GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light-Emitting Diode (LED) Roadway Lighting on Residential and Commercial Streets

Host Site: Palo Alto, California

Final Report prepared in support of the
U.S. DOE Solid-State Lighting
Technology Demonstration GATEWAY Program

Study Participants:
Pacific Northwest National Laboratory
U.S. Department of Energy
City of Palo Alto

June 2010

Prepared for the U.S. Department of Energy by
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3.0 Methodology and Measurement Results

Computer modeling provides useful information but there are always differences when the luminaires are installed and measured in the field. Illuminance measurements were taken in the field per RP-8-00 recommendations.[1] Power measurements were also taken to determine the energy usage of the luminaires.

3.1 Installation

Prior to their replacement, the existing cobra heads were cleaned, relamped, and operated for over 100 hours[2] before baseline illumination and power measurements were taken. Following this initial measurement, the HPS luminaires were replaced with the both the induction and LED luminaires; power and illumination measurements were then repeated.

3.2 Power and Energy

Power measurements for both the baseline and new luminaires were taken at the same point in the circuit. Measurements were taken for many luminaires, and the average values are presented in Table 3.1 Palo Alto supplies a nominal 240 V to the roadway luminaires.

Table 3.1. Power Measurements

Source	Voltage (V)	Current (A)	Power Factor	Power (W)
HPS	243.1	0.44	0.94	96
20-LED	240.7	0.19	0.89	42
30-LED	231.5	0.27	0.87	54
Induction	241.4	0.41	0.93	90

Each luminaire is controlled via photocell integral to the luminaire. Operating hours were assumed to average 11.2 hours per day because of the use of a photocell. Table 3.2 lists the assumed energy usage of the different lighting systems based on the power for each luminaire type (from Table 3.1) and the operating hours. A representative 100 were selected to show sample magnitude of converting from the baseline HPS to the other technology.

In summary, all three lighting systems examined on the residential streets saved energy ranging from 6% to 56% compared to the baseline HPS system.

[1] IESNA RP-8-00, "American National Standard Practice for Roadway Lighting" (Reaffirmed 2005).
[2] IESNA LM-54-99, "IESNA Guide to Lamp Seasoning," recommends operating discharge lamps for 100 hours so that measurements can establish initial or rated lumens. The output of HID lamps in the 0- to 10-hour range is between 8% and 10% lower than rated.

Table 3.2. Energy Calculations

Quantity	Source Type	Luminaire Power (W)	Total Power (W)	Hours[3]	Energy (kWh)	Reduction
100	HPS	96	9,600	4,100	39,360	N/A
100	20 LEDs	42	4,200	4,100	17,220	56%
100	30 LEDs	54	5,400	4,100	22,140	44%
100	Induction	90	9,000	4,100	36,900	6%

3.3 Illuminance

Illuminance is the preferred metric for verifying roadway lighting system performance. All of the measured illuminance values can be found in Appendix A of this report.

Illuminance was measured after 10:00 pm PST on July 6 (baseline) and on July 7 (LED and induction) along grids spaced ≈16 ft × ≈8 ft (specific grids varied per street). The temperature was 62°F, and the weather conditions were dry, clear, and post-full moon. Other environmental conditions included the fact that a direct view of the moon was mostly blocked by nearby houses and trees, and most porch lights were on in the neighborhood. Tables 3.3 through 3.5 provide summary results of the measured illuminance values including average, maximum, and minimum illuminance.

As stated in Section 2.1.1, if Palo Alto adopted IESNA RP-8-00 for illuminance requirements, the streets should be lighted to an average of either 0.3 or 0.4 fc (depending on the pavement reflectance), and the uniformity (average-to-minimum) ratio should be 6.0 or less. The tables of illuminance values in the following sections include standard uniformity metrics of maximum:minimum (max/min) and average:minimum (avg/min). Additional uniformity metrics provided in these tables include the standard deviation (Std. Dev.) and coefficient of variation (CV). The CV is the Std. Dev. divided by the mean. These relatively non-standard uniformity metrics provide an indication of the consistency of the measured data as a whole, reducing sensitivity to single measurement points.

3.3.1 20-LED luminaires

The 20-LED system was designed to match the minimum illuminance produced by the HPS system. For this measured roadway, the minimum HPS value found was 0.03 fc, and the minimum LED value was 0.02 fc. Table 3.3 provides the illuminance of the HPS and LED systems, both measured and as calculated.

The illuminance from the LED lighting system produced 54% of the average illuminance produced by the HPS lighting system, which is similar to the 56% reduction in power from the HPS to the LED system. The maximum illuminance values from the LED system were only 38% of the HPS system. The Std. Dev. and CV are strong indicators of variability within a population of data; the lower the value, the less variation about the average. The LED system showed less variation among illuminance values in both metrics.

[3] According to Palo Alto, the city operates its luminaires for 11.2 hours per day × 365.25 days = 4,100 hours per year.

If GHG cost is excluded, then the NPV of replacing HPS with LED luminaires is lowered by around $20, and that of replacing HPS with induction, by around $5. The simple payback period remains virtually the same. As stated earlier, Palo Alto is part of the Climate Protection Plan and is striving to reduce GHG by 15% of 2005 levels. Based on this analysis, the monetization of GHG really does not affect the payback period. Therefore, Palo Alto will have to consider steps that reduce GHG (e.g., reducing the energy used by the streetlights) without the benefit of GHG costs helping the economic case.

5.4 Sensitivity Analysis

The analysis also investigated the sensitivity of the NPV to uncertainties in a number of variables, including the life of the LED luminaire, reduction in maintenance cost, and initial LED luminaire cost. For the sensitivity analysis, only the 70- HPS retrofit scenario was examined, and that required recalculation of the NPV by changing the uncertainty variable from the base case value by -20%, -10%, +10%, and +20%.

5.4.1 Sensitivity Analysis on the In-Service Period of LEDs

The base case assumes an in-service period for the LEDs of 15 years, with 4,100 hours of operation per year. A typical warranty for LED luminaires by this manufacturer runs between 5 to 10 years. The actual in-service period could be less or more than 15 years, however.

A sensitivity analysis on the effect of the in-service period to the economic results (Table 5.5) shows that as the period of the 20-LED luminaire increases by 20% to 18 years, the NPV increases from $122 to $217. This result indicates that estimates of cost-effectiveness are fairly sensitive to the assumed lifetime, due to the impact that assumption has on the number of years the investment is generating returns in the form of energy and maintenance savings.

Table 5.5. Results of the Sensitivity Analysis on the In-Service Period of LEDs

Base case: In-service period of LED luminaires = 15 years					
	-20%	-10%	0%	+10%	+20%
20-LED Luminaire	$21	$55	$122	$155	$217
30-LED Luminaire	-$105	-$74	-$15	$14	$69

5.4.2 Sensitivity Analysis on the Luminaire Cost of LEDs

The price of LED luminaires has been declining steadily over the last several years.[4] Pricing continues to vary significantly, however, often even among products from the same manufacturer due to different color temperatures, product lines, or other differences. A sensitivity analysis on the luminaire cost shows that as cost of this 20-LED luminaire decreases by 20% to $280, the NPV increases from $122 to $195 (Table 5.6).

[4] For example, the City of Oakland conducted two demonstration projects with LED streetlights and found that over a single 12 month period between the two projects, the luminaire cost decreased 34%. See http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html.

Table 5.6. Results of the Sensitivity Analysis on the Luminaire Cost

Base case: 20-LED luminaire cost = $350; 30-LED luminaire cost = $420					
	-20%	-10%	0%	+10%	+20%
20-LED Luminaire	$195	$159	$122	$86	$49
30-LED Luminaire	$73	$29	-$15	-$59	-$103

5.4.3 Sensitivity Analysis on the Initial Efficacy of LEDs

In the base case, the analysis uses the metered power draw for the LED luminaires to determine the NPV of converting a 70-W HPS to a 20-LED or 30-LED luminaire. The metered values are 42 W for the 20-LED luminaire and 56 W for the 30-LED luminaire. As LED technology continues to improve, the efficacy of LED luminaires is expected to increase, meaning that lower-wattage luminaires will be needed to supply a given illumination. A sensitivity analysis on the system wattage under a 70-W HPS retrofit scenario of LEDs gives the following results: as the system power draw for the 20-LED luminaire decreases by 20% to 33.6 W, the NPV increases from $122 to $160 (Table 5.7).

Table 5.7. Results of the Sensitivity Analysis on the Initial Efficacy of LEDs

Base case: System watts for 20-LED luminaire = 42 W; system watts for 30-LED luminaire = 56W					
	-20%	-10%	0%	+10%	+20%
20 LEDs	$160	$141	$122	$103	$84
30 LEDs	$36	$11	-$15	-$40	-$66

5.4.4 Sensitivity Analysis on the Maintenance Cost of LEDs

For the base case, the analysis assumes that LED or induction luminaires will reduce maintenance cost by 30%, attributed to the reduced hours to replace HPS lamps (i.e., $39/luminaire for LED versus $56/luminaire for HPS.) The actual maintenance costs of LED and induction luminaires may, however, deviate from this estimate. A sensitivity analysis on the annual maintenance cost for the 20-LED luminaire shows that decreasing it by 20% to $31.2 increases the NPV from $122 to $217.

Table 5.8. Results of the Sensitivity Analysis on the Maintenance Cost of LEDs

Assumption: Annual maintenance cost for 20 LEDs and 30 LEDs = $39/luminaire					
	-20%	-10%	0%	+10%	+20%
20 LEDs	$217	$170	$122	$75	$27
30 LEDs	$80	$33	-$15	-$62	-$110

1. Figures 5.1 and 5.2 plot the NPV against the uncertainty variables with values ranging from -20% to +20%. Based on the plots, the uncertainty variables are ranked according to their

impact on the NPV (from the highest impact to the least impact) as follows: maintenance cost, in-service period, luminaire cost, and luminaire efficacy.

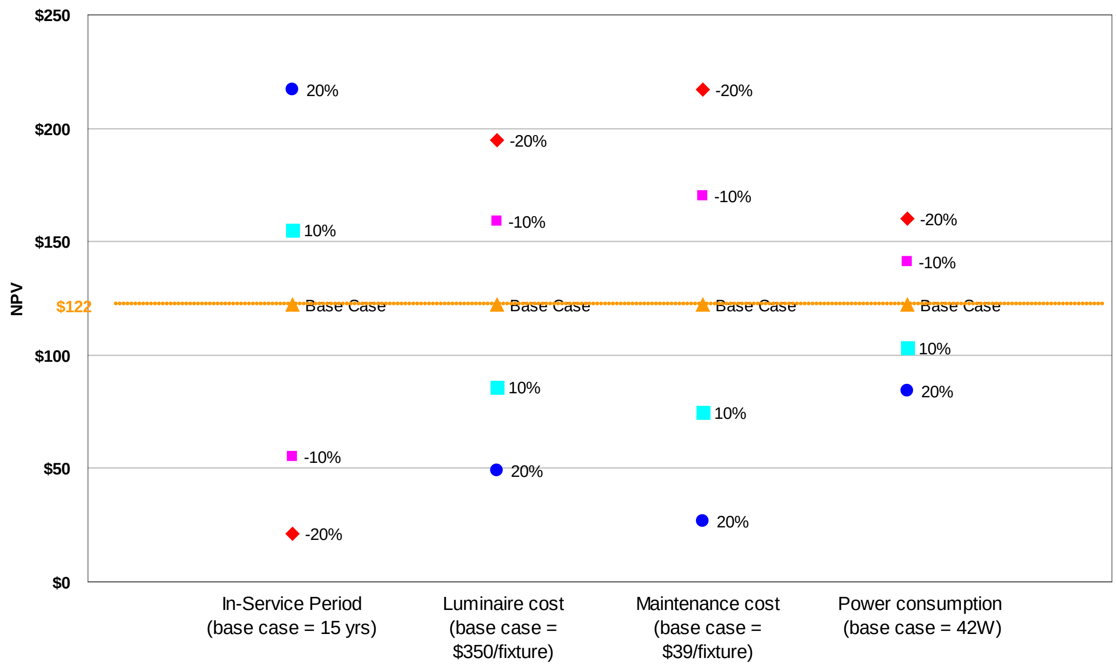

Figure 5-1. Sensitivity Analysis on the Net Present Value of 20-LED Luminaires Replacing 70-W HPS

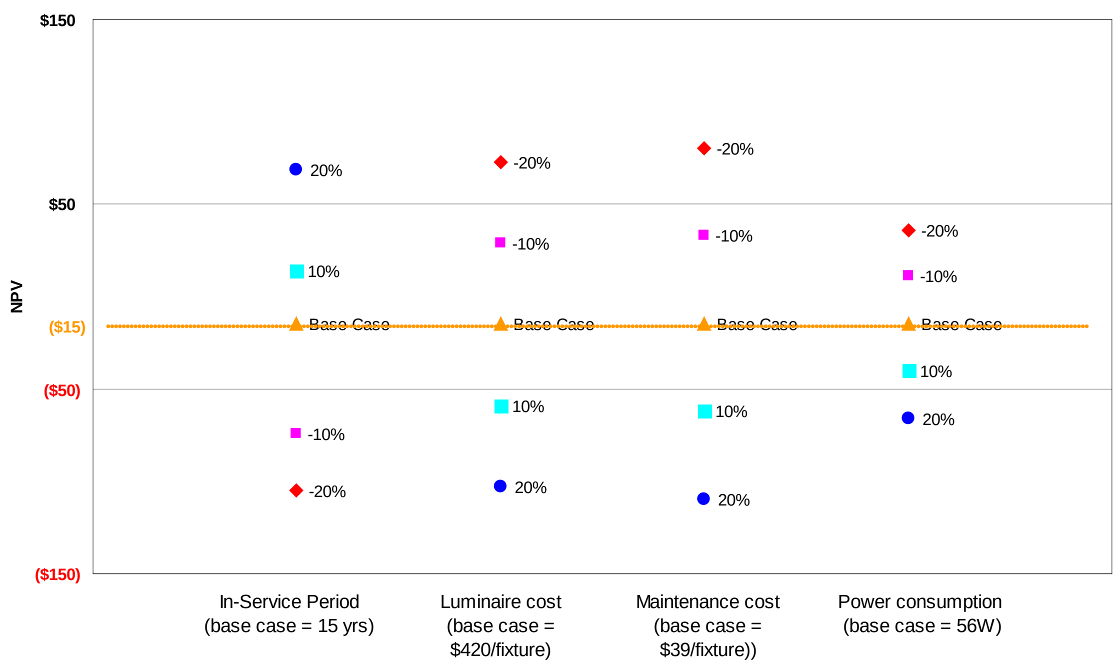

Figure 5-2. Sensitivity Analysis on the Net Present Value of 30-LED Luminaires Replacing 70-W HPS

5.5 Economics for Replacing Different HPS Wattage with LED Luminaires

Palo Alto employs HPS lamps with different wattages throughout the city. Residential areas typically use 70-W and 100-W (nominal) lamps, while commercial and high-traffic areas have 150-W and 250-W (nominal) lamps in the luminaires. Therefore, the economic analysis also looked at the simple payback and NPV for replacing 70-W, 100-W, 150-W, and 250-W HPS luminaires with LED luminaires. Table 5.9 summarizes the results using the base case assumptions for operating period and maintenance cost reductions.

Table 5.9. Net Present Value of Different LED Systems Replacing Different-Wattage HPS Systems

	Retrofit		New Construction	
	Simple Payback (years)	Net Present Value	Simple Payback (years)	Net Present Value
20 LEDs replacing 70-W HPS	9	$127	7	$205
30 LEDs replacing 70-W HPS	12	-$15	10	$64
40 LEDs replacing 100-W HPS	10	$90	7	$216
60 LEDs replacing 150-W HPS	12	-$63	10	$99
90 LEDs replacing 250-W HPS	13	-$157	11	$16

Given that Palo Alto has a total number of around 6,300 HPS luminaires, the projected payback for replacing all existing HPS luminaires is 11 years, with an NPV of $330,000. The initial investment for retrofitting all HPS luminaires with LED luminaires including installation cost is $4,169,442. The assumptions for this analysis are given in Table 5.10.

Table 5.10. Assumptions Underlying Installation and Payback Costs for Retrofitting HPS Luminaires with LED Luminaires

HPS rated lamp power (watts)	70	100	150	250
Number of luminaires	2847	1975	371	1106
HPS input power (watts)	97	130	185	295
Replacement LED luminaire type	20-LED	40-LED	60-LED	90-LED
Replacement LED luminaire unit cost before tax	$350	$465	$650	$980
Installation cost per unit	$100	$100	$100	$100
LED input power (watts)	42	70	109	168
Power reduction	57%	46%	41%	43%
LED useful life (hours)	61,500	61,500	61,500	61,500

LED useful life (years)	15	15	15	15

5.6 Economics for Remote Monitoring and Dimming Control

The demonstration also tested the use of remote monitoring and dimming control with LED and induction streetlight luminaires. The remote dimming control system was deployed in downtown Palo Alto with LED and induction luminaires replacing 150-W HPS luminaires. Cost components to the remote monitoring system include Echelon's i.LON segment controller ($2,000), the modem and router that work with the segment controller and communicate to individual luminaires over the power line ($500), installation of the segment controller on a streetlight pole ($100), and the i.Lon chip that is pre-installed with each luminaire ($75). Assuming 10 streetlight luminaires per circuit and that one segment controller is needed for each circuit, the estimated incremental cost per luminaire for the remote monitoring and dimming control is $335. This same incremental cost would apply to any replacement luminaire, regardless of the wattage of the existing HPS luminaire.

Based on 25% dimming for 5 hours per day, the simple paybacks and net present values under the remote monitoring scenario are as summarized in Table 5.11.

Table 5.11. Economic Analysis of Dimming Control for LED or Induction

Retrofit scenario: replacing 150-W HPS)	Without Dimming		With Dimming	
	Simple Payback (years)	Net Present Value	Simple Payback (years)	Net Present Value
60 LEDs	12	-$63	15+	-$358
165-W induction	15	-$145	17+	-$199

The deployment of the remote monitoring system is currently not economical, based on the additional system costs. In addition, Palo Alto staff has other concerns related to the deployment of a dimming system, including the unknown failure rates of the electronic components and potential complaints about the lower illumination level when the luminaires are dimmed.

6.0 Discussion

6.1 Illuminance

The analysis of three sites and four different luminaires in this demonstration produced some significant findings regarding illuminance:

- Measured values can vary greatly. It is worth noting that the three different sets of points measured used the same HPS luminaire with approximately the same spacing, yet the averages for the three sets of measurements ranged from 0.27 to 0.44 fc. These values differed somewhat (two lower, one higher) from the computer-calculated average illuminance. Computer models cannot accurately take into account all realities like tree canopies and manufacturing tolerances.
- Palo Alto does not currently have illuminance criteria for its streets. However, if the three sets of HPS illuminance data taken are averaged, the result is 0.37 fc. This value rounded to the nearest single significant digit is 0.4 fc, which is consistent with RP-8-00 for local roads having low pedestrian conflicts. Therefore, Palo Alto could consider adopting RP-8-00 as the city moves forward.
- None of the measured lighting systems produced results compliant with RP-8-00 in terms of uniformity (which requires 6:1 avg/min). Shadowing from both tree canopies and cars, along with pole spacing, are probably responsible for the most part. The City could mitigate the tree shadowing effects by either pruning the trees or by lowering the luminaires below the canopy.

6.2 Economics

The analysis demonstrates that converting existing streetlights in Palo Alto from HPS to LED would not be economically favorable by most measures, with simple paybacks ranging between 9 and 13 years, depending on the wattage of the HPS luminaire being replaced. Using a relatively low discount rate of 4.5% among other conservative assumptions, most options offered a negative net present value. Under a new construction scenario, the corresponding paybacks are slightly shorter, ranging from 7 to 10 years, with a longer payback for the higher-wattage replacements. For the city of Palo Alto overall, replacing the existing 6,300 HPS luminaires with LED luminaires would have a projected payback of 11 years.

A comparison of the cost-effectiveness of replacing different wattages of HPS with LED luminaires demonstrates that the lower-wattage LED products are more cost-effective than the higher-wattage versions. This is explained by the fact that a close correlation exists between the required output of an LED product and its cost, due to a general requirement for an increased number of LEDs, more heat sink material, a physically larger luminaire to house the additional components, and other factors. This correlation between output and cost exists to a much smaller degree with conventional products; hence, LEDs tend to become less cost-competitive as their required output increases. Additionally, the relative significance of losses in magnetic HPS ballasts decreases as the lamp rated power increases. For example, the ballast for the 70-W lamp draws 96 W (ballast loss 27% of input power), the ballast for the 150-W lamp draws 185 W (ballast loss 19% of input power), and the ballast for the 250-W lamp draws 295 W (ballast loss 15% of input power). Therefore, under the retrofit scenario, the payback increases from 9 to 13 years as the HPS wattage increases from 70 W to 250 W.

In this case, the economics of replacing HPS luminaires with induction luminaires is less favorable than with LEDs. The cost of the induction luminaire used to replace a 70-W HPS is higher than the cost of a 30-LED luminaire and achieves only 6% energy savings compared to the 44% energy savings of the LED. In the base case of replacing a 70-W HPS luminaire with an induction luminaire, the payback periods under the retrofit and new construction scenarios are 17+ and 15 years, respectively.

The analysis also shows that it is currently uneconomical to integrate a remote monitoring and dimming control system with LED or induction streetlights into the Palo Alto system. The incremental cost per streetlight luminaire for remote monitoring is $335. This is based on the current communication technology for the segment controller to communicate to individual luminaires, which requires one segment controller for every circuit. Assuming a dimming schedule of 5 hours per day with 25% less energy usage, the deployment of such a system increases the payback for a 60-LED luminaire from 12 to 15+ years. Although deploying a remote dimming system might make sense for HPS and other higher-wattage streetlights, the incremental energy savings from dimming low-wattage LED lights are insufficient to justify the cost.

6.3 Stakeholder Feedback

The demonstration project sought to engage the city's residents and other stakeholders to get input on the options to reduce the energy usage of its streetlighting system. Feedback was gathered from three interested parties—the local community, the Palo Alto Police Department, and the city's Utilities Department operations staff who currently maintain the HPS streetlights.

To inform the community of the demonstration project, a notification letter with an enclosed survey form was sent to approximately 200 residents living near the test sites along Amarillo Avenue and Colorado Avenue. A news page was created in the City of Palo Alto's website for the streetlight demonstration (www.cityofpaloalto.org/streetlightpilot) with a link to an online feedback form. Signs were posted on the poles of each test streetlight luminaire to indicate the type of streetlight technology deployed and to direct the viewer to the online news page for additional information and feedback. Additionally, the city and Palo Alto Neighborhoods (PAN) jointly hosted an evening walk-through tour to solicit in-person feedback from residents.

The informal survey questionnaire reported the types and characteristics of alternative streetlighting technologies being tested as a replacement to the HPS streetlights. The results of the survey, therefore, may be biased due to the information presented to survey respondents; for example, energy efficiency and/or mercury content of the different lighting technologies, or projected maintenance savings of the alternatives. However, it is still useful to report some of the results specifically pertaining to perceived quality of the various light sources.

Overall, respondents subjectively preferred the 30-LED streetlights over the other lighting choices. The 20-LED and HPS streetlights were tied in a close second, and induction was the least preferred technology. Increased color perception and visibility were given as key advantages of LED luminaires. There were some negative comments related to LED luminaires, including excessive glare and the color (6000K) of the LED light output, which was perceived as "too cold" and "harsh" compared to that of induction and HPS light.

Another stakeholder group, the streetlight maintenance staff within the city's Electric Utilities operations division, expressed concerned about the long-term maintenance of the various systems. This division currently employs a group replacement schedule for the HPS lamps of once every 5 years. However, it is not yet clear what the maintenance procedures will be for LED streetlights, given that LEDs do not burn out but rather gradually reduce output over time. Further, concerns were raised that the in-service periods might be different based on the number of LEDs per luminaire, in which case a replacement schedule for the LED lights might have to account for the locations of different-wattage luminaires.

Of the issues above, probably the only one of real remaining concern is CCT. Since these products were installed, comparable products of lower CCT have become available, and the evaluated 30-LED luminaires have since been replaced by the manufacturer with 4300K units.

6.4 Preferred Luminaire/Light Source

Based on the combined metrics of subjective satisfaction, illuminance performance, energy savings, and economics, the 30-LED luminaire ranked the highest compared to both the HPS and induction luminaires. The 30-LED luminaire produced the highest average illuminance (0.43 fc) of the systems while saving 44% of the energy compared to the baseline HPS. The 30-LED system had a payback of 12 years under a retrofit scenario and 10 years under a new construction scenario. Note, however, that prices continue to change rapidly so that these payback periods have likely improved in the short time since the test samples were originally purchased.

Appendix A

Luminaire Photometric Testing Results

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Luminaire Photometric Testing Results

The tables in this appendix provide the measured illuminance values in footcandles (fc) for both products across the measured grid.

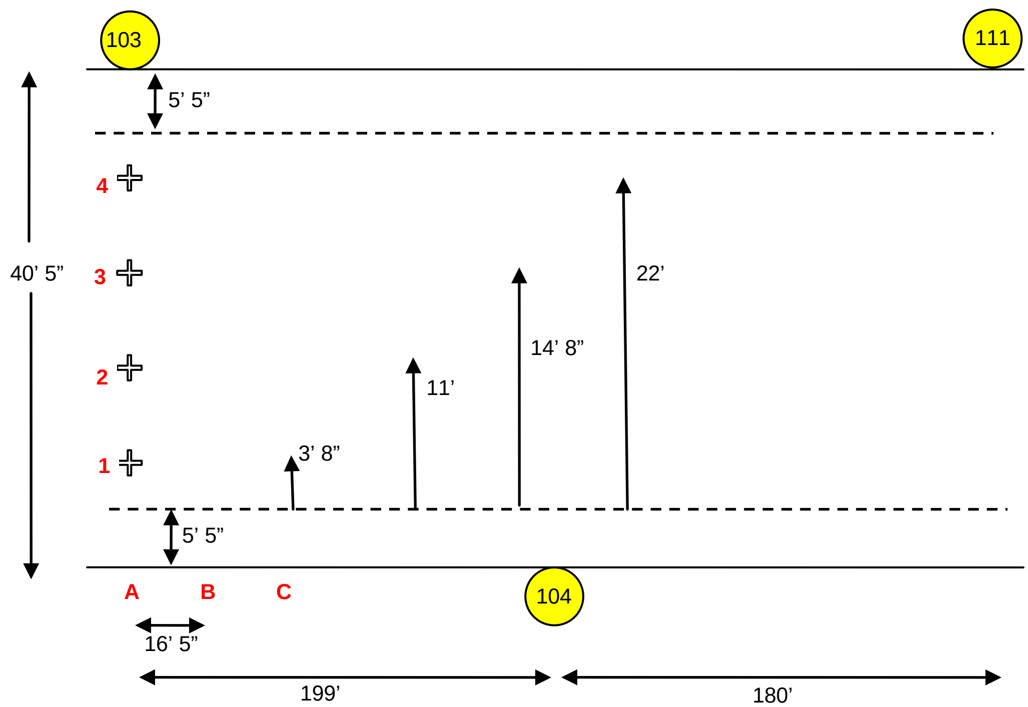

Figure A.1. 20-LED Test Site Colorado 1

TableA.1. Comparison of Colorado Poles 103, 104, and 111

	High-Pressure Sodium				Light-Emitting Diode			
	1	2	3	4	1	2	3	4
A	0.38	0.86	1.65	1.99	0.51	0.65	0.92	0.98
B	0.39	0.71	0.88	0.45	0.21	0.4	0.39	0.39
C	0.28	0.68	0.25	0.12	0.14	0.16	0.14	0.19
D	0.09	0.37	0.29	0.12	0.08	0.07	0.10	0.09
E	0.21	0.14	0.07	0.12	0.10	0.09	0.07	0.09
F	0.14	0.08	0.06	0.2	0.05	0.06	0.03	0.03
G	0.07	0.13	0.08	0.08	0.02	0.03	0.02	0.03
H	0.06	0.12	0.14	0.08	0.03	0.03	0.04	0.04

	High-Pressure Sodium				Light-Emitting Diode			
	1	2	3	4	1	2	3	4
I	0.11	0.14	0.18	0.05	0.05	0.08	0.05	0.08
J	0.10	0.13	0.22	0.19	0.17	0.15	0.09	0.08
K	0.26	0.71	0.93	0.21	0.4	0.35	0.32	0.17
L	1.48	1.3	0.56	0.33	0.83	0.75	0.67	0.5
M	2.50	1.95	0.91	0.41	1.02	0.88	0.68	0.48
N	0.86	0.91	0.67	0.37	0.56	0.42	0.46	0.32
O	0.24	0.59	0.71	0.3	0.25	0.19	0.20	0.16
P	0.23	0.2	0.15	0.11	0.13	0.07	0.08	0.09
Q	0.04	0.05	0.08	0.08	0.06	0.03	0.04	0.03
R	0.03	0.04	0.18	0.04	0.03	0.03	0.03	0.05
S	0.06	0.05	0.05	0.16	0.03	0.04	0.07	0.08
T	0.09	0.07	0.12	0.18	0.03	0.04	0.07	0.07
U	0.28	0.35	0.16	0.08	0.04	0.08	0.1	0.11
V	0.34	0.58	0.97	0.35	0.04	0.22	0.25	0.19
W	0.25	0.63	1.04	1.4	0.17	0.55	0.54	0.58
X	0.35	0.78	1.79	2.64	0.36	0.53	0.7	0.72

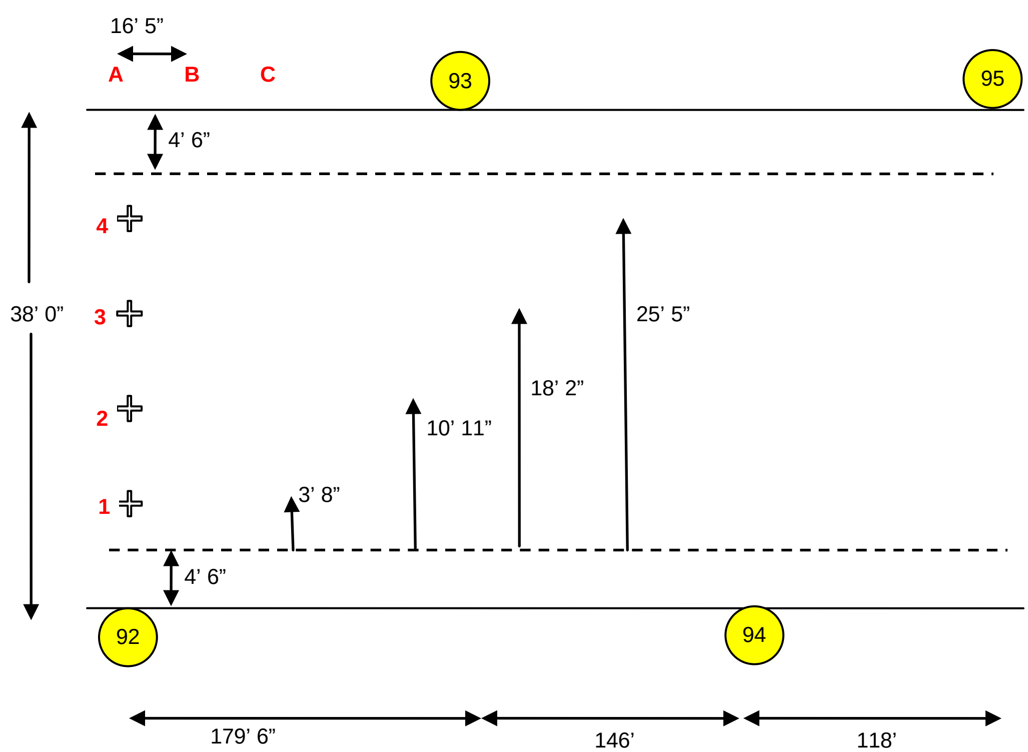

Figure A-2 30-LED Test Site Colorado 2

TableA.2. Comparison of Colorado Poles 92, 93, 94, and 95

	High-Pressure Sodium				Light-Emitting Diode			
	1	2	3	4	1	2	3	4
A	0.79	0.72	0.35	0.17	1.38	1.29	1.08	0.63
B	0.3	0.43	0.43	0.17	0.55	0.64	0.55	0.35
C	0.1	0.23	0.4	0.22	0.26	0.23	0.22	0.15
D	0.02	0.07	0.08	0.04	0.12	0.06	0.03	0.03
E	0.08	0.03	0.04	0.04	0.05	0.04	0.03	0.02
F	0.08	0.08	0.09	0.09	0.03	0.03	0.02	0.01
G	0.17	0.13	0.04	0.06	0.02	0.03	0.04	0.02
H	0.06	0.09	0.18	0.18	0.06	0.12	0.08	0.02
I	0.44	0.56	0.22	0.11	0.11	0.22	0.28	0.23
J	0.34	0.61	0.57	0.33	0.29	0.59	0.65	0.57
K	0.27	0.62	1.08	1.19	0.58	1.06	1.29	1.43
L	0.22	0.53	1.15	1.32	0.61	1.08	1.28	1.42
M	0.21	0.33	0.5	0.3	0.27	0.5	0.56	0.55
N	0.13	0.13	0.18	0.15	0.12	0.17	0.2	0.24
O	0.16	0.07	0.06	0.08	0.09	0.07	0.08	0.11
P	0.06	0.02	0.07	0.06	0.07	0.09	0.07	0.08
Q	0.17	0.11	0.25	0.19	0.15	0.13	0.14	0.08
R	0.2	0.43	0.56	0.36	0.31	0.25	0.26	0.16
S	0.52	0.58	0.48	0.32	0.58	0.65	0.66	0.32
T	1.57	1.3	0.72	0.41	1.47	1.34	1.12	0.64
U	1.68	1.44	0.92	0.4	1.33	1.23	1.04	0.88

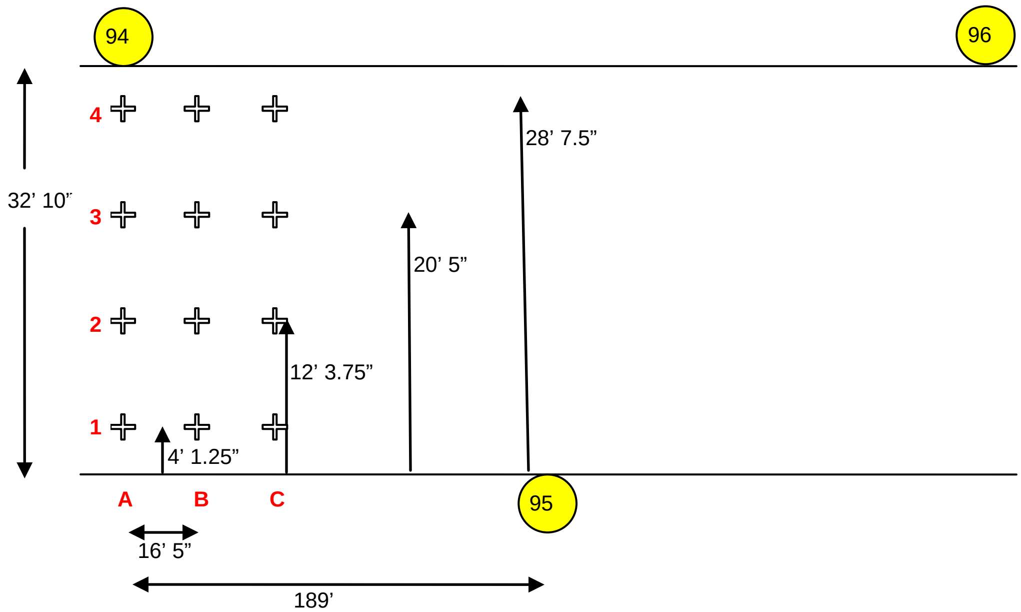

Figure A.3. Induction Test Site Colorado

TableA.3. Comparison of Colorado Poles 94, 95, and 96

	High-Pressure Sodium				Induction			
	1	2	3	4	1	2	3	4
A	0.21	0.46	1.09	1.34	0.36	0.65	1.30	1.45
B	0.13	0.34	0.80	0.01	0.19	0.35	0.46	0.21
C	0.06	0.27	0.18	0.12	0.13	0.15	0.11	0.07
D	N/A	0.04	0.19	0.08	**N/A**	0.22	0.09	0.05
E	0.12	.018	0.17	0.20	0.11	0.02	0.04	0.03
F	0.11	0.06	0.03	0.11	0.02	0.05	0.03	0.04
G	0.26	0.35	0.35	0.35	0.02	0.04	0.03	0.05
H	0.36	.011	0.26	**N/A**	0.03	0.05	0.08	**N/A**
I	N/A	0.14	0.23	0.35	0.04	0.04	0.08	0.08
J	0.09	0.012	0.20	0.18	0.11	0.15	0.24	0.22
K	N/A	0.50	0.44	0.38	**N/A**	0.75	0.62	0.38
L	N/A	1.01	0.57	0.19	**N/A**	1.13	0.76	0.38
M	0.08	0.75	0.39	0.25	0.86	0.86	0.58	0.39
N	0.29	0.37	0.41	0.23	0.30	0.32	0.29	0.22
O	0.14	0.14	0.42	**N/A**	0.10	0.13	0.14	**N/A**
P	0.04	0.21	0.09	0.36	0.05	0.04	0.08	0.09
Q	0.06	0.05	0.14	0.17	0.03	0.02	0.03	0.03

	High-Pressure Sodium				Induction			
	1	2	3	4	1	2	3	4
R	0.12	0.11	0.23	0.04	0.04	0.04	0.02	0.02
S	N/A	0.12	0.20	0.16	N/A	0.01	0.03	0.04
T	N/A	0.17	0.14	0.14	0.07	0.08	0.09	0.03
U	0.33	0.20	0.13	0.16	0.09	0.09	0.09	0.04
V	0.44	0.83	0.18	0.19	0.16	0.22	0.06	0.03
W	0.21	0.33	0.15	0.15	0.33	0.43	0.08	0.13
X					0.40	0.78	1.5	**N/A**

Appendix B

Considerations Regarding Photometry and .IES Files

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Considerations Regarding Photometry and .IES Files

Photometry is used in evaluating luminaires, characterize the distribution of the luminaire, modeling the lighting in a space, and creating three-dimensional renderings and footprints to lay out for spacing.

The data detailing photometric performance for a given luminaire is contained in an .IES file. The IESNA publishes LM-63-02, "IESNA Standard File Format for the Electronic Transfer of Photometric Data and Related Information." Although this document sets the standard for photometric data, it is not foolproof. .IES files can be problematic or modified by anyone because they consist of simple text files containing a string of numbers. As shown in this report, one manufacturer did not actually test its luminaire but rather provided computer-simulated data. Only when investigating the raw text of this file did it become apparent that this file was not actually produced by an independent testing laboratory.

Manipulation of .IES files does not necessarily imply malfeasance and, in fact, may sometimes be appropriate given the cost of testing. For instance, relative photometry is sometimes substituted for absolute photometry to avoid having to test every possible permutation of a modular luminaire. One version of the product is tested via absolute photometry, with instructions provided to users on how the .IES file should be modified to accommodate different available configurations. It may be difficult to determine whether the manufacturer's instructions yield accurate results.

In another example, in using a goniophotometer, testing laboratories charge per angle (both horizontal and vertical) in which a given luminaire is tested. Manufacturers sometimes choose to measure fewer angles to save money. Although some loss of precision may result, this practice is not necessarily done to mislead or exaggerate performance.

In short, this demonstration experienced a range of different circumstances regarding .IES files that were created to LM-63 specifications. However, the mere existence of an .IES file does not guarantee success or accuracy. Specifiers and sites need to request photometry when evaluating a product, but as they request the photometry, the specifier must perform due diligence. Specifiers should ascertain:

- whether he photometry was generated by an independent testing laboratory

- if tested by the manufacturer, whether the manufacturer is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP)
- if not NVLAP-accredited, whether the laboratory is used in the DOE CALiPER program
- whether the data presented in the file represents absolute or relative photometry.

Appendix C

LED/Induction Streetlight Pilot Project Notification Letter to Residents

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LED/Induction Streetlight Pilot Project Notification Letter to Residents

City of Palo Alto
Utilities Department

June 30, 2009

LED/INDUCTION STREETLIGHT PILOT PROJECT

DEAR RESIDENT:

The City of Palo Alto Utilities Department is currently embarking on a pilot project to evaluate alternative streetlighting technologies with the objective of saving energy without compromising current lighting levels. Light Emitting Diode (LED) and induction technologies are designed to use 40% less energy and last longer than the existing High Pressure Sodium (HPS) streetlights, thereby lowering maintenance costs.

The new streetlights will be installed in three locations along Colorado Avenue and Amarillo Avenue on July 6 to 7, 2009 and will stay in place until the end of the year. The attached map shows the locations of these new streetlights. Additionally, there will also be test streetlights installed nearby City Hall along Bryant Street and Ramona Street.

You may experience street activity by City and contractor staff to take lighting measurements in the middle of the night of July 6th and 7th. We will be taking utmost care in reducing vehicular noise levels during this measurement period.

Opportunity to provide feedback

We welcome your feedback on the lighting quality of the new fixtures. A survey form is attached, or go to **www.cityofpaloalto.org/streetlightpilot**. Please complete the survey and return to us in the pre-stamped envelope by July 31, 2009. Your feedback will help the City better design and implement a City-wide rollout of new, more energy efficient streetlighting technologies. For more information about the streetlight pilot project, please contact Christine Tam at 329-2289. (email: christine.tam@cityofpaloalto.org)

Sincerely,

Joyce Kinnear
Manager, Utility Marketing Services

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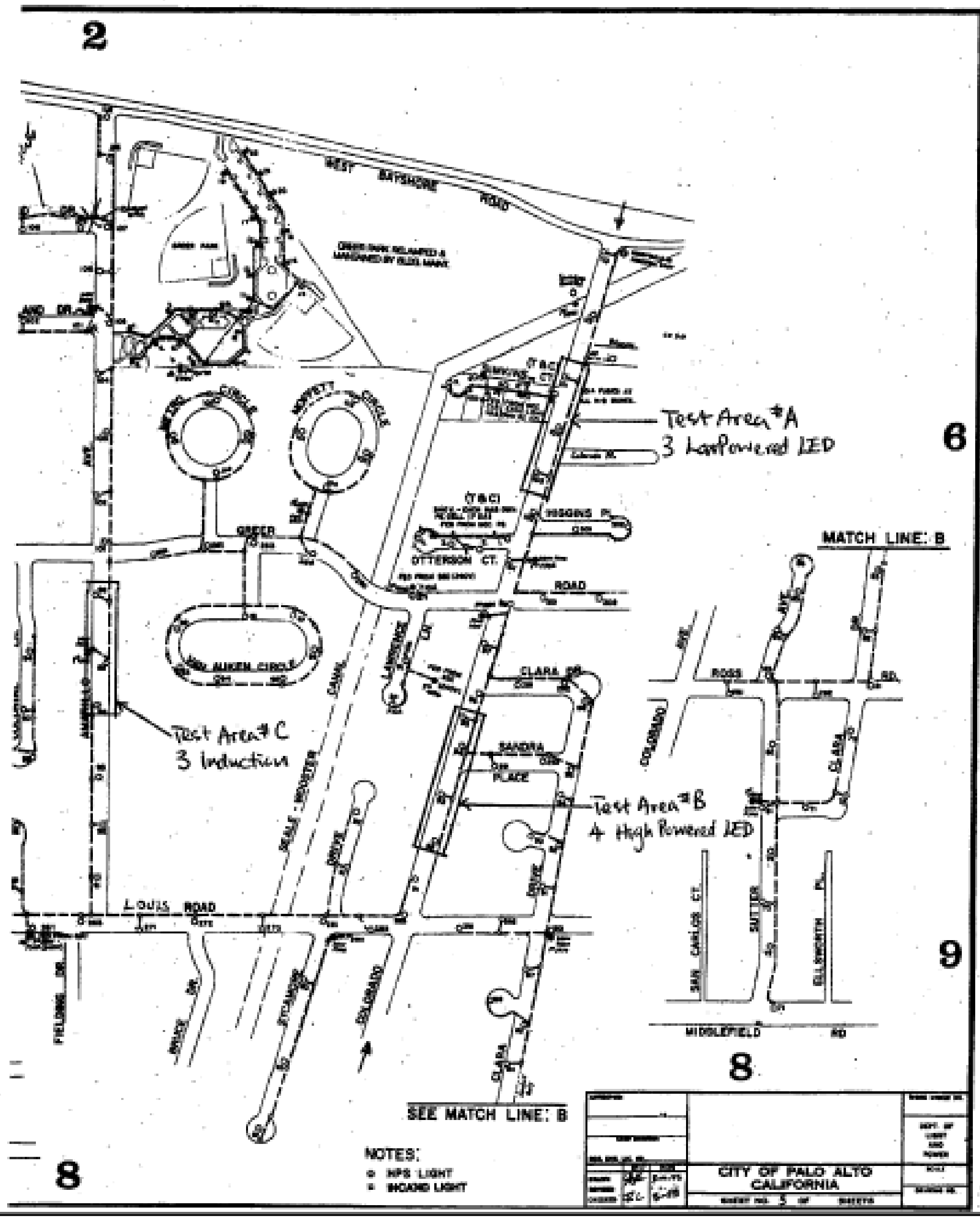
Printed with soy-based inks on 100% recycled paper processed without chlorine

CITY OF PALO ALTO LED/INDUCTION STREETLIGHT PILOT PROJECT

Site Identification along Colorado Ave and Amarillo Ave



Palo Alto LED/Induction Streetlight Pilot Project Feedback Survey

For one or more of the following streetlight test areas, please indicate your answers to the questions below. Your responses to each set of fixtures are independent, so there is no need to decide which set you like best. You may, however, provide additional feedback at the end if you have preference for one set over another.

I. **Test Area #A**: 3 low-powered LED lights on Colorado Ave between Simkins Ct and Higgins Pl:

1. Did you notice that the streetlights in Test Area #A along Colorado Avenue have been replaced?
☐ Yes ☐ No

2. How did you experience the new lights?
☐ By car ☐ By bicycle ☐ As a pedestrian ☐ From a residence

3. Do you feel that the new street lights have improved your visibility as a pedestrian compared to the older HPS-based adjacent fixtures?
☐ Yes ☐ No ☐ About the same

4. Do you feel that the new street lights have improved your visibility as a driver?
☐ Yes ☐ No ☐ About the same

5. If the new lights are installed along the entire street, it would make the street feel:

Safer?	☐ Yes	☐ No	☐ About the same
Better ambiance?	☐ Yes	☐ No	☐ About the same
Too bright?	☐ Yes	☐ No	☐ About the same
Too dim?	☐ Yes	☐ No	☐ About the same
Better color distinction?	☐ Yes	☐ No	☐ About the same

II. **Test Area #B**: 4 high-powered LED lights on Colorado Ave between Clara Dr and Louis Rd:

1. Did you notice that the streetlights in Test Area #B along Colorado Avenue have been replaced?
☐ Yes ☐ No

2. How did you experience the new lights?
☐ By car ☐ By bicycle ☐ As a pedestrian ☐ From a residence

3. Do you feel that the new street lights have improved your visibility as a pedestrian compared to the older HPS-based adjacent fixtures?
☐ Yes ☐ No ☐ About the same

4. Do you feel that the new street lights have improved your visibility as a driver?
☐ Yes ☐ No ☐ About the same

5. If the new lights are installed along the entire street, it would make the street feel:

Safer?	☐ Yes	☐ No	☐ About the same
Better ambiance?	☐ Yes	☐ No	☐ About the same
Too bright?	☐ Yes	☐ No	☐ About the same
Too dim?	☐ Yes	☐ No	☐ About the same
Better color distinction?	☐ Yes	☐ No	☐ About the same