replacing a large fraction of today's streetlights. If they were network controlled, energy savings would depend on the controls strategies employed and whether or not adaptive street lighting became a widespread practice. However, if the entire roadway inventory were replaced with dimmable networked LEDs operating on average at 50% baseline HID power, the achievable annual energy savings would be over 14.3 TWh, which represents a CO_2 emissions reduction of over 10.3 million metric tons, or an equivalent savings of 23.9 million barrels of oil.[51]

ECONOMIC FEASIBILITY

Market adoption of networked LED streetlights on a large scale will hinge not only on lighting and energy performance, but also on economic competitiveness. The initial investment in LED streetlights and network controls will only be made if system savings warrant the extra upfront cost. The cost premium for the LED streetlights and controls package in San Jose was over 50%, compared with the cost of LPS luminaires and photocells. However, non-networked LED streetlights were only slightly more expensive than the LPS luminaires (less than 20% premium). Energy and maintenance savings represent the ongoing value of a networked LED streetlight investment, but the degree of savings will depend on each location's maintenance costs and how much savings these technologies enable.

For the San Jose case, replacement of LPS streetlights at end of useful life with non-networked LED streetlights at minimum and including LED streetlights in all new construction, represents an almost immediate payback and tremendous net present value, with a project return of over 500% (incentives included). Including network controls would increase the payback to around two years, and also requires a minimum number of replacements in the same area to be worthwhile, since individual networked streetlights are not feasible. Even so, there is a clear economic motivation for proposing networked LED streetlights for new developments and subdivisions in the City, with a 15-year NPV of $547 in the worst case.

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[49] Cook, et al. San Francisco and Oakland Reports.

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

[51] See the EPA's Greenhouse Gas Equivalencies Calculator http://www.epa.gov/RDEE/energy-resources/calculator.html

The retrofit case is more costly, so even with high annual savings it will take more time to recover the full expense of replacing operating equipment with new streetlights and controls; paybacks were in the 10 year range in this case. Nonetheless, in the long term project returns were positive. Interestingly, as the energy costs and maintenance savings difference was small between the adaptive streetlight scenario and the networked scenario at 50% power, there was relatively little economic difference between the two in this study in terms of simple payback, though there was some improvement for in NPV for the adaptive scenario. In different situations where increased energy savings through adaptive strategies is possible, the difference could be even larger. Similarly, non-networked LED streetlight economics were very close to networked options for the retrofit case in this study, as upfront cost savings were eventually cancelled by smaller maintenance savings.

Incentive programs like PG&E's recently launched program for LED streetlights are helping offset some of the upfront cost, and the economics shift to slightly longer paybacks and lower present value if incentives are excluded (retrofit simple paybacks averaging 11 years). PG&E's program is also important in that it provides guidance in terms of performance and quality by qualifying only products that are likely to deliver long term lighting performance and energy savings.

It is important to remember that for street lighting customers to realize the energy cost savings achievable through adaptive street lighting or simple scheduling changes, metered rate schedules based on actual energy usage are necessary. Furthermore, controls technologies with metering capabilities will need to deliver data at acceptable accuracy and in a format that can be shared with utilities for billing purposes.

Conclusion

This assessment of the San Jose networked LED streetlight pilot answered many questions about the technologies deployed and raised many more that should be considered for future studies and possible incentive programs and as LED streetlights and network controls are installed at scale in several locations around the U.S.

Remote, web-based control, monitoring, and management of street lighting inventories is possible through available network controls technologies.

Network controls communication strategies are complex and all options may not be suitable for all locations; PLC-based technologies will be more suited to areas with uninterrupted street lighting circuits and would be improved by wireless bridges to broadcast communication signals between lights and/or circuits.

Adaptive street lighting practices with dimmable LEDs are possible, but questions remain as to how dimming schedules based on cyclical traffic and pedestrian volume will comply with current and future lighting standards.

Real-time streetlight energy monitoring via network controls may be possible, though it was not demonstrated in this pilot. Further work is necessary to outline how controls system data collection will translate into revenue-grade metering for utilities and customers, and how utilities will develop appropriate rate schedules to bill actual streetlight energy use.

Dimmable LED streetlights, as replacements for incumbent LPS streetlights in residential settings, can achieve similar photopic performance and can meet some performance requirements, though higher output models would likely be required to meet the most current version of RP-8-00. LED streetlights can deliver improved mesopic performance over LPS according to several mesopic models, and further development of standards and evaluation procedures to account for mesopic lighting performance in nighttime conditions is important.

While large scale network controls and LED streetlights projects will require upfront capital outlay, they can deliver positive present value and returns and short paybacks, especially in new construction and replacement-at-failure scenarios, where at a minimum, non-networked LED streetlights should be considered. Incentive programs can help offset some of the initial costs and differentiate higher quality products. Many standards and voluntary rating programs are being developed to further assist potential LED street lighting customers in selecting appropriate products, such as DOE's ENERGY STAR criteria for SSL outdoor lighting and IESNA's forthcoming TM-21 that is expected to provide standard methods for predicting LED device life. Similar standards development on the network controls side would also be helpful.

Appendix A: Monitoring Data

POWER DATA

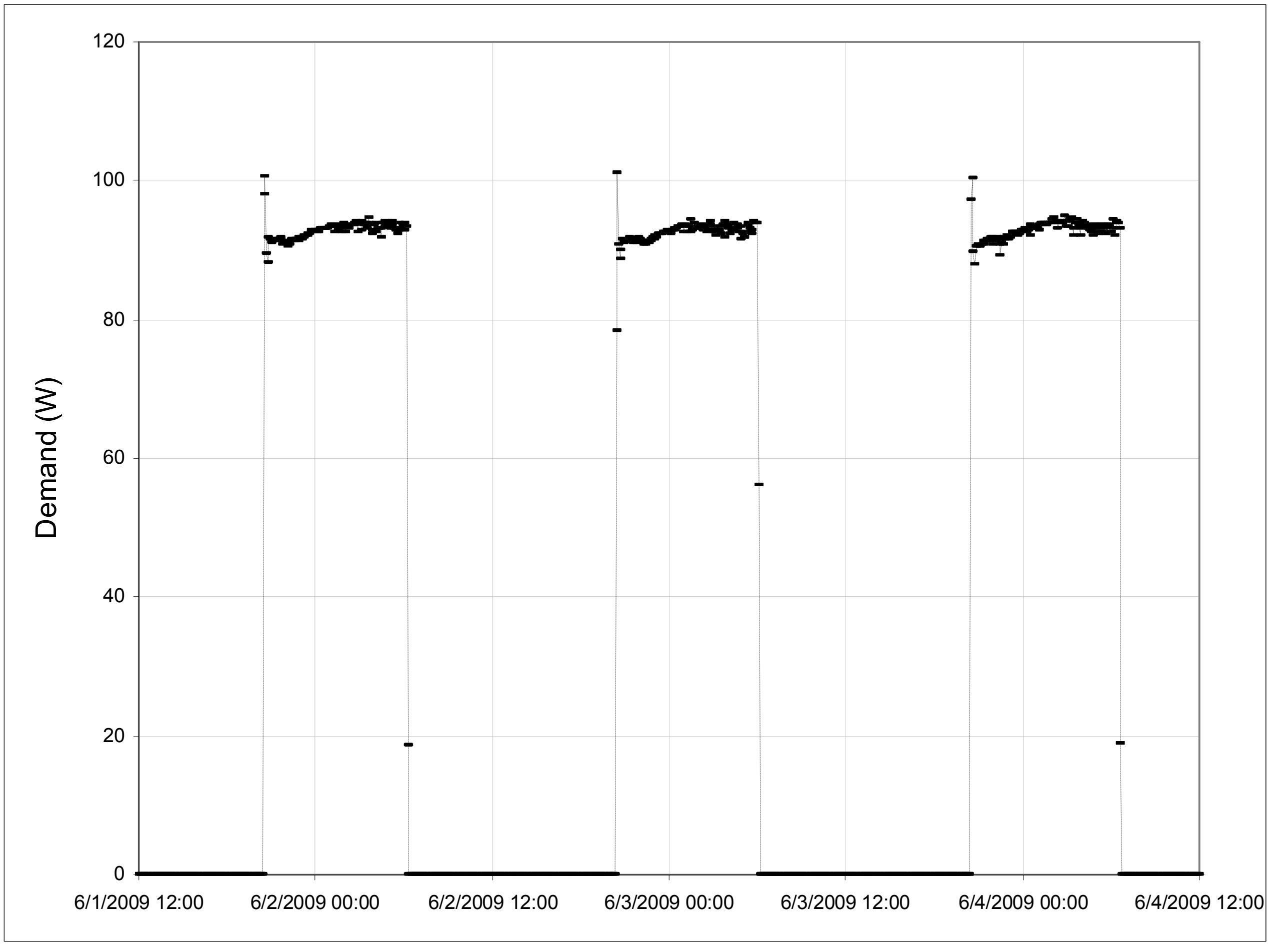

Figure 31: Sample of LPS Power Demand Data Series

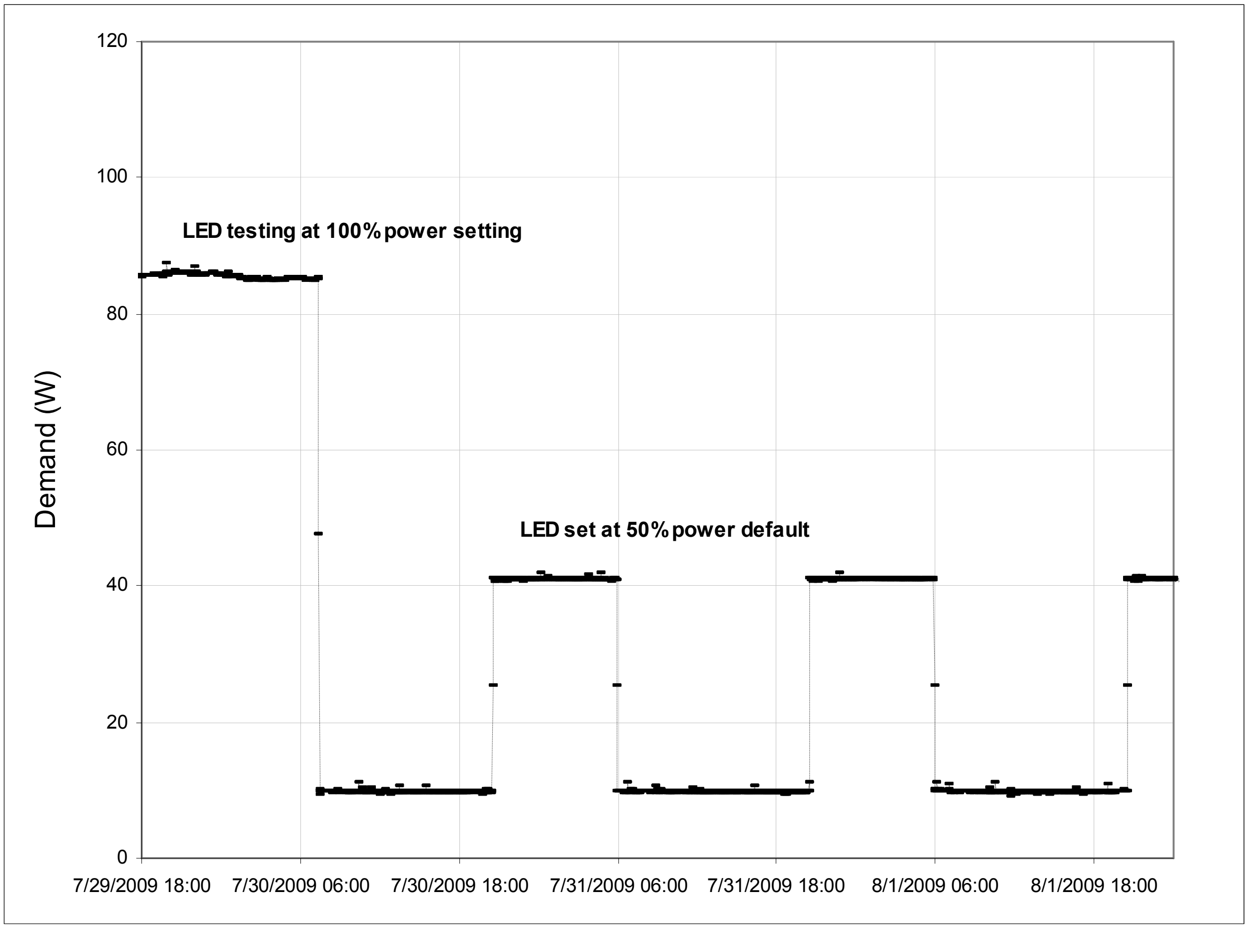

Figure 32: Sample of LED Power Demand Data Series

MEASURED ILLUMINANCE DATA

LPS Fixture Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.5	0.6	0.4	0.3	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.2		11.25'
4	0.3	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.6	0.4	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.4	15.75'
5	0.4	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.3	0.3	0.4	20.25'
6	0.4	0.3	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.3	0.3	0.4	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXV: Photopic Illuminance (fc) for LPS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.1	0.1	0.1		11.25'
4	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.1	0.1	0.2	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.1	0.1	0.2	0.2	15.75'
5	0.1	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	20.25'
6	0.2	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXVI: Scotopic Illuminance (fc) for LPS

LED 100% Power setting Fixture Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.6	0.4	0.2	0.2	0.1	0.0	0.0	0.1	0.0	0.1	0.2	0.2	0.6	0.9	0.9	0.7	0.3	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.6	11.25'
4	0.6	0.5	0.2	0.3	0.1	0.0	0.0	0.1	0.1	0.1	0.3	0.3	0.5	0.7	0.8	0.6	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.7	15.75'
5	0.7	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.1	0.1	0.3	0.2	0.4	0.7	0.8	0.5	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.7	20.25'
6	0.9	0.6	0.3	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.6	0.6	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.5	1.0	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXVII: Photopic Illuminance (fc) for LED at 100% Power Setting

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	1.2	0.8	0.4	0.5	0.3	0.1	0.1	0.2	0.1	0.2	0.4	0.4	1.3	2.1	1.8	1.4	0.6	0.5	0.2	0.1	0.2	0.4	0.6	0.5	0.9	1.4	11.25'
4	1.3	0.9	0.5	0.6	0.3	0.1	0.1	0.2	0.2	0.2	0.5	0.7	1.0	1.6	1.6	1.2	0.5	0.5	0.3	0.2	0.1	0.4	0.6	0.6	0.9	1.5	15.75'
5	1.4	1.0	0.5	0.5	0.2	0.1	0.1	0.1	0.2	0.3	0.5	0.4	1.0	1.5	1.6	1.1	0.5	0.5	0.3	0.2	0.1	0.4	0.7	0.6	1.1	1.6	20.25'
6	1.9	1.3	0.6	0.4	0.2	0.1	0.1	0.2	0.2	0.2	0.5	0.5	0.8	1.3	1.3	0.8	0.6	0.4	0.3	0.2	0.1	0.5	0.6	0.6	1.2	2.2	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXVIII: Scotopic Illuminance (fc) for LED at 100% Power Setting

LED 75% Power setting Fixture Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.5	0.4	0.2	0.2	0.1	0.1	0.0	0.0	0.1	0.2	0.2	0.2	0.4	0.7	0.7	0.6	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.4	11.25'
4	0.5	0.4	0.2	0.2	0.1	0.1	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.4	0.2	0.2	0.2	0.1	0.0	0.1	0.2	0.2	0.4	0.5	15.75'
5	0.5	0.4	0.2	0.1	0.2	0.1	0.0	0.1	0.1	0.2	0.2	0.2	0.4	0.6	0.6	0.4	0.3	0.3	0.1	0.1	0.0	0.2	0.2	0.2	0.4	0.5	20.25'
6	0.7	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.5	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.7	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXIX: Photopic Illuminance (fc) for LED at 75% Power Setting

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	1.1	0.7	0.4	0.3	0.3	0.1	0.1	0.1	0.2	0.3	0.5	0.6	1.0	1.6	1.6	1.4	0.5	0.4	0.3	0.3	0.1	0.2	0.3	0.4	0.6	0.9	11.25'
4	1.1	0.8	0.4	0.3	0.3	0.2	0.0	0.1	0.2	0.6	0.5	0.5	0.9	1.3	1.4	1.0	0.4	0.4	0.3	0.3	0.1	0.4	0.3	0.5	0.8	1.0	15.75'
5	1.0	0.9	0.5	0.4	0.4	0.2	0.1	0.1	0.3	0.4	0.5	0.6	0.7	1.3	1.4	0.8	0.4	0.6	0.4	0.2	0.1	0.4	0.3	0.6	0.9	1.1	20.25'
6	1.5	0.9	0.4	0.2	0.3	0.1	0.2	0.1	0.2	0.1	0.4	0.4	0.7	1.2	1.1	0.8	0.4	0.5	0.3	0.2	0.1	0.5	0.5	0.5	0.9	1.5	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXX: Scotopic Illuminance (fc) for LED at 75% Power Setting

LED 50% Power setting Fixture Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.5	0.4	0.3	0.2	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.2	0.2	11.25'
4	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.4	0.4	0.3	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.2	0.2	0.3	15.75'
5	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.4	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.4	20.25'
6	0.4	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.2	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.5	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXXI: Photopic Illuminance (fc) for LED at 50% Power Setting

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.5	0.4	0.2	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.5	0.9	0.8	0.6	0.3	0.1	0.2	0.1	0.1	0.2	0.2	0.3	0.2	0.5	11.25'
4	0.5	0.3	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.2	0.2	0.1	0.4	0.7	0.7	0.5	0.2	0.1	0.2	0.1	0.2	0.2	0.3	0.3	0.3	0.6	15.75'
5	0.5	0.4	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.3	0.6	0.6	0.5	0.2	0.3	0.2	0.1	0.2	0.2	0.3	0.3	0.4	0.7	20.25'
6	0.8	0.5	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.1	0.3	0.5	0.6	0.3	0.3	0.3	0.2	0.1	0.1	0.3	0.4	0.3	0.4	1.0	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXXII: Scotopic Illuminance (fc) for LED at 50% Power Setting

MODELED ILLUMINANCE DATA

LPS Fixture Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.37	0.29	0.35	0.17	0.07	0.04	0.03	0.04	0.05	0.08	0.19	0.47	0.48	0.66	0.66	0.48	0.47	0.20	0.09	0.06	0.06	0.08	0.18	0.36	0.29	0.37	11.25'
4	0.46	0.36	0.40	0.18	0.07	0.04	0.03	0.04	0.05	0.08	0.19	0.43	0.42	0.56	0.56	0.42	0.44	0.19	0.08	0.06	0.06	0.08	0.18	0.40	0.36	0.46	15.75'
5	0.57	0.42	0.44	0.19	0.08	0.05	0.04	0.04	0.04	0.07	0.18	0.40	0.35	0.45	0.45	0.35	0.40	0.18	0.08	0.06	0.06	0.08	0.19	0.44	0.43	0.57	20.25'
6	0.66	0.49	0.47	0.19	0.08	0.05	0.04	0.04	0.04	0.07	0.17	0.35	0.29	0.36	0.36	0.29	0.35	0.18	0.08	0.05	0.06	0.09	0.20	0.47	0.49	0.67	24.75'
7	11 P186																									11 P188	29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXXIII: Modeled Photopic Illuminance (fc) for LPS

LED Fixture Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.59	0.44	0.30	0.20	0.15	0.10	0.07	0.08	0.13	0.20	0.24	0.35	0.62	0.68	0.68	0.62	0.35	0.25	0.22	0.17	0.15	0.17	0.21	0.30	0.44	0.59	11.25'
4	0.66	0.49	0.33	0.23	0.17	0.12	0.08	0.08	0.12	0.19	0.24	0.35	0.53	0.64	0.64	0.53	0.35	0.25	0.21	0.17	0.16	0.19	0.24	0.34	0.49	0.66	15.75'
5	0.64	0.53	0.35	0.24	0.19	0.12	0.08	0.08	0.11	0.17	0.23	0.33	0.49	0.66	0.66	0.49	0.34	0.24	0.19	0.16	0.17	0.21	0.25	0.36	0.54	0.64	20.25'
6	0.69	0.63	0.35	0.24	0.20	0.13	0.08	0.07	0.10	0.15	0.20	0.29	0.43	0.58	0.58	0.43	0.30	0.21	0.17	0.15	0.17	0.22	0.25	0.35	0.63	0.69	24.75'
7	11 P186																									11 P188	29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXXIV: Modeled Photopic Illuminance (fc) for LED at 100% Power Setting

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.50	0.37	0.25	0.17	0.13	0.09	0.06	0.07	0.11	0.17	0.21	0.30	0.53	0.58	0.58	0.53	0.30	0.21	0.19	0.15	0.13	0.15	0.18	0.26	0.37	0.50	11.25'
4	0.56	0.42	0.28	0.20	0.15	0.10	0.07	0.07	0.11	0.16	0.21	0.30	0.46	0.55	0.55	0.46	0.30	0.21	0.18	0.14	0.14	0.17	0.20	0.29	0.42	0.56	15.75'
5	0.55	0.46	0.30	0.21	0.16	0.11	0.07	0.07	0.10	0.15	0.20	0.28	0.42	0.56	0.56	0.42	0.29	0.20	0.17	0.14	0.14	0.18	0.21	0.30	0.46	0.55	20.25'
6	0.59	0.54	0.30	0.21	0.17	0.11	0.07	0.06	0.09	0.13	0.17	0.25	0.37	0.50	0.50	0.37	0.25	0.18	0.15	0.13	0.15	0.19	0.21	0.30	0.54	0.59	24.75'
7		11 P186																							11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXXV: Modeled Photopic Illuminance (fc) for LED at 75% Power Setting

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.34	0.25	0.17	0.12	0.09	0.06	0.04	0.05	0.08	0.12	0.14	0.20	0.35	0.39	0.39	0.35	0.20	0.14	0.13	0.10	0.09	0.10	0.12	0.17	0.25	0.34	11.25'
4	0.38	0.28	0.19	0.13	0.10	0.07	0.05	0.05	0.07	0.11	0.14	0.20	0.31	0.37	0.37	0.31	0.20	0.14	0.12	0.10	0.09	0.11	0.14	0.19	0.28	0.38	15.75'
5	0.37	0.31	0.20	0.14	0.11	0.07	0.05	0.05	0.07	0.10	0.13	0.19	0.28	0.38	0.38	0.28	0.19	0.14	0.11	0.09	0.10	0.12	0.14	0.20	0.31	0.37	20.25'
6	0.39	0.36	0.20	0.14	0.12	0.08	0.05	0.04	0.06	0.09	0.12	0.17	0.25	0.33	0.33	0.25	0.17	0.12	0.10	0.09	0.10	0.13	0.14	0.20	0.36	0.39	24.75'
7		11 P186																							11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XXXVI: Modeled Photopic Illuminance (fc) for LED at 50% Power Setting

CORRELATED COLOR TEMPERATURE

Table XXXVII: Color Correlated Temperature of LPS and LED Luminaires

LPS Luminaires	Correlated Color Temp (K)	LED Luminaires (100% Setting)	Correlated Color Temp (K)	LED Luminaires (75% Setting)	Correlated Color Temp (K)	LED Luminaires (50% Setting)	Correlate d Color Temp (K)
1	1682	**1**	6398	**1**	6331	**1**	6035
2	1719	**2**	6570	**2**	6403	**2**	6168
3	1691	**3**	6522	**3**	6418	**3**	6115
Avg	***1697***	***Avg***	***6497***	***Avg***	***6384***	***Avg***	***6106***

Appendix B: Mesopic Illuminance Calculations

For mesopic calculations, field photopic and scotopic illuminance measurements were converted to luminance values, assuming a reflectance of 0.07 (IES road surface class R 2, 3):

1) fc to lx: E (illuminance, lx) = E (illuminance, fc) / (0.092903 fc/lx)

2) L (luminance, cd/m^2) = E (illuminance, lx) * P (surface reflectance, 0.07) / Π

The end of this appendix includes data tables of the converted photopic and scotopic luminance values for the LPS streetlights and the LED streetlights at 50% power setting.

Unified System of Photometry

With field illuminance data converted to luminance, using the unified system of photometry to calculate mesopic luminance is straightforward. Rea's closed-form expression for combining photopic and scotopic luminance levels to calculate unified (mesopic) luminance, as published in the ASSIST article referenced in the text, is:

$$L_{mesopic}\ (cd/m^2) = 0.834P - 0.335S - 0.2 + \sqrt{(0.696P^2 - 0.333P\ \ 0.56PS + 0.113S^2 + 0.537S + 0.04)}$$

P = photopic luminance (cd/m^2)
S = scotopic luminance (cd/m^2)

Resulting mesopic luminance was converted to mesopic illuminance for comparison with original photopic levels and mesopic results from other models. These values are presented in the tables at the end of this appendix.

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. 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's mesopic spectral luminous efficiency function is:

$$L_{mesopic} = ((X_i * P + (1 - X_i) * S * 683/1699)) / (X_i + (1 - X_i) * (683/1699))$$

X_i is the weighting factor between the photopic and scotopic spectral luminous efficiency functions, defined as:

$$X_{i+1} = 1.49 + 0.282 * \text{Log}\ ((X_i * P/683 + (1 - X_i) * S/1699) / (1 - 0.65 * X_i + 0.65 * X_i * X_i))$$

$X_1 = 0.5$
P = photopic luminance (cd/m^2)
S = scotopic luminance (cd/m^2)

X_i converges to a single value after several iterations; the model used 20 iterations to calculate the weighting factor.

Under the LPS luminaires, several points had measurable photopic illuminance but no scotopic illuminance measurable at the study illuminometer's sensitivity. For very low scotopic luminance levels, the X_i calculation breaks down because it would require taking the log of zero or a negative number. It is likely that some scotopic illuminance, however little, was present if photopic illuminance was measured, but if the model does not allow calculation of any mesopic luminance for these points, it unfairly weights the mesopic results against the LPS source. To allow the calculator to produce mesopic value for these instances, logic was added to include a minimal level of scotopic luminance that would not have been detected.

If $L_{scotpic} = 0$ Then

$L_{scotpic} = 0.01$

Resulting mesopic luminance values, converted to illuminance, are presented in the tables at the end of this appendix.

Lumen Effectiveness Multipliers (LEM):

Based on previous studies of apparent brightness and visual performance in the mesopic range, Lewin developed LEMs in 2001 for light sources that could be multiplied into photopic luminance levels to arrive at mesopic luminance.

> "The subject is complex, and many variables are involved. If, however, better vision is achievable through judicious selection of the light source type, then it may be reasonable to treat lighting achieved with white sources as having a higher "effectiveness" than HPS lighting. The concept of "Lumen Effectiveness Multipliers", LEM, has been developed, whereby a luminance level computed using the normal photopic response curve of the eye and lamp manufacturer's rated lumens can be multiplied by the LEM to represent an effective increase in lighting level resulting from use of an improved lamp spectrum."[52]

LEM's were developed based on Adrain's brightness matching mesopic functions and He and Rea's reaction time mesopic functions (as discussed previously). The original light sources were HPS, LPS, Mercury Vapor, and Metal Halide. More recently Lewin has developed multipliers for four additional light sources; warm and cool white LEDs, warm and cool white Induction.

Lewin's brightness matching function LEMs were used here. LEMs are only published for certain photopic luminance levels, as shown in the following table. Because converted luminance values from field data ranged from 0 to over 0.14cd/m^2, it was necessary to interpolate between reported LEMs. Logarithmic regressions of LEMs as a function of photopic luminance were computed through the range of published LEMs for LPS and cool white LEDs. Photopic luminance from field illuminance measurements was multiplied by the resulting LEMs to calculate mesopic luminance:

[52] Lewin, Ian. "Lumen Effectiveness Multipliers for Outdoor Lighting Design." Journal of the Illuminating Engineering Society, JIES, Summer 2001. Illuminating Engineering Society of North America, New York, NY.

Table XXXVIII: LEMs for Evaluated Light Sources and Photopic Luminance Ranges

Photopic Luminance level (cd/m^2)	.001	.01	.10	1.00	3.00	10.00
Cool White LED (5,500K CCT) LEM	2.75	2.57	2.09	1.47	1.22	1.00
LPS LEM	.47	0.51	0.61	0.82	0.95	1.00

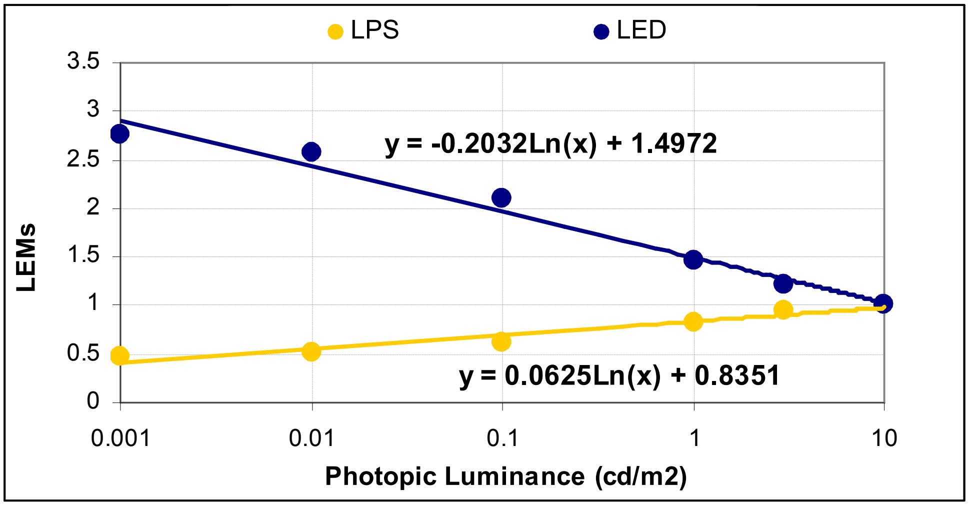

Figure 33: LEMs as a Function of Photopic Luminance

LED: $L_{mesopic} = L_{photopic} * (-0.2032 * \mathrm{Ln}\ (L_{photopic}) + 1.4972)$

LPS: $L_{mesopic} = L_{photopic} * (0.0625 * \mathrm{Ln}\ (L_{photopic}) + 0.8351)$

Resulting mesopic luminance values, converted to illuminance, are presented in the tables at the end of this appendix.

Table XXXIX: Luminance Values for LPS (Converted from Field Data)

Photopic Luminance

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1																										
2														11 P187												
3	0.048	0.048	0.048	0.048	0.024	0.024	0.024	0.024	0.048	0.048	0.048	0.048	0.072	0.120	0.144	0.096	0.072	0.048	0.048	0.024	0.024	0.024	0.048	0.072	0.048	
4	0.072	0.048	0.048	0.024	0.048	0.024	0.024	0.024	0.024	0.048	0.048	0.048	0.072	0.096	0.144	0.096	0.048	0.048	0.048	0.024	0.024	0.024	0.048	0.048	0.072	0.096
5	0.096	0.072	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.048	0.048	0.072	0.072	0.072	0.096	0.072	0.048	0.048	0.024	0.024	0.048	0.048	0.024	0.072	0.072	0.096
6	0.096	0.072	0.024	0.048	0.024	0.024	0.024	0.000	0.024	0.048	0.048	0.072	0.048	0.072	0.072	0.072	0.048	0.048	0.024	0.048	0.048	0.048	0.024	0.072	0.072	0.096
7																										
8	11 P186																								11 P188	
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'

Scotopic Luminance

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1																										
2														11 P187												
3	0.000	0.000	0.024	0.024	0.000	0.000	0.000	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.048	0.000	0.000	0.000	0.024	0.024	0.024	
4	0.024	0.024	0.024	0.024	0.024	0.000	0.000	0.000	0.000	0.048	0.024	0.000	0.024	0.024	0.048	0.000	0.000	0.024	0.048	0.000	0.000	0.000	0.024	0.024	0.048	0.048
5	0.024	0.048	0.000	0.024	0.000	0.000	0.000	0.000	0.024	0.048	0.024	0.048	0.024	0.024	0.024	0.024	0.024	0.024	0.000	0.024	0.024	0.024	0.024	0.024	0.024	0.024
6	0.048	0.048	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.024	0.024	0.048	0.024	0.024	0.048	0.048	0.048	0.024	0.024	0.024	0.024	0.024	0.000	0.024	0.024	0.024
7																										
8	11 P186																								11 P188	
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'

Table XL: Luminance Values for LED at 50% Power Setting (Converted from Field Data)

Photopic Luminance

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1																										
2														11 P187												
3	0.072	0.048	0.024	0.024	0.024	0.024	0.000	0.000	0.000	0.024	0.024	0.024	0.072	0.120	0.096	0.072	0.048	0.024	0.024	0.000	0.024	0.024	0.024	0.048	0.048	0.048
4	0.072	0.048	0.048	0.024	0.024	0.024	0.000	0.000	0.000	0.024	0.024	0.024	0.072	0.096	0.096	0.072	0.024	0.024	0.024	0.000	0.024	0.024	0.048	0.048	0.048	0.072
5	0.072	0.072	0.048	0.024	0.000	0.000	0.000	0.000	0.000	0.024	0.024	0.024	0.048	0.072	0.096	0.072	0.024	0.048	0.024	0.024	0.024	0.024	0.048	0.024	0.048	0.096
6	0.096	0.072	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.048	0.024	0.048	0.072	0.072	0.048	0.048	0.048	0.024	0.024	0.024	0.048	0.048	0.048	0.048	0.120
7																										
8	11 P186																								11 P188	
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'

Scotopic Luminance

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1																										
2														11 P187												
3	0.120	0.096	0.048	0.024	0.048	0.000	0.000	0.000	0.000	0.024	0.048	0.048	0.120	0.216	0.192	0.144	0.072	0.024	0.048	0.024	0.024	0.048	0.048	0.072	0.048	0.120
4	0.120	0.072	0.072	0.048	0.048	0.024	0.000	0.000	0.000	0.048	0.048	0.024	0.096	0.168	0.168	0.120	0.048	0.024	0.048	0.024	0.048	0.048	0.072	0.072	0.072	0.144
5	0.120	0.096	0.072	0.048	0.000	0.000	0.000	0.000	0.000	0.048	0.048	0.024	0.072	0.144	0.144	0.120	0.048	0.072	0.048	0.024	0.048	0.048	0.072	0.072	0.096	0.168
6	0.192	0.120	0.048	0.000	0.024	0.000	0.000	0.000	0.000	0.048	0.072	0.024	0.072	0.120	0.144	0.072	0.072	0.072	0.048	0.024	0.024	0.072	0.096	0.072	0.096	0.240
7																										
8	11 P186																								11 P188	
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'

Table XLI: MOVE Mesopic Illuminance Values for LPS

Mesopic Illuminance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.09	0.09	0.14	0.14	0.05	0.05	0.05	0.10	0.14	0.14	0.14	0.14	0.19	0.32	0.39	0.25	0.19	0.14	0.20	0.05	0.05	0.05	0.14	0.19	0.14	0.00	11.25'
4	0.19	0.14	0.14	0.10	0.14	0.05	0.05	0.05	0.05	0.20	0.14	0.09	0.19	0.25	0.44	0.22	0.09	0.14	0.20	0.05	0.05	0.05	0.14	0.14	0.25	0.31	15.75'
5	0.25	0.25	0.05	0.10	0.05	0.05	0.05	0.05	0.10	0.20	0.14	0.25	0.19	0.19	0.25	0.19	0.14	0.14	0.05	0.10	0.14	0.14	0.10	0.19	0.19	0.25	20.25'
6	0.31	0.25	0.05	0.14	0.05	0.05	0.05	0.04	0.05	0.14	0.14	0.25	0.14	0.19	0.25	0.25	0.20	0.14	0.10	0.14	0.14	0.14	0.05	0.19	0.19	0.25	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XLII: MOVE Mesopic Illuminance Values for LED at 50% Power Setting

Mesopic Illuminance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.38	0.29	0.16	0.10	0.16	0.00	0.00	0.00	0.00	0.10	0.16	0.16	0.38	0.64	0.55	0.42	0.25	0.10	0.16	0.08	0.10	0.16	0.16	0.25	0.20	0.33	11.25'
4	0.38	0.25	0.25	0.16	0.16	0.10	0.00	0.00	0.00	0.16	0.16	0.10	0.34	0.51	0.51	0.38	0.16	0.10	0.16	0.08	0.16	0.16	0.25	0.25	0.25	0.42	15.75'
5	0.38	0.34	0.25	0.16	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.10	0.25	0.42	0.48	0.38	0.16	0.25	0.16	0.10	0.16	0.16	0.25	0.20	0.29	0.51	20.25'
6	0.55	0.38	0.20	0.00	0.08	0.00	0.00	0.00	0.00	0.16	0.25	0.10	0.25	0.38	0.42	0.25	0.25	0.25	0.16	0.10	0.10	0.25	0.29	0.25	0.29	0.67	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XLIII: Unified Photometry Mesopic Illuminance Values for LPS

Mesopic Illuminance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.00	0.00	0.11	0.11	0.00	0.00	0.00	0.10	0.11	0.11	0.11	0.11	0.12	0.16	0.18	0.14	0.12	0.11	0.20	0.00	0.00	0.00	0.11	0.12	0.11	0.00	11.25'
4	0.12	0.11	0.11	0.10	0.11	0.00	0.00	0.00	0.00	0.20	0.11	0.00	0.12	0.14	0.31	0.00	0.00	0.11	0.20	0.00	0.00	0.00	0.11	0.11	0.22	0.24	15.75'
5	0.14	0.22	0.00	0.10	0.00	0.00	0.00	0.00	0.10	0.20	0.11	0.22	0.12	0.12	0.14	0.12	0.11	0.11	0.00	0.10	0.11	0.11	0.10	0.12	0.12	0.14	20.25'
6	0.24	0.22	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.22	0.11	0.12	0.22	0.22	0.20	0.11	0.10	0.11	0.11	0.11	0.00	0.12	0.12	0.14	24.75'
7		11 P186																							11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XLIV: Unified Photometry Mesopic Illuminance Values for LED at 50% Power Setting

Mesopic Illuminance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.43	0.35	0.18	0.10	0.18	0.00	0.00	0.00	0.00	0.10	0.18	0.18	0.43	0.71	0.62	0.49	0.28	0.10	0.18	0.09	0.10	0.18	0.18	0.28	0.20	0.41	11.25'
4	0.43	0.28	0.28	0.18	0.18	0.10	0.00	0.00	0.00	0.18	0.18	0.10	0.37	0.58	0.58	0.43	0.18	0.10	0.18	0.09	0.18	0.18	0.28	0.28	0.28	0.49	15.75'
5	0.43	0.37	0.28	0.18	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.10	0.28	0.49	0.52	0.43	0.18	0.28	0.18	0.10	0.18	0.18	0.28	0.26	0.35	0.58	20.25'
6	0.62	0.43	0.20	0.00	0.09	0.00	0.00	0.00	0.00	0.18	0.28	0.10	0.28	0.43	0.49	0.28	0.28	0.28	0.18	0.10	0.10	0.28	0.35	0.28	0.35	0.75	24.75'
7		11 P186																							11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XLV: LEM Mesopic Illuminance Values for LPS

Mesopic Illuminance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.13	0.13	0.13	0.13	0.06	0.06	0.06	0.06	0.13	0.13	0.13	0.13	0.20	0.35	0.43	0.28	0.20	0.13	0.13	0.06	0.06	0.06	0.13	0.20	0.13	0.00	11.25'
4	0.20	0.13	0.13	0.06	0.13	0.06	0.06	0.06	0.06	0.13	0.13	0.13	0.20	0.28	0.43	0.28	0.13	0.13	0.13	0.06	0.06	0.06	0.13	0.13	0.20	0.28	15.75'
5	0.28	0.20	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.13	0.13	0.20	0.20	0.20	0.28	0.20	0.13	0.13	0.06	0.06	0.13	0.13	0.06	0.20	0.20	0.28	20.25'
6	0.28	0.20	0.06	0.13	0.06	0.06	0.06	0.00	0.06	0.13	0.13	0.20	0.13	0.20	0.20	0.20	0.13	0.13	0.06	0.13	0.13	0.13	0.06	0.20	0.20	0.28	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Table XLVI: LEM Mesopic Illuminance Values for LED at 50% Power Setting

Mesopic Illuminance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1																											2.25'
2														11 P187													6.75'
3	0.61	0.42	0.23	0.23	0.23	0.23	0.00	0.00	0.00	0.23	0.23	0.23	0.61	0.96	0.79	0.61	0.42	0.23	0.23	0.00	0.23	0.23	0.23	0.42	0.42	0.42	11.25'
4	0.61	0.42	0.42	0.23	0.23	0.23	0.00	0.00	0.00	0.23	0.23	0.23	0.61	0.79	0.79	0.61	0.23	0.23	0.23	0.00	0.23	0.23	0.42	0.42	0.42	0.61	15.75'
5	0.61	0.61	0.42	0.23	0.00	0.00	0.00	0.00	0.00	0.23	0.23	0.23	0.42	0.61	0.79	0.61	0.23	0.42	0.23	0.23	0.23	0.23	0.42	0.23	0.42	0.79	20.25'
6	0.79	0.61	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.42	0.23	0.42	0.61	0.61	0.42	0.42	0.42	0.23	0.23	0.23	0.42	0.42	0.42	0.42	0.96	24.75'
7	11 P186																								11 P188		29.25'
8																											33.75'
	7.5'	22.5'	37.5'	52.5'	67.5'	82.5'	97.5'	112.5'	127.5'	142.5'	157.5'	172.5'	187.5'	202.5'	217.5'	232.5'	247.5'	262.5'	277.5'	292.5'	307.5'	322.5'	337.5'	352.5'	367.5'	382.5'	

Appendix C: Network Controls Survey Results

Emerging Technologies Street Lighting Network Controls Feedback Survey

INSTALLATION AND COMMISSIONING

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the overall ease of installation of streetlight network controls system?

   1 2 3 4 5

   Comments, including relevant feedback received from installation staff:

   4- With the installation of 118 streetlights we installed 45 segment controllers to communicate with the streetlights. With these segment controllers we installed three gateway units to connect to the internet. The streetlight installation went in without any issues it was the segment controllers and the gateways that seamed to be a major challenge requiring a redesign of the originally proposed communication system.

2. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the streetlight network controls system's compatibility with existing lighting circuits and wiring (i.e. required modifications to local wiring, hardware, etc)?

   1 2 3 4 5

   Comments: 4 – This was challenge due to power line communication system. Additional segment controllers needed to be added due to the fact that in residential areas throughout the City, PG&E can only feed a limited number of streetlight on each circuit. Thus requiring the communication network to be redesigned with an additional number of segment controllers, this was in lieu of having PG&E modify their circuits.

3. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the training required to prepare your field staff for system installation?

1 2 3 4 5

Comments: 1 - We where in charge of installing the units on the streetlight poles and connecting power to the units. The installation was straight forward on mounting and connection. We did spend a considerable amount of time with the contractor assisting him on making sure the communication was working.

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the commissioning process for the controls network, i.e. programming and populating the streetlight database in the system, establishing communication and connectivity across the network, and network interface setup?

   1 2 3 4 5

   Comments: 2 – This was the contractors responsibility to set up the software and populate with the City streetlight inventory. This web based program was fairly simple to connect with, and navigate through the Street Vision program.

2. Briefly explain the process for setting up and commissioning the network controls system for your streetlights, including issues encountered and resolution to challenges in network commissioning. See comment number 4.

SYSTEM OPERATION AND FUNCTIONALITY

3. Please identify the primary users of the network controls system (organization, unit, and title):

Department of Transportation

Streetlight Section

Streetlight Supervisor

Senior Office Specialist

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the ease of use of the streetlight network control system interface and its functions?

   1 2 3 4 5

   Comments: 2 The control of individual streetlight and monitoring is self explanatory.

2. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the training and experience required for you or your staff to become familiar and comfortable with operating the streetlight network controls system?

   1 2 3 4 5

   Comments: Ask Kelly

3. On a scale of 1-5, with 1 being the most useful and 5 being the least useful, how would you characterize the usefulness of the functions that the streetlight network controls system provides to improve streetlight operations and management practices?

   1 2 3 4 5

   Comments: 2 Real time command of the streetlight with dimming capability will allow the City to operate the streetlights more efficiently. This will provide the option of adaptive or dimming the lights at a given time.

4. On a scale of 1-5, with 1 being very high and 5 being very low, how would you characterize the energy benefits that the network controls system provides your street lighting system?

   1 2 3 4 5

   Comments: 2 The streetlight is designed to operate at a maximum output of 82 watt, currently we are using the network controls to operate the streetlights at 38 watt. We also have the capability of dimming the lights even further in the early morning.

1. On a scale of 1-5, with 1 being very high and 5 being very low, how would you characterize the maintenance benefits that the network controls system provides your street lighting system?

   1 2 3 4 5

   Comments: 3 The elimination of the photocell takes out the possibility of the light coming on during the day and reduces the number of complaints reported to the City.

2. On a scale of 1-5, with 1 being the most useful and 5 being the least useful, how would you characterize the usefulness of the data and reporting capabilities that the controls network offers?

   1 2 3 4 5

   Comments: 1 – The network reports are valuable in determining the system efficiency.

Please indicate which functions are available in the network control interface and which you plan to use:

	Available	Plan to Use
Manual Scheduling	☒	☐
Time clock Scheduling	☒	☐
Dimming	☒	☐
Streetlight grouping	☒	☐
Energy monitoring	☒	☐
Ballast, luminaire temperature	☐	☐
Voltage fluctuation	☐	☐
Pole Tilt	☐	☐
Outage detection	☐	☐
Maintenance tickets, reports	☐	☐
Data reports	☒	☐
Other features:		
	☐	☐
	☐	☐
	☐	☐

1. If this technology met your minimum cost-effectiveness requirements, would you be inclined to implement it widely throughout your street lighting fleet?

   Yes No Maybe

   Comments: At this time the system is still under evaluation.

CUSTOMER SUPPORT

2. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the customer support from the streetlight network controls manufacturer or vendor?

   1 2 3 4 5

   Comments: 1 – The installation City forces installed all equipment in the field, we had a single contact that assisted with the installing of the equipment. An questions or issues that may have come up where promptly addressed.

OVERALL SATISFACTION

3. On a scale of 1-5, with 1 being the highest and 5 being the lowest, how would you rate your overall satisfaction with the streetlight network controls system?

   1 2 3 4 5

   Final Comments: 3 – With some of the deficiencies above the City is proving feedback to the contractor in order to address some of the issues.

Emerging Technologies Street Lighting Network Controls Feedback Survey

INSTALLATION AND COMMISSIONING

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the overall ease of installation of streetlight network controls system?

   1 2 3 4 5

   Comments, including relevant feedback received from installation staff:

2. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the streetlight network controls system's compatibility with existing lighting circuits and wiring (i.e. required modifications to local wiring, hardware, etc)?

   1 2 3 4 5

   Comments:

3. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the training required to prepare your field staff for system installation?

   1 2 3 4 5

   Comments:

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the commissioning process for the controls network, i.e. programming and populating the streetlight database in the system, establishing communication and connectivity across the network, and network interface setup?

   1 2 3 4 5

   Comments:

2. Briefly explain the process for setting up and commissioning the network controls system for your streetlights, including issues encountered and resolution to challenges in network commissioning.

SYSTEM OPERATION AND FUNCTIONALITY

3. Please identify the primary users of the network controls system (organization, unit, and title):

Kelly Noble (City of San Jose, Streetlight Maintenance, Senior Office Specialist)

Tony Ortiz (City of San Jose, Streetlight Maintenance, Electrical Supervisor)

4. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the ease of use of the streetlight network control system interface and its functions?

   1 **2** 3 4 5

   Comments:

Its simple once you get the hang of the system, but until then it's a little difficult to understand. The other difficult part is trying to figure out how to schedule different wattages for specific lights on certain days (ie Fourth of July).

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the training and experience required for you or your staff to become familiar and comfortable with operating the streetlight network controls system?

   1 2 3 4 5

   Comments:

   The training received was simple, but I would have liked a little more hands on to fully grasp all aspects of the program.

2. On a scale of 1-5, with 1 being the most useful and 5 being the least useful, how would you characterize the usefulness of the functions that the streetlight network controls system provides to improve streetlight operations and management practices?

   1 2 3 4 5

   Comments:

   All the functions are useful once you get the hand of how to work the program.

3. On a scale of 1-5, with 1 being very high and 5 being very low, how would you characterize the energy benefits that the network controls system provides your street lighting system?

   1 2 3 4 5

   Comments:

   The LED lights use about half the energy as the LPS/HPS lights did.

4. On a scale of 1-5, with 1 being very high and 5 being very low, how would you characterize the maintenance benefits that the network controls system provides your street lighting system?

   1 2 3 4 5

   Comments:

   At this time we are just monitoring, not really using the program for maintenance or reporting capabilities. I believe though when we finally do use it for those characteristics that it would be very beneficial.

5. On a scale of 1-5, with 1 being the most useful and 5 being the least useful, how would you characterize the usefulness of the data and reporting capabilities that the controls network offers?

   1 2 3 4 5

Comments:

At this time we are just monitoring, not really using the program for maintenance or reporting capabilities. I believe though when we finally do use it for those characteristics that it would be very beneficial.

Please indicate which functions are available in the network control interface and which you plan to use:

	Available	Plan to Use
Manual Scheduling	☒	☐
Time clock Scheduling	☒	☐
Dimming	☒	☐
Streetlight grouping	☐	☐
Energy monitoring	☒	☐
Ballast, luminaire temperature	☐	☐
Voltage fluctuation	☐	☐
Pole Tilt	☐	☐
Outage detection	☒	☐
Maintenance tickets, reports	☒	☐
Data reports	☒	☐
Other features:		
	☐	☐
	☐	☐
	☐	☐

1. If this technology met your minimum cost-effectiveness requirements, would you be inclined to implement it widely throughout your street lighting fleet?

   Yes No Maybe

Comments:

Unsure this would be something Tony would be more inclined to answer.

CUSTOMER SUPPORT

1. On a scale of 1-5, with 1 being the easiest and 5 being the most difficult, how would you characterize the customer support from the streetlight network controls manufacturer or vendor?

   1 2 3 4 5

   Comments:

OVERALL SATISFACTION

2. On a scale of 1-5, with 1 being the highest and 5 being the lowest, how would you rate your overall satisfaction with the streetlight network controls system?

   1 **2** 3 4 5

   Final Comments:

   So far I am satisfied with this program.

Appendix D: Economic Data and Calculations

Project Economic Assumptions: New Construction

Scenario:	Networked LEDs, 50% Power Setting	Non-networked LEDs, 50% Power Setting	Adaptive Networked LEDs	
Costs and Savings				
Incremental Cost[1]	$128.49	$9.13	$128.49	/fixture
Annual Energy Savings	$26.22	$26.22	$29.96	/fixture
Annual Maintenance Savings	$28.00	$20.00	$28.00	/fixture
Payback and Financing				
Simple Payback[2]	2.4	0.2	2.2	yrs
Energy Cost Escalation	3%	3%	3%	/yr
Maintenance Cost Escalation	2%	2%	2%	/yr
Discount Rate[3]	4%	4%	4%	/yr
Term of Analysis	15	15	15	yrs

[1] LED Luminaire Cost - LPS Luminaire Cost

[2] Incremental Cost / [Annual Maintenance Savings + Annual Energy Savings]

[3] Rate used in this analysis is an estimated cost of capital for municipal efficiency investments. Discount rate and escalation rates are highly variable.

Project Economic Assumptions: Retrofit

Scenario:	Networked LEDs, 50% Power Setting	Non-networked LEDs, 50% Power Setting	Adaptive Networked LEDs	
Costs and Savings				
Incremental Cost[1]	$565.13	$445.77	$565.13	/fixture
Annual Energy Savings	$26.22	$26.22	$29.96	/fixture
Annual Maintenance Savings	$28.00	$20.00	$28.00	/fixture
Payback and Financing				
Simple Payback[2]	10.4	9.6	9.8	yrs
Energy Cost Escalation	3%	3%	3%	/yr
Maintenance Cost Escalation	2%	2%	2%	/yr
Discount Rate[3]	4%	4%	4%	/yr
Term of Analysis	15	15	15	yrs

[1] LED Luminaire Cost + Installation Cost

[2] Incremental Cost / [Annual Maintenance Savings + Annual Energy Savings]

[3] Rate used in this analysis is an estimated cost of capital for municipal efficiency investments. Discount rate and escalation rates are highly variable.

Project Cashflow, NPV, and IRR: New Construction

Scenario: **Networked LEDs, 50% Power Setting**

Year:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Escalated energy savings:		$ 27.01	$ 27.82	$ 28.65	$ 29.51	$ 30.40	$ 31.31	$ 32.25	$ 33.21	$ 34.21	$ 35.24	$ 36.29	$ 37.38	$ 38.50	$ 39.66	$ 40.85
Escalated maintenance savings:		$ 28.56	$ 29.13	$ 29.71	$ 30.31	$ 30.91	$ 31.53	$ 32.16	$ 32.81	$ 33.46	$ 34.13	$ 34.81	$ 35.51	$ 36.22	$ 36.95	$ 37.68
Initial investment:	-$128.49															
Total project revenue:	-$128.49	$ 55.57	$ 56.95	$ 58.37	$ 59.82	$ 61.31	$ 62.84	$ 64.41	$ 66.02	$ 67.67	$ 69.37	$ 71.11	$ 72.89	$ 74.73	$ 76.61	$ 78.53
Discounted project revenue:	-$128.49	$ 53.43	$ 52.65	$ 51.89	$ 51.13	$ 50.39	$ 49.66	$ 48.95	$ 48.24	$ 47.55	$ 46.86	$ 46.19	$ 45.53	$ 44.88	$ 44.24	$ 43.61

NPV: **$ 596.71**
IRR: **45.51%**

Project Cashflow, NPV, and IRR: New Construction

Scenario: **Non-networked LEDs, 50% Power Setting**

Year:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Escalated energy savings:		$ 27.01	$ 27.82	$ 28.65	$ 29.51	$ 30.40	$ 31.31	$ 32.25	$ 33.21	$ 34.21	$ 35.24	$ 36.29	$ 37.38	$ 38.50	$ 39.66	$ 40.85
Escalated maintenance savings:		$ 20.40	$ 20.81	$ 21.22	$ 21.65	$ 22.08	$ 22.52	$ 22.97	$ 23.43	$ 23.90	$ 24.38	$ 24.87	$ 25.36	$ 25.87	$ 26.39	$ 26.92
Initial investment:	-$9.13															
Total project revenue:	-$9.13	$ 47.41	$ 48.62	$ 49.88	$ 51.16	$ 52.48	$ 53.83	$ 55.22	$ 56.65	$ 58.11	$ 59.62	$ 61.16	$ 62.75	$ 64.38	$ 66.05	$ 67.77
Discounted project revenue:	-$9.13	$ 45.58	$ 44.96	$ 44.34	$ 43.73	$ 43.13	$ 42.54	$ 41.96	$ 41.39	$ 40.83	$ 40.28	$ 39.73	$ 39.19	$ 38.66	$ 38.14	$ 37.63

NPV: **$ 612.97**
IRR: **521.81%**

Project Cashflow, NPV, and IRR: New Construction

Scenario: **Adaptive Networked LEDs**

Year:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Escalated energy savings:		$ 30.86	$ 31.78	$ 32.74	$ 33.72	$ 34.73	$ 35.77	$ 36.84	$ 37.95	$ 39.09	$ 40.26	$ 41.47	$ 42.71	$ 43.99	$ 45.31	$ 46.67
Escalated maintenance savings:		$ 28.56	$ 29.13	$ 29.71	$ 30.31	$ 30.91	$ 31.53	$ 32.16	$ 32.81	$ 33.46	$ 34.13	$ 34.81	$ 35.51	$ 36.22	$ 36.95	$ 37.68
Initial investment:	-$128.49															
Total project revenue:	-$128.49	$ 59.42	$ 60.91	$ 62.45	$ 64.03	$ 65.64	$ 67.30	$ 69.01	$ 70.76	$ 72.55	$ 74.39	$ 76.28	$ 78.22	$ 80.22	$ 82.26	$ 84.36
Discounted project revenue:	-$128.49	$ 57.13	$ 56.32	$ 55.52	$ 54.73	$ 53.95	$ 53.19	$ 52.44	$ 51.70	$ 50.97	$ 50.26	$ 49.55	$ 48.86	$ 48.18	$ 47.50	$ 46.84

NPV: **$ 648.66**
IRR: **48.59%**

Project Cashflow, NPV, and IRR: Retrofit

Scenario: **Networked LEDs, 50% Power Setting**

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Escalated energy savings:		$ 27.01	$ 27.82	$ 28.65	$ 29.51	$ 30.40	$ 31.31	$ 32.25	$ 33.21	$ 34.21	$ 35.24	$ 36.29	$ 37.38	$ 38.50	$ 39.66	$ 40.85
Escalated maintenance savings:		$ 28.56	$ 29.13	$ 29.71	$ 30.31	$ 30.91	$ 31.53	$ 32.16	$ 32.81	$ 33.46	$ 34.13	$ 34.81	$ 35.51	$ 36.22	$ 36.95	$ 37.68
Initial investment:	-$565.13															
Total project revenue:	-$565.13	$ 55.57	$ 56.95	$ 58.37	$ 59.82	$ 61.31	$ 62.84	$ 64.41	$ 66.02	$ 67.67	$ 69.37	$ 71.11	$ 72.89	$ 74.73	$ 76.61	$ 78.53
Discounted project revenue:	-$565.13	$ 53.43	$ 52.65	$ 51.89	$ 51.13	$ 50.39	$ 49.66	$ 48.95	$ 48.24	$ 47.55	$ 46.86	$ 46.19	$ 45.53	$ 44.88	$ 44.24	$ 43.61

NPV: $ **160.07**
IRR: **7.56%**

Project Cashflow, NPV, and IRR: Retrofit

Scenario: **Non-networked LEDs, 50% Power Setting**

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Escalated energy savings:		$ 27.01	$ 27.82	$ 28.65	$ 29.51	$ 30.40	$ 31.31	$ 32.25	$ 33.21	$ 34.21	$ 35.24	$ 36.29	$ 37.38	$ 38.50	$ 39.66	$ 40.85
Escalated maintenance savings:		$ 20.40	$ 20.81	$ 21.22	$ 21.65	$ 22.08	$ 22.52	$ 22.97	$ 23.43	$ 23.90	$ 24.38	$ 24.87	$ 25.36	$ 25.87	$ 26.39	$ 26.92
Initial investment:	-$445.77															
Total project revenue:	-$445.77	$ 47.41	$ 48.62	$ 49.88	$ 51.16	$ 52.48	$ 53.83	$ 55.22	$ 56.65	$ 58.11	$ 59.62	$ 61.16	$ 62.75	$ 64.38	$ 66.05	$ 67.77
Discounted project revenue:	-$445.77	$ 45.58	$ 44.96	$ 44.34	$ 43.73	$ 43.13	$ 42.54	$ 41.96	$ 41.39	$ 40.83	$ 40.28	$ 39.73	$ 39.19	$ 38.66	$ 38.14	$ 37.63

NPV: $ **176.33**
IRR: **8.84%**

Project Cashflow, NPV, and IRR: Retrofit

Scenario: **Adaptive Networked LEDs**

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Escalated energy savings:		$ 30.86	$ 31.78	$ 32.74	$ 33.72	$ 34.73	$ 35.77	$ 36.84	$ 37.95	$ 39.09	$ 40.26	$ 41.47	$ 42.71	$ 43.99	$ 45.31	$ 46.67
Escalated maintenance savings:		$ 28.56	$ 29.13	$ 29.71	$ 30.31	$ 30.91	$ 31.53	$ 32.16	$ 32.81	$ 33.46	$ 34.13	$ 34.81	$ 35.51	$ 36.22	$ 36.95	$ 37.68
Initial investment:	-$565.13															
Total project revenue:	-$565.13	$ 59.42	$ 60.91	$ 62.45	$ 64.03	$ 65.64	$ 67.30	$ 69.01	$ 70.76	$ 72.55	$ 74.39	$ 76.28	$ 78.22	$ 80.22	$ 82.26	$ 84.36
Discounted project revenue:	-$565.13	$ 57.13	$ 56.32	$ 55.52	$ 54.73	$ 53.95	$ 53.19	$ 52.44	$ 51.70	$ 50.97	$ 50.26	$ 49.55	$ 48.86	$ 48.18	$ 47.50	$ 46.84

NPV: $ **212.02**
IRR: **8.62%**

Appendix E: PG&E Rate Schedule

ELECTRIC SCHEDULE LS-2 Sheet 1

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

APPLICABILITY: This schedule is applicable to services for lighting installations which illuminate streets, highways, and other outdoor ways and places where the Customer is a Governmental Agency (Agency) and owns the lighting fixtures, poles and interconnecting circuits. This schedule is also applicable for service to those installations where service is initially established in the name of a developer who has installed such systems as required by an Agency and, where ownership of facilities and responsibility for service will be transferred to an Agency. Where the Agency does not accept facilities or where no transfer is intended, service will be provided under an otherwise appropriate rate schedule and rule. Class C is closed to new installations and additional lamps in existing accounts. (D)

TERRITORY: The entirety of PG&E's service territory.

RATES: The total monthly charge per lamp is equal to the sum of the facility charge and the energy charge. The monthly charge per lamp used for billing is calculated using unrounded facility and energy charges.

Monthly facility charges include the costs of owning, operating and maintaining the various lamp types and size. Monthly energy charges are based on the kWh usage of each lamp.

Monthly energy charges per lamp are calculated using the following formula: (Lamp wattage + ballast wattage) x 4,100 hours/12 months/1000 x streetlight energy rate per kilowatt hour (kWh). Ballast wattage = ballast factor x lamp wattage.

Total bundled monthly facility and energy charges are shown below.

The various ballast wattages used in the monthly energy charge calculations can be found in the Ballast Factor table following the monthly energy charges. Ballast factors are averaged within each grouping (range of wattages). The same ballast factor is applied to all of the lamps that fall within its watt range. Applicant or Customer must provide third party documentation where manufacturer's information is not available for rated wattage consumption before PG&E will accept lamps for this schedule.

Direct Access (DA) and Community Choice Aggregation (CCA) charges shall be calculated in accordance with Condition 13, Billing, below.

(Continued)

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

Sheet 2

RATES: (Cont'd.)

Facilities Charge Per Lamp Per Month

CLASS:	A	C**
	PG&E supplies energy and service only.	PG&E supplies the energy and maintenance service as described in Special Condition 8
	$0.187	$2.688

Energy Charge Per Lamp Per Month
All Night Rates

Nominal Lamp Rating:

LAMP WATTS	kWh per MONTH	AVERAGE INITIAL LUMENS*	Per Lamp Per Month: All Classes			Half-Hour Adjustment
INCANDESCENT LAMPS:						
58	20	600	$2.441			$0.111
92	31	1,000	$3.784			$0.172
189	65	2,500	$7.934			$0.361
295	101	4,000**	$12.328			$0.560
405	139	6,000**	$16.966			$0.771
620	212	10,000**	$25.877			$1.176
860	294	15,000**	$35.886			$1.631
MERCURY VAPOR LAMPS:						
40	18	1,300	$2.197			$0.100
50	22	1,650	$2.685			$0.122
100	40	3,500	$4.882			$0.222
175	68	7,500	$8.300			$0.377
250	97	11,000	$11.840			$0.538
400	152	21,000	$18.553			$0.843
700	266	37,000	$32.468			$1.476
1,000	377	57,000	$46.017			$2.092

(D)

* 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)

ELECTRIC SCHEDULE LS-2

Sheet 3

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

RATES: (Cont'd.)

HIGH PRESSURE SODIUM VAPOR LAMPS AT: 120 VOLTS				
35	15	2,150	$1.831	$0.083
50	21	3,800	$2.563	$0.117
70	29	5,800	$3.540	$0.161
100	41	9,500	$5.004	$0.227
150	60	16,000	$7.324	$0.333
200	80	22,000	$9.765	$0.444
250	100	26,000	$12.206	$0.555
400	154	46,000	$18.797	$0.854
HIGH PRESSURE SODIUM VAPOR LAMPS AT: 240 VOLTS				
50	24	3,800	$2.929	$0.133
70	34	5,800	$4.150	$0.189
100	47	9,500	$5.737	$0.261
150	69	16,000	$8.422	$0.383
200	81	22,000	$9.887	$0.449
250	100	25,500	$12.206	$0.555
310	119	37,000	$14.525	$0.660
360	144	45,000	$17.577	$0.799
400	154	46,000	$18.797	$0.854
LOW PRESSURE SODIUM VAPOR LAMPS:				
35	21	4,800	$2.563	$0.117
55	29	8,000	$3.540	$0.161
90	45	13,500	$5.493	$0.250
135	62	21,500	$7.568	$0.344
180	78	33,000	$9.521	$0.433
METAL HALIDE LAMPS:				
70	30	5,500	$3.662	$0.166
100	41	8,500	$5.004	$0.227
150	63	13,500	$7.690	$0.350
175	72	14,000	$8.788	$0.399
250	105	20,500	$12.816	$0.583
400	162	30,000	$19.774	$0.899
1,000	387	90,000	$47.237	$2.147
INDUCTION LAMPS:				
40	14	2,200	$1.709	$0.078
55	19	3,000	$2.319	$0.105
80	27	4,500	$3.296	$0.150
85	30	4,800	$3.662	$0.166
120	42	8,500	$5.067	$0.230
150	51	10,900	$6.225	$0.283
165	58	12,000	$7.079	$0.322

(Continued)

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

Sheet 4

RATES: (Cont'd.)

LIGHT EMITTING DIODE (LED) LAMPS: 120-240 VOLTS

LAMP WATTS****	kWh per MONTH*****	A Only		Half-Hour Adjustment	
0.00-5.00	0.9	$0.110	(N)	$0.005	(N)
5.01-10.00	2.6	$0.317	(N)	$0.014	(N)
10.01-15.00	4.3	$0.525	(N)	$0.024	(N)
15.01-20.00	6.0	$0.732	(N)	$0.033	(N)
20.01-25.00	7.7	$0.940	(N)	$0.043	(N)
25.01-30.00	9.4	$1.147	(N)	$0.052	(N)
30.01-35.00	11.1	$1.355	(N)	$0.062	(N)
35.01-.40.00	12.8	$1.562	(N)	$0.071	(N)
40.01-45.00	14.5	$1.770	(N)	$0.080	(N)
45.01-50.00	16.2	$1.977	(N)	$0.090	(N)
50.01-55.00	17.9	$2.185	(N)	$0.099	(N)
55.01-60.00	19.6	$2.392	(N)	$0.109	(N)
60.01-65.00	21.4	$2.612	(N)	$0.119	(N)
65.01-70.00	23.1	$2.820	(N)	$0.128	(N)
70.01-75.00	24.8	$3.027	(N)	$0.138	(N)
75.01-80.00	26.5	$3.235	(N)	$0.147	(N)
80.01-85.00	28.2	$3.442	(N)	$0.156	(N)
85.01-90.00	29.9	$3.650	(N)	$0.166	(N)
90.01-95.00	31.6	$3.857	(N)	$0.175	(N)
95.01-100.00	33.3	$4.065	(N)	$0.185	(N)
100.01-105.00	35.0	$4.272	(N)	$0.194	(N)
105.01-110.00	36.7	$4.480	(N)	$0.204	(N)
110.01-115.00	38.4	$4.687	(N)	$0.213	(N)
115.01-120.00	40.1	$4.895	(N)	$0.223	(N)
120.01-125.00	41.9	$5.114	(N)	$0.232	(N)
125.01-130.00	43.6	$5.322	(N)	$0.242	(N)
130.01-135.00	45.3	$5.529	(N)	$0.251	(N)
135.01-140.00	47.0	$5.737	(N)	$0.261	(N)
140.01-145.00	48.7	$5.944	(N)	$0.270	(N)

(N)

(N)

(Continued)

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

Sheet 5

RATES: (Cont'd.)

LIGHT EMITTING DIODE (LED) LAMPS: 120-240 VOLTS (Cont'd.)

LAMP WATTS****	kWh per MONTH*****	A Only		Half-Hour Adjustment	
145.01-150.00	50.4	$6.152	(N)	$0.280	(N)
150.01-155.00	52.1	$6.359	(N)	$0.289	(N)
155.01-160.00	53.8	$6.567	(N)	$0.299	(N)
160.01-165.00	55.5	$6.774	(N)	$0.308	(N)
165.01-170.00	57.2	$6.982	(N)	$0.317	(N)
170.01-175.00	58.9	$7.189	(N)	$0.327	(N)
175.01-180.00	60.6	$7.397	(N)	$0.336	(N)
180.01-185.00	62.4	$7.617	(N)	$0.346	(N)
185.01-190.00	64.1	$7.824	(N)	$0.356	(N)
190.01-195.00	65.8	$8.032	(N)	$0.365	(N)
195.01-200.00	67.5	$8.239	(N)	$0.375	(N)
200.01-205.00	69.2	$8.447	(N)	$0.384	(N)
205.01-210.00	70.9	$8.654	(N)	$0.393	(N)
210.01-215.00	72.6	$8.862	(N)	$0.403	(N)
215.01-220.00	74.3	$9.069	(N)	$0.412	(N)
220.01-225.00	76.0	$9.277	(N)	$0.422	(N)
225.01-230.00	77.7	$9.484	(N)	$0.431	(N)
230.01-235.00	79.4	$9.692	(N)	$0.441	(N)
235.01-240.00	81.1	$9.899	(N)	$0.450	(N)
240.01-245.00	82.9	$10.119	(N)	$0.460	(N)
245.01-250.00	84.6	$10.326	(N)	$0.469	(N)
250.01-255.00	86.3	$10.534	(N)	$0.479	(N)
255.01-260.00	88.0	$10.741	(N)	$0.488	(N)
260.01-265.00	89.7	$10.949	(N)	$0.498	(N)
265.01-270.00	91.4	$11.156	(N)	$0.507	(N)
270.01-275.00	93.1	$11.364	(N)	$0.517	(N)
275.01-280.00	94.8	$11.571	(N)	$0.526	(N)
280.01-285.00	96.5	$11.779	(N)	$0.535	(N)

(N)

(N)

(Continued)

ELECTRIC SCHEDULE LS-2

Sheet 6

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

RATES: (Cont'd.)

LIGHT EMITTING DIODE (LED) LAMPS: 120-240 VOLTS (Cont'd.)

LAMP WATTS****	kWh per MONTH*****	A Only		Half-Hour Adjustment		
						(N)
285.01-290.00	98.2	$11.986	(N)	$0.545	(N)	|
290.01-295.00	99.9	$12.194	(N)	$0.554	(N)	|
295.01-300.00	101.6	$12.401	(N)	$0.564	(N)	|
300.01-305.00	103.4	$12.621	(N)	$0.574	(N)	|
305.01-310.00	105.1	$12.829	(N)	$0.583	(N)	|
310.01-315.00	106.8	$13.036	(N)	$0.593	(N)	|
315.01-320.00	108.5	$13.244	(N)	$0.602	(N)	|
320.01-325.00	110.2	$13.451	(N)	$0.611	(N)	|
325.01-330.00	111.9	$13.659	(N)	$0.621	(N)	|
330.01-335.00	113.6	$13.866	(N)	$0.630	(N)	|
335.01-340.00	115.3	$14.074	(N)	$0.640	(N)	|
340.01-345.00	117.0	$14.281	(N)	$0.649	(N)	|
345.01-350.00	118.7	$14.489	(N)	$0.659	(N)	|
350.01-355.00	120.4	$14.696	(N)	$0.668	(N)	|
355.01-360.00	122.1	$14.904	(N)	$0.677	(N)	|
360.01-365.00	123.9	$15.123	(N)	$0.687	(N)	|
365.01-370.00	125.6	$15.331	(N)	$0.697	(N)	|
370.01-375.00	127.3	$15.538	(N)	$0.706	(N)	|
375.01-380.00	129.0	$15.746	(N)	$0.716	(N)	|
380.01-385.00	130.7	$15.953	(N)	$0.725	(N)	|
385.01-390.00	132.4	$16.161	(N)	$0.735	(N)	|
390.01-395.00	134.1	$16.368	(N)	$0.744	(N)	|
395.01-400.00	135.8	$16.576	(N)	$0.753	(N)	|
						(N)

**** Wattage based on total consumption of lamp and driver. Customer may be required to provide verification of total energy consumption of lamp and driver upon request by PG&E.

***** Assumptions consistent with tariff, based on 4100 hours of operation for a full year; mid-point in range established by deducting 2.5 watts from highest wattage in range. The energy use calculation is: (high wattage in range-2.5 watts)x(4,100 hours/12 months/1000)

(Continued)

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

Sheet 7

RATES: (Cont'd.)

Ballast Factors by Lamp Type and Wattage Range (L)

Watt Range			Ballast Factor
MERCURY VAPOR			
1	to	75	31.00%
76	to	125	17.07%
126	to	325	13.69%
326	to	800	11.22%
801	+		10.34%
LOW PRESSURE SODIUM VAPOR			
1	to	40	75.61%
41	to	75	54.32%
76	to	110	46.34%
111	to	160	34.42%
161	+		26.83%
METAL HALIDE			
1	to	85	25.44%
86	to	200	20.39%
201	to	375	22.93%
376	to	700	18.54%
701	+		13.27%

Watt Range			Ballast Factor
HIGH PRESSURE SODIUM VAPOR			
120 Volts			
1	to	40	25.44%
41	to	60	22.93%
61	to	85	21.25%
86	to	125	20.00%
126	+		17.07%
240 Volts			
1	to	60	40.49%
61	to	85	42.16%
86	to	125	37.56%
126	to	175	34.63%
176	to	225	18.54%
226	to	280	17.07%
281	to	380	12.35%
381	+		12.68%

(Continued)

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

Sheet 8

RATES: (Cont'd.)

(L)

TOTAL ENERGY RATES

Total Energy Charge Rate ($ per kWh)	$0.12206

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	$0.08032
Distribution	$0.02507
Transmission*	$0.00650
Transmission Rate Adjustments*	($0.00096)
Reliability Services*	$0.00027
Public Purpose Programs	$0.00270
Nuclear Decommissioning	$0.00028
Competition Transition Charge	$0.00066
Energy Cost Recovery Amount	$0.00231
DWR Bond	$0.00491

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

(Continued)

ELECTRIC SCHEDULE LS-2 Sheet 9
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

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. (L)

   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**:

   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 79-1007 for installation and energizing, and form 79-1008 for removing or de-energizing Customer's facilities.

(Continued)

ELECTRIC SCHEDULE LS-2 Sheet 10
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

3. **SERVICE INSTALLATION** (L)

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. Any load, other then the lighting loads listed in the Rate table above, is non conforming load. Non conforming load may be connected to customer circuits not to exceed 150 watts per circuit, or light for individually connected lights. Loads will conform to the requirements of Agreement form 79-1048 available on PG&E's web site, http://www.pge.com/tariffs/EF.SHTML#EF for electric forms. All other non conforming load connected to unmetered LS-2 facilities exceeding this limitation requires metering of the Customer's system at PG&E's service delivery point.

(Continued)

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

SPECIAL CONDITIONS: (Cont'd.)

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

   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.

(Continued)

ELECTRIC SCHEDULE LS-2 Sheet 12
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

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, and may be applied for 24-hour operation. Photo control devices used for more or less than AN must be approved by PG&E prior to adjustments in billing. (L)

8. **MAINTENANCE, ACCESS, CLEARANCES**

a) Maintenance

The 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 C rates are closed to new installations and to additional lamps in existing accounts as of March 1, 2006. (T) (T)

b) Under the grand fathered Class 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.

2) PG&E will Isolate any trouble in the Customer's system which has resulted in an outage or diminished light output.

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.

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.

5) Customer shall compensate PG&E for any material furnished by PG&E not included in 8.A. above. Customer must have been on Class C for this service. (D)

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

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

(Continued)

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

Sheet 13

SPECIAL CONDITIONS: (Cont'd.)

8. **MAINTENANCE, ACCESS, CLEARANCES** (Cont'd.): (L)

c) Access

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.

(Continued)

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

Sheet 14

SPECIAL CONDITIONS: (Cont'd.)

9. **LINE EXTENSIONS** (L)

   A. Where PG&E extends its facilities to street light installations in advance of subdivision projects where subdivision maps have been approved by local authorities, extensions will be installed under the provisions of electric Rule 15, except as noted below.

   B. Where PG&E extends its facilities to street light installations in the absence of any approved subdivision maps, applicant shall pay PG&E's estimated cost, plus cost of ownership and applicable tax. Standard form contract 62-4527, Agreement to Perform Tariff Schedule Related Work, shall be used for these installations.

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.

11. **ENERGY EFFICIENT STREET LIGHTS:** Where Customer permanently installs energy efficient street lights and total energy use cannot be verified through industry standard test results and customer requests that the energy efficient street lights be added to this tariff, customer may be required to provide specific performance data on the total energy consumption of the fixture (which includes controls, lamp and ballast or driver) as requested by PG&E. (N)

12. **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. (T)

13. **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)

ELECTRIC SCHEDULE LS-2

Sheet 15

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

14. **BILLING:** This Rate Schedule is subject to PG&E's other rules governing billing issues, as may be applicable. PG&E performs regular auditing as part of this rate schedule. (T) (L)

Limited testing of Energy Efficient Street Light Technology will be allowed under this Rate Schedule where a light of the type and wattage of the fixture and lamp to be tested are not presently included in the rate tables. Such test installations are subject to approval by PG&E. Following approval, test installations will be billed at the customer's currently billed rate. Customer will provide a monthly inventory of streetlights that will be tested. The format and content of the inventory must be approved by PG&E. The Company reserves the right to audit customer. PG&E also reserves the right to collect the cost of any such audit from the customer. Testing is limited to existing street light fixtures and the total energy consumption per fixture must not exceed current energy use per fixture. Additional energy efficient street light fixtures installed will also be subject to billing under the current rate upon the approval of PG&E. The test period will not exceed 12 months.

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)	$0.00231	$0.00231
Power Charge Indifference Adjustment (per kWh)	($0.00062)	$0.01934
DWR Bond Charge (per kWh)	$0.00491	$0.00491
CTC Charge (per kWh)	$0.00066	$0.00066
Total CRS (per kWh)	$0.00726	$0.02722

15. **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. (T)