# LED Streetlight Application Assessment Project

## Pilot Study

Prepared for

Seattle City Light

Prepared by

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TRANSPORTATION SOLUTIONS

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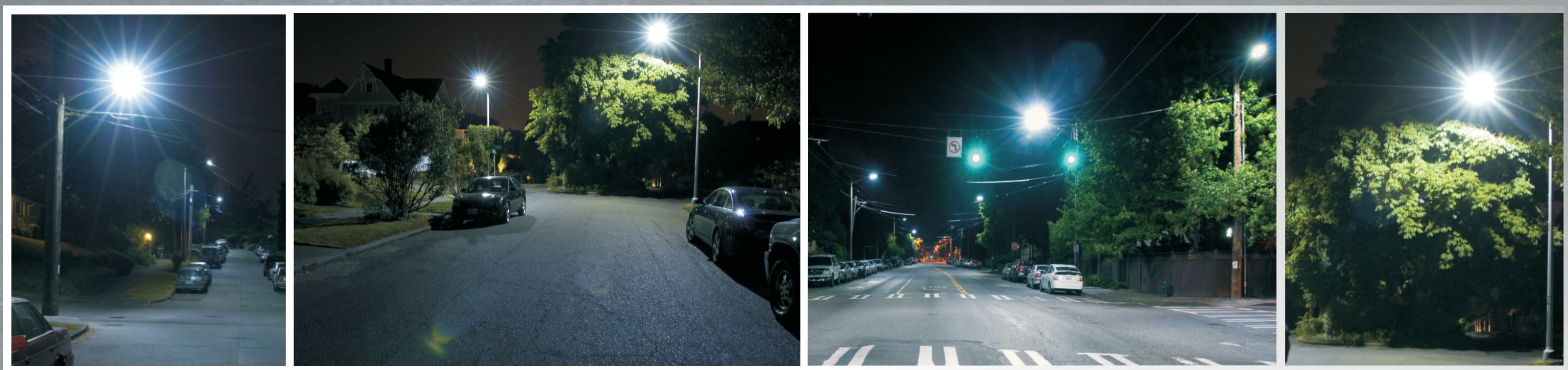

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# Executive Summary

Recent studies have found that light emitting diode (LED) technology is becoming competitive for outdoor applications with the commonly employed high intensity discharge (HID) light sources such as high pressure sodium (HPS) and metal halide (MH). The expectation is that LED street lighting technology will not only provide more efficient light distribution and increased uniformity, but will also save energy and reduce maintenance costs.

Seattle City Light (SCL) has a street lighting system of nearly 84,000 street and area lights that use predominantly HPS light sources. Because of the potential benefits of installing LED luminaires as a replacement for these lights, SCL launched the *LED Streetlight Application Assessment Project Pilot Study* to evaluate LED luminaires for photometric performance, energy efficiency, economic performance, and the impact of the new lights on SCL streetlight system. The findings contained in this report will be used by SCL to develop a strategy for the installation of LED streetlights in developing an energy efficient lighting system.

This study was conducted in collaboration with Pacific Northwest National Laboratory (PNNL), representing the DOE, and is part of the DOE Solid-State Lighting GATEWAY Demonstration program, which is designed to showcase emerging LED lighting products.

## Goals

SCL conducted this study to evaluate LED streetlights and their ability to bring energy-saving lighting to Seattle neighborhoods and streets. To assess benefits of LED streetlights, this project focused on the following key goals:

- Select a suitable LED product(s) for use by SCL on residential roadways.
- Evaluate the lighting, economic, and energy consumption performance.
- Evaluate the ability for LED products to produce a 40 percent energy savings compared to existing HPS cobra head style luminaires.
- Develop a functional specification and recommendations for the installation and maintenance of these products.
- Identify next steps to increasing energy efficiency of LED lighting.

## Study Area and Test Sites

Two study areas, Capitol Hill and South Park were selected by SCL for this project. Factors considered during the study area selection included roadway type, community socioeconomic makeup, size of street level retail, mix of single family and multi-family housing, and other factors such as park fronts. In the Capitol Hill Area, Test Sites 2 and 10 were included in this study. Test Sites 11 and 12 were included in the Stage II South Park portion of the study. See Figure 1 for the two Study areas and test sites.

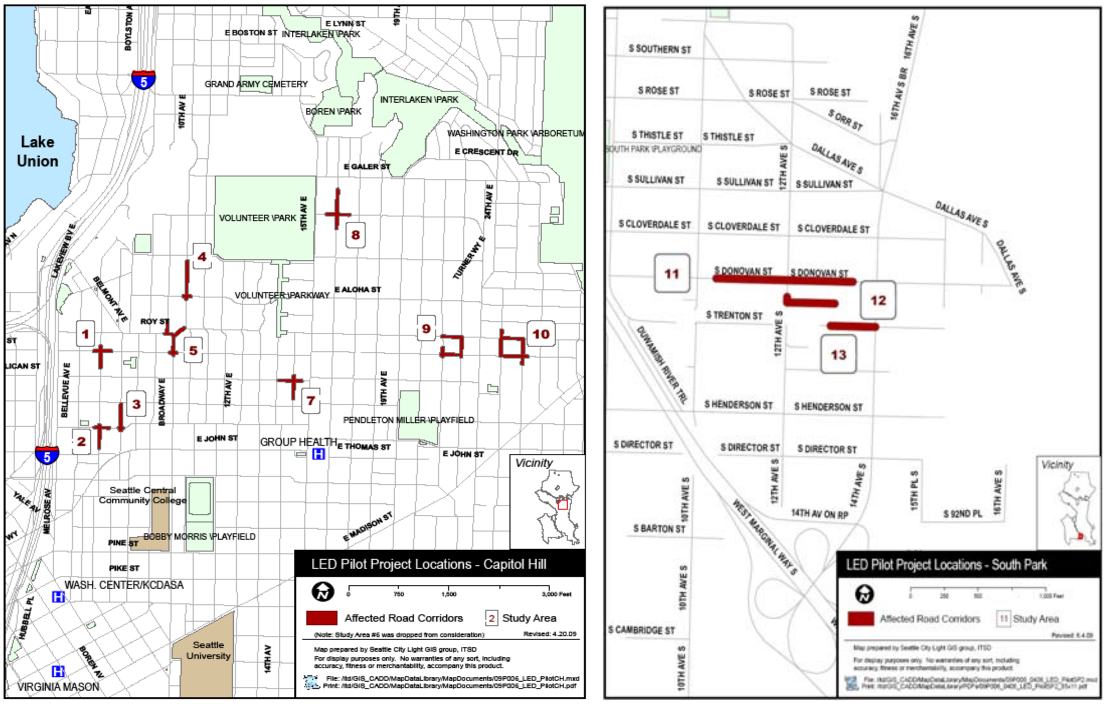


Figure 1 – Test Sites (Capitol Hill and South Park)

## Project Approach

Rather than identifying vendors and luminaires by name, a coding system was developed in this project to identify the vendors and luminaires under test. The vendors are coded as “A”, “B”, “C”, “D”, “E”, and “F”. A luminaire code A1 means Vendor A, Luminaire 1.

The SCL LED Application Assessment project pilot study was conducted in two stages. In the Stage I Capitol Hill test sites, SCL selected LED luminaires from two vendors, conducted computer simulation, and field testing. Before and after field comparisons for the replacement of HPS cobra head style luminaires with LED luminaires were conducted. The Stage II South Park test sites included selecting and testing up to three additional LED streetlight luminaires with an emphasis on luminaires that are considered “Made in America” as well as further testing select luminaires from Stage I. A field testing methodology was also developed for the Stage II test sites.

Aside from test site selection (previously discussed), the major elements of this pilot project included:

- LED luminaire selection.
- Simulated photometric performance evaluation of selected LED products.
- Field photometric performance evaluation.
- Economic performance evaluation in comparison to HPS luminaires.

Candidate LED luminaires were selected from criteria developed specifically for this study which included:

- Photometric performance (Stage I and II).
- Pricing (Stage I and II).
- "Made in America" status (Stage II only).
- Manufacturers' production capabilities (Stage I and II).

The performance of luminaires selected for testing was simulated using the lighting analysis software AGI32. Tests were conducted for typical residential roadway sections and for field conditions at each test site. Major factors considered when ranking the candidate luminaires included:

- Luminaire mounting height.
- Average maintained illuminance values.
- Uniformity ratios (average/minimum).
- Light pole spacing[1].

The light loss factor (LLF) used for the analysis assumed the following:

- Luminaire Dirt Depreciation factor (LDD): based on a clean to very clean environment and a seven-year maintenance cycle. A clean environment with an LDD of 0.85 was assumed for the initial luminaire selection. Additional simulation analysis under the Stage II test sites assumed a very clean environment with an LDD of 0.92.
- Lamp Lumen Depreciation factor (LLD): obtained from each of the luminaire manufacturers and based on the manufacturers LM-80 test data.

Selected LED luminaires were field tested for photometric performance at the Stage I and II sites. The LED photometric measurements were compared to measurements from existing HPS luminaires, City of Seattle Standards, and the Illuminance values recommended for local roadway facilities in the Illuminating Engineering Society of North America's, *RP-8-00 Reaffirmed 2005, American National Standard Practice for Roadway Lighting* (RP-8-00). The Stage I testing was conducted by PNNL and Stage II testing was conducted by the Lighting Design Lab (LDL).

The economic analysis focused on simple payback calculations methods and included SCL incentive rebates. The following assumptions included in the calculations were:

- 15-year luminaire life cycle.
- Maintenance cycle of seven years.
- LED luminaire failure rates of 10 percent.

[1] Light pole spacing is an important factor since the general practice on residential streets is to place light poles on every third property line giving typically 150 foot spacing between light poles. Mounting heights of luminaires were simulated at 30 feet. It was assumed this would provide the worst case illuminance values.

- $0.22 incentive rebate per kilowatt-hour saved.

The analysis was based on the replacement of 100-watt HPS luminaires (consuming 142 Watts) on residential roadways. Maintenance costs, energy rates and power consumption of existing luminaires were obtained from SCL.

## Simulation and Field Test Results

The simulation and field test results from the Stage I and Stage II Study Areas show from an illuminance level perspective, LED luminaires are a viable option to replace existing HPS luminaires. Minimum illuminance levels, as published through the RP-8-00 can be met[2]. Seattle's average illuminance requirement is only met by some of the larger LED luminaires being tested under the study. These larger luminaires mean lower cost savings due to the larger LED arrays in use. Important findings from the computer simulation and field tests included:

1. Not all luminaires met the average maintained illuminance and uniformity values required by National or Local Standards. It is important to conduct simulation and field testing of each type of LED luminaires to understand their photometric performance.
2. Type II light distribution minimized back lighting onto private property more than the Type III distribution pattern. This was apparent in both the simulation and field tests.
3. In the Stage II South Park area field tests, the initial lumen output of the LED luminaires is approximately two times greater than the design year of the lighting system (in this case the design year of the system is seven years into the future). This additional lumen output is wasted energy. New control systems and dimmable drivers can be used to reduce initial lumen output and then increase it as the lamp lumen depreciation increases. In theory, this means a longer life for the luminaire since it is being driven at a lower amperage during the first few years of its life. Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries like A4 a viable and economic option.
4. Public feedback on the field installations at the Stage I test sites identified the "cooler" color temperatures from 5500°K to 6000°K created a dismal and unwelcoming environment. Subsequent installations of luminaires at the Stage II sites with a warmer color temperature from 4100°K to 4300°K created a more welcoming and comfortable environment.
5. General Stage I public feedback supported the pursuit of additional installations of LED luminaires.

[2] The RP-8-00 standards for a residential street with low pedestrian volumes are an average maintained illuminance level of 0.4fc and uniformity ratio of 6:1. Seattle's average illuminance requirement is 0.7fc.

6. Approximately 25 percent of Vendor C's luminaires installed in the test sites have failed (two out of eight) under Stage II. There have been no failures of the field installed luminaires from Vendor A.
7. A lamp dirt depreciation factor (LDD) of 0.92 was determined to be appropriate for residential streets.

## Conservation Incentives

The following energy conservation incentive programs have been identified:

- **SCL Conservation Division**: With the installation of energy efficient streetlights, the SCL Conservation Division will pay back $0.22 per kilowatt-hour saved. The incentive amount is returned to SCL as a one-time rebate.
- **Washington State Transportation Improvement Board (TIB):** TIB has a selection process for agencies to apply for grants. TIB funding programs are available if the project falls under three categories: Urban Arterial Program, Urban Corridor Program, or Urban Sidewalk Program.
- **Department of Energy:** Provides funding and grants through various conservation energy programs. Local governments can apply for block grants to improve energy efficiency and renewable energy systems.
- **Qualified Energy Conservation Bonds**: These bonds are issued through state or local governments for financing governmental programs to reduce greenhouse gas emissions and other conservation purposes.
- **The Clinton Climate Initiative (CCI)**: CCI can help by advising on project management, purchasing, financing, and technology.

## Economic Analysis -Simple Payback

Using simple economic payback calculations and setting aside energy conservation goals of 40 percent savings over currently used HPS luminaires, LED luminaires can be an economical alternative. With SCL conservation rebates of $0.22 included in the overall calculation for each kilowatt-hour saved, the following payback periods were realized for the Stage I and Stage II luminaires under study:

- Small LED array luminaires
  - Luminaire A1 (39 watts) – 1.9 years
  - Luminaire B1 (58 watts) – 3.3 years
- Medium LED array luminaires
  - Luminaire C2 (75 watts) – 4.7 years
  - Luminaire A2 (109 watts) – 6.1 years
- Large LED array luminaires
  - Luminaire C3 (137 Watts) – 13.8 years

- Luminaire A3 (142 Watts) – 14.6 years

When the SCL energy conservation goal of 40 percent energy savings is taken into account, a luminaire must consume 85 watts of energy or less. Only luminaires A1, B1 and C2 fell into that category. However, A1 and B1 are not an option due to their photometric performance.

A continued improvement in LED luminaire efficacy is expected over the short term. This will continue to reduce costs and increase savings in operations costs. Taking advantage of new control systems with dimmable drivers is an option that can provide additional energy savings.

## Recommendations

### Luminaire

Based on the analysis conducted in this study, the following luminaire has been identified as a viable option for replacement of 100-watt HPS cobra head style luminaires in residential areas. These recommendations are being made not because the luminaire meets the 40 percent energy reduction goal, but because of their economic, photometric, and maintenance performance. The following recommendation is subject to change as LED products with better photometric and economic performance are available.

**Recommendations (Luminaire):**

1. **Luminaire A2: 60LED-Type II Distribution-4300K-525mA**
2. **General Recommendations: Type II Light Distribution,**
   **Correlated Color Temperature of 4000°K to 4300°K**

Luminaire A2 performed favorably with the following characteristics:

- Power consumption: 109 Watts
- Distribution: Type II
- Initial Lumens: 4,968 (60 LED Array)
- Correlated Color Temperature: 4300°K
- Color Rendering Index: 75 minimum
- Driver Current: 525mA
- Efficacy: 46 lumens/Watt
- IP Rating: IP66
- Weight: 16 lbs

The computer simulation test of the luminaire generates an illuminance level of 0.65fc, which falls between the RP-8-00 requirements. The field test revealed that the LED luminaires generally produced higher illuminance levels than the existing HPS luminaires.

As a late development in the study, Vendor A has released their new generation luminaires. The new generation luminaires are designed to provide better uniformity than the previous products. In an effort to provide up to date information, a review of the new generation luminaires showed better photometric performance with greater spacing and comparable uniformity than the previous products. It is anticipated that an economic evaluation of the new generation luminaire will yield similar results to the previous generation. The new generation luminaire should be considered as a replacement for the previous luminaire product. The new generation luminaire is as follows:

**Luminaire A2 Rev. 11/02/09: 60LED-Type II Distribution-4300K-525m**

### Specification

A functional specification has been developed for SCL to use in purchasing LED luminaires and the evaluation of future luminaires for residential roadways. The specification is based on the research conducted on LED luminaires available on the market today, computer simulations, and field testing.

**Recommendation (Specification):**
**Review specification every six months to take into account rapid advances in the LED lighting technology.**

### Luminaire Selection

LEDs are a new and rapidly developing technology in the roadway lighting arena. An understanding of industry lighting standards, manufacturing (including an in-depth understanding of heat dissipation), and testing of LED products is essential to making good decisions on luminaire selection.

**Recommendation (Luminaire Selection):**

1. **Utilize an LLD factor based on LM-80 tests.**
2. **Utilize an LDD factor of 0.92 for residential roadways.**
3. **Require independent LM-79 and LM-80 test results for all luminaire submittals.**

### Recommended Next Steps

LEDs are an instant on/instant off technology with no start-up or re-strike time. Combining LED roadway luminaires with new light control systems provides many new options for overall light control, facilitating maintenance, increasing luminaire life, and further reducing operating costs. The following are benefits of incorporating lighting control systems with LED lighting technology include:

- **Dimming of Lighting Circuits after Hours:** This can be based on time of day or traffic volumes. Dimming of luminaires can provide reduced energy costs and prolong the life of the luminaire.

- **Step Dimming or Continuous Dimming:** Lighting systems are designed to meet standard illuminance levels at a future year with a given amount of lumen and dirt depreciation incorporated into the design. This means at initial installation, more lumens are being produced than required. Step or continuous dimming of a lighting system would reduce the initial lumen output to its design standard by reducing the drive current and then gradually increase that drive current at predefined time intervals to maintain the same lumen output over the life of the system (Figure 2). Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries likeA4 a viable and economic option.

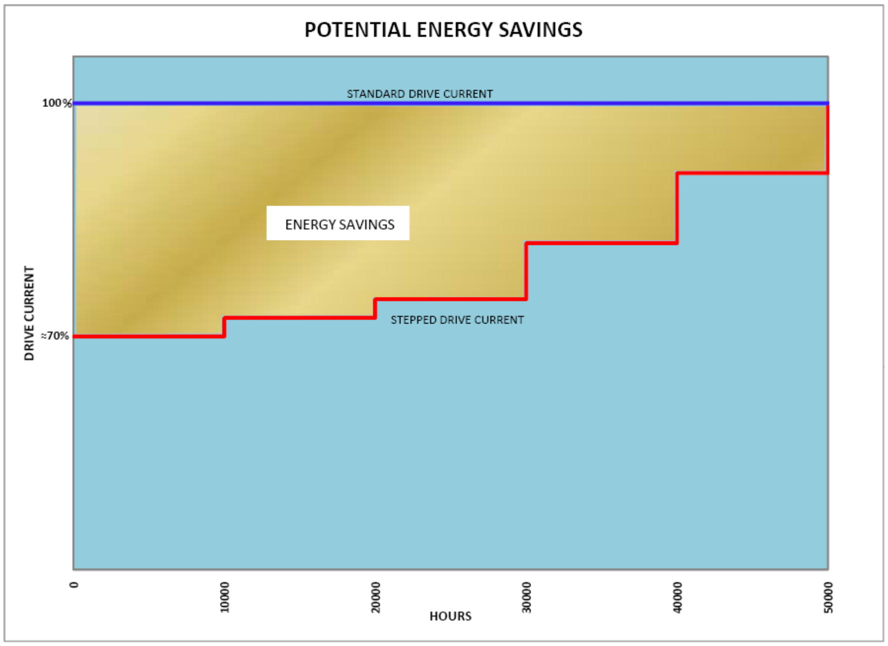


Figure 2 – Diming energy savings

- **Emergency Services Support:** If tied into traffic operations centers, emergency management centers, or electric utility operations centers lighting control systems can increase illuminance levels at select locations to facilitate emergency services and then be reduced back to normal levels when the emergency is over.

- **Pedestrian or Vehicle Activated Lighting Circuits:** Lit corridors with motion sensors incorporated into the luminaire, can be turned off or dimmed until a person or vehicle is in the vicinity. Dimming of luminaires can provide reduced energy costs and prolonged life.

- **Luminaire Health Monitoring:** Control systems can monitor the health of luminaire components such as LED drivers. Many benefits are available through luminaire monitoring:
    - Luminaires can be GPS located to provide maintenance with exact geographical locations reducing time in locating outages,
    - Maintenance can respond in a more efficient manner reducing the number of system wide outages and down times, improving customer service,
    - Outage patrols can be reduced, and

- Trend analysis can be conducted from information received from the field.

There are many new light control systems on the market today. Just as with LED luminaires, care needs to be taken to select the correct system to meet agency needs. There are many different items that need to be considered both for the control system itself and the infrastructure needs to support that system.  Further evaluation of lighting control systems and their potential benefits for Seattle City Light is recommended.

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# 1 PROJECT BACKGROUND

The US Department of Energy (DOE) is evaluating the light emitting diode (LED) technology for outdoor applications such as street and area lighting. Recent studies show that LED technology is becoming competitive for outdoor applications with the commonly employed high intensity discharge (HID) light sources such as high pressure sodium (HPS) and metal halide (MH). The expectation is that not only will LED street lighting technology provide more efficient light distribution and increased uniformity, but it will also save energy and reduce maintenance costs.

Seattle City Light (SCL) has a street lighting system of nearly 84,000 street and area lights that use predominantly HPS light sources. To explore the potential benefits of installing LED luminaires, SCL launched the *LED Streetlight Application Assessment Project Pilot Study* in 2008 to evaluate LED luminaire photometric performance, energy efficiency, economic performance, and the impact of the new lights on SCL street lighting system. This project was conducted in collaboration with Pacific Northwest National Laboratory (PNNL), representing the DOE, and is part of the DOE Solid-State Lighting GATEWAY Demonstration program, which is designed to showcase emerging LED lighting products.

Rather than identifying vendors and luminaires by name, a coding system was developed in this project to identify the vendors and luminaires under test. The vendors are coded as “A”, “B”, “C”, “D”, “E”, and “F”. A luminaire code “A1” means Vendor A, Luminaire 1.

The SCL LED Streetlight Application Assessment Project was conducted in two stages. In Stage I, SCL selected LED luminaires from two vendors: Vendor A and Vendor B. SCL conducted computer simulation and field testing of the selected LED products. Stage I testing included Illuminance measurements (photopic) collected before and after replacement of HPS cobra head style luminaires with LED luminaires. The Stage I study recommended Vendor A products to be further evaluated. Stage II included selecting and testing up to three additional LED streetlight luminaires with an emphasis on luminaires that are considered “Made in America” and further performance testing of Vendor A products.

This report summarizes the results of Stage I and Stage II tests. Based on these results, conclusions are drawn and recommendations for future studies are proposed. An economic analysis of replacing the existing HPS luminaires with LED luminaires is also presented. This report also provides a portfolio for each of the selected LED luminaires, an LED product maintenance plan, an update on the national LED streetlight projects, a photometric measurement methodology, and a standard specification for solid state luminaire for residential roadway applications.

# 2 Project Goals

SCL conducted this pilot study to evaluate LED streetlights and their ability to bring energy-saving lighting to Seattle neighborhoods and streets. To assess benefits of LED streetlights, this project focused on the following key goals:

- Select suitable LED products for use by SCL for roadway and area lighting.
- Evaluate the lighting, economic, and energy consumption performance as well as benefits of installing the LED products.
- Evaluate the ability for LED products to produce a 40 percent energy savings compared to existing HPS cobra head style luminaires.
- Develop a functional specification and recommendations for the installation and maintenance.
- Identify next steps to increasing energy efficiency of LED lighting.

The findings contained in this report will be used by SCL to develop a strategy for the installation of LED streetlights and to determine the next steps in developing an energy efficient lighting system for Seattle City Light. This report does not measure or evaluate the potential environmental (climate change) benefits of installing the tested products.

# 3 Project Approach

The SCL LED Application Assessment project pilot study was conducted in two stages. In the Stage I Capitol Hill test sites, SCL selected LED luminaires from two vendors, conducted computer simulation, and field testing. Before and after field comparisons for the replacement of HPS cobra head style luminaires with LED luminaires were conducted. The Stage II South Park test sites included selecting and testing up to three additional LED streetlight luminaires with an emphasis on luminaires that are considered "Made in America" as well as further testing select luminaires from Stage I. A field testing methodology was also developed for the Stage II test sites.

The major elements of this pilot project included:

- Test site selection.
- LED luminaire selection.
- Simulated photometric performance evaluation of selected LED products.
- Field photometric performance evaluation.
- Economic performance evaluation in comparison to HPS luminaires.

Before product evaluation was conducted, test sites and candidate products were selected. Test sites were chosen in the Capitol Hill and South Park areas of Seattle. LED luminaires were selected from a criteria developed specifically for this project. The criteria included:

- Photometric performance (Stage I and II).
- Pricing (Stage I and II).
- “Made in America” status (Stage II only).
- Manufacturers’ production capabilities (Stage I and II).

The candidate luminaires photometric performance were simulated using AGI32 lighting software, a program routinely used by the lighting industry to design and test luminaire performance. The IES photometric files used in the simulation were obtained from the respective luminaire manufacturers.

The selected LED luminaires were field tested at the test sites to determine photometric performance. The LED photometric measurements were compared to measurements from the existing HPS luminaires as well as to the Illuminance values recommended for local roadway facilities in the Illuminating Engineering Society of North America’s, *RP-8-00 Reaffirmed 2005, American National Standard Practice for Roadway Lighting* (RP-8-00). The Stage I field tests were conducted by PNNL. Stage II field tests were conducted by the City’s Lighting Design Lab (LDL). A methodology for Stage II photometric field measurements (Appendix A) was developed to guide the field tests.

The economic analysis focused on simple payback calculations methods and included SCL incentive rebates. The analysis was based on the replacement of 100-watt HPS luminaires on residential roadways.  Maintenance costs, energy rates and power consumption of existing luminaires were obtained from SCL.

# 4 Site Selection

Two demonstration sites in Seattle were selected by SCL for this project. Stage I test sites were located within the Capitol Hill area and Stage II test sites in the South Park area. Factors considered during site selection included: roadway type, community socioeconomic makeup, size of street level retail, mix of single family and multi-family housing, and other factors such as park fronts.

## Stage I - Capitol Hill

Capitol Hill (Figure 4-1) is the second most densely populated neighborhood in Seattle. It is bound by SR 520 and Interlaken Park to the north, E. Pike and E. Madison Streets to the south, 23rd and 24th Avenue E. to the east, and Interstate 5 (I-5) to the west. The Capitol Hill neighborhood features many nightlife and entertainment spots hosting live music and numerous fringe theaters. As shown in Figure 4-1, 10 potential test sites were originally identified for the Capitol Hill neighborhood, from which Sites 2 and 10 were selected as the final Stage I field test sites to be included in this report. The locations of these two sites are:

**Site 2: Summit Avenue E.** between E. John Street and E. Thomas Street

**Site 10: 24th Avenue E. and 25th Avenue E.** between E. Harrison Street and E. Valley Street

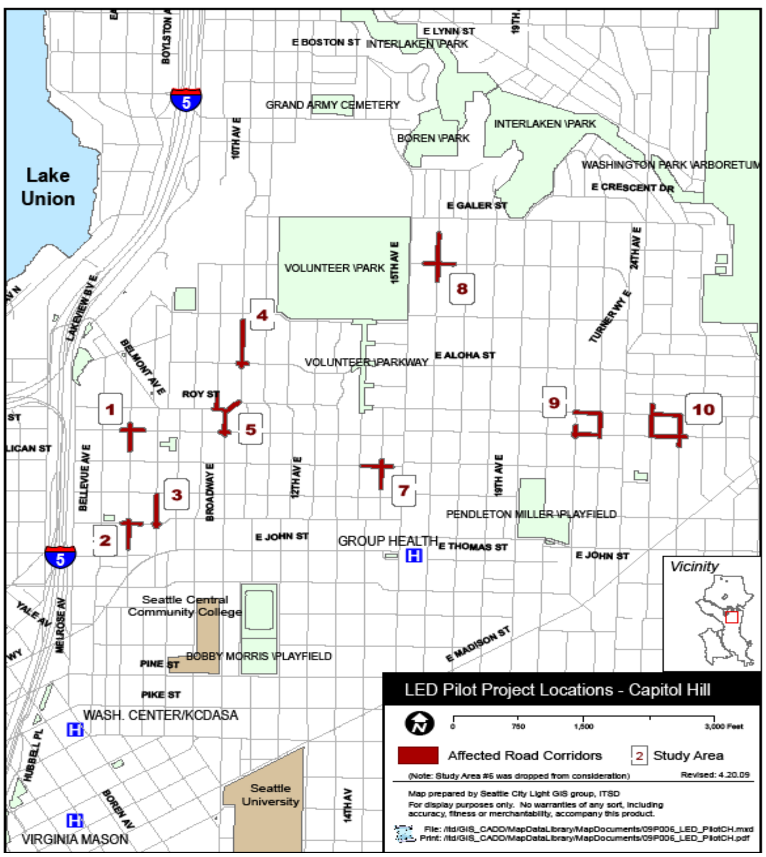


Figure 4-1 Vicinity of the Stage I study area – Capitol Hill

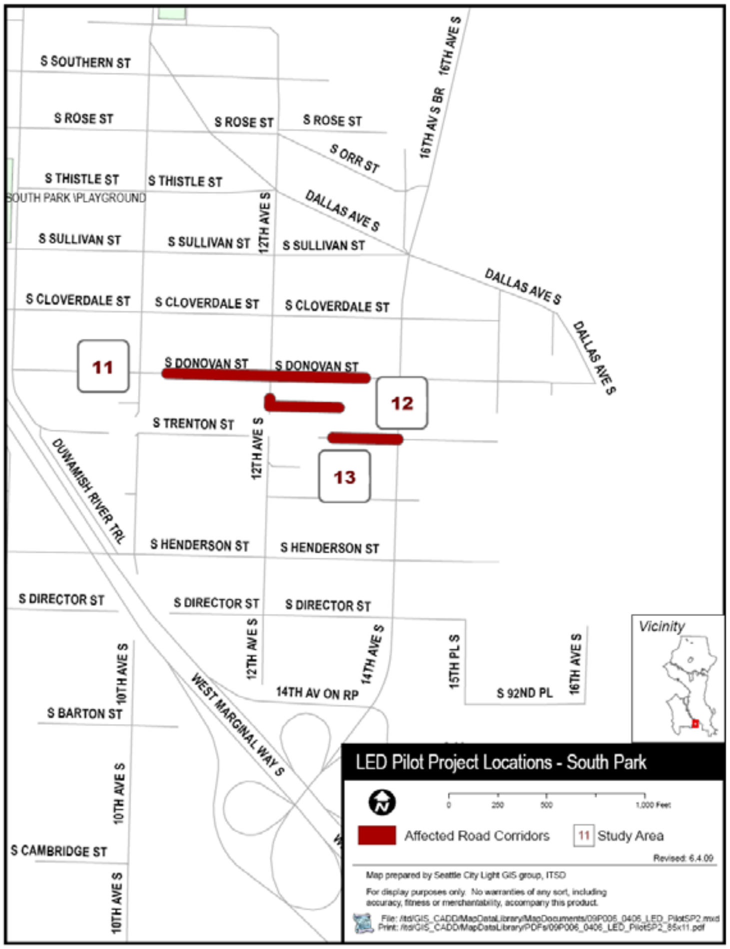


Figure 4-2 Vicinity of the Stage I study area – South Park

## Stage II - South Park

South Park (Figure 4-2) is a mixed residential and commercial neighborhood located just south of Georgetown across the Duwamish River and just north of the City of Tukwila. Three sites within this neighborhood were selected for testing:

**Site 11: S. Donovan Street** - between 10th Avenue S. and 14th Avenue S.

**Site 12: Alleyway** - between 12th Avenue S. and 14th Avenue S.

**Site 13: S. Trenton Street** - between 12th Avenue S. and 14th Avenue S.

# 5 LED Product Selection

This section describes the process used to select and recommend LED products for testing at the Stage I Capitol Hill and Stage II South Park sites.

## Manufacturer Screening and Product Selection

LED luminaire manufacturers and suppliers were contacted and screened for potential use and testing of their products. The following criteria were applied to screen potential manufacturers and suppliers.

1. Stage I and II: The selected LED luminaires must be able to photometrically replace the existing HPS cobra head style luminaires with either Type II/III light distributions with full cutoff.

2. Stage II: Only LED luminaires that are "Made in America" were considered. The definition of "Made in America" is defined as:

   *The product must meet the requirements of the Buy American Act; Section 1605 of the American Recovery Reinvestment Act (ARRA). The purpose of this requirement is to restrict the purchase of supplies that are not domestic end products. For manufactured end products, there is a two part test to define a domestic end product: 1) the article must be manufactured in the United States; and 2) the cost of the domestic components must exceed 50% of the cost of all of the components.*

3. Stage II: The manufacturer must have the information to address the request for further information (RFI) letter sent out by SCL before the May 26, 2009 cutoff date. The RFI letter has been included in Appendix B.

4. Stage II: The manufacturer must have a sample product shipped to SCL for a mockup test before June 23, 2009.

5. Stage I and II: The manufacturer must already have the luminaire in production or be prepared to have it in production by the time the test is performed.

6. Stage I and II: The manufacturer must be able to respond to and fulfill bulk orders of up to luminaire quantities of 5,000.

7. Stage I and II: The luminaire must replace utility grade cobra head style luminaires and would need to be priced to compete in that market.

For the Stage I luminaire selection, SCL selected luminaires A1 and B1. The luminaire selection process was slightly different than for Stage II. The main differences include:

- Under Stage I, being "Made in America" was not one of the overall requirements for the luminaire to be considered for use in the pilot study.

- Type II distributions were not being considered on the Stage I installations on residential streets.
- Dates for providing RFI information and field testing dates where not a requirement of the Stage I selection process.

For Stage II, a total of 150 LED luminaire manufacturers and suppliers were contacted. Many of these suppliers did not meet the “Made in America” requirement. Others could not provide a sample product by the June 23, 2009 cutoff date. Products from the manufacturers that met the above criteria were selected for testing.

## Outcome of Stage I and II LED Product Selection Process

The manufacturers and the products selected for the Stage I and II testing are summarized in Table 5-1.

Table 5-1 Candidate LED luminaires proposed to be tested

| Description | Candidate Luminaires | | | | | |
|---|---|---|---|---|---|---|
| | Stage I | | Stage II | | | |
| | Luminaire A1 | Luminaire B1 | Luminaire C1 | Luminaire D1 | Luminaire E1 | Luminaire F1 |
| Power Watts | 39W | 58W | 75W | 78W | 56W | 88W |
| Distribution Type | Type II | Type III | Type III | Type II | Type III | Type III |
| Color Correlated Temperature (CCT) | 6000°K | 5500°K | 5000°K | 5400°K | 6500°K | 5100°K |
| Color Rendering Index (CRI) | 75 | 72 | 70 | 70 | 75 | 75 |
| Initial Lumens Delivered | 2070 | 2890 | 4,856 | 5,100 | 4,228 | 3,075 |
| Efficacy (Lm/W) | 53 | 50 | 66 | 62 | 75.5 | 32 |
| Driver Current (mA) | 525mA | 325mA | 350mA | 350mA | 311mA | 350mA |
| IP Rating | IP66 | IP67 | IP65 | IP66 | IP66 | IP66 |
| Weight (lbs) | 10.5lbs | 20lbs | 22lbs | 28lbs | 36lbs | 17lbs |

Under Stage I testing, it was found that the field tested Vendor A luminaires performed favorably. However, information gained from public feedback, indicated the color temperature was too cool (too blue) and created a somewhat dismal and unwelcoming environment. Since the Vendor A luminaire performed well in Stage I testing and was a “Made in America” product, it was added to the list of manufacturers to be tested under Stage II with the plan to test a warmer color temperature in the range of 4000°K to 4300°K (less blue with more red and yellow light) and change the light distribution from Type III to Type II. As with the Vendor A luminaire, the Vendor C luminaire would be tested at the warmer color temperature with a Type II distribution. The following luminaires were added to the list for further testing:

- Vendor A
  - Luminaire A2: 60LED-Type II Distribution-4300K-525mA
  - Luminaire A3: 80LED-Type II Distribution-4300K-525mA

- Vendor C
    - Luminaire C2: 63LED-Type II Distribution-4100K-350mA
    - Luminaire C3: 119LED-Type II Distribution-4100K-350mA

# 6 Simulation Test Results

The performance of the selected LED luminaires was simulated using the lighting analysis software AGI32 for typical residential roadway sections and for field conditions at the Stage I and Stage II test sites. For the typical residential roadway condition, each luminaire was modeled to determine the light pole spacing needed to meet the illuminance levels and uniformity ratios required by RP-8-00 and the City of Seattle's Lighting Standards. For the field condition at each test site, the proposed luminaires were modeled using the AGI32 software based upon actual site conditions. Major factors considered when ranking the candidate products included:

- Luminaire mounting height.
- Average maintained illuminance values.
- Uniformity ratios (average/minimum).
- Light pole spacing[1].

The light loss factors (LLF) used for the analysis assumed a dirt depreciation factor (LDD) based on a clean environment and a seven-year maintenance cycle. The lamp lumen depreciation factor (LLD) used in the analysis was recommended by the manufacturers for their individual luminaires. It was assumed that the LLF factors provided by the manufacturers were based on LM-80 test data.

## Typical Roadway Simulation Test Results

Each of the LED products was modeled for a typical residential roadway with a 32-foot-wide cross section (Figure 6-1)[2]. The mounting height of the luminaire is 25 feet with a six foot bracket arm and a pole set back of three feet from the curb. The spacing and uniformity ratios were calculated for the typical residential roadway with low and medium pedestrian activities.[3] The results are summarized in Table 6-1 and compared against a typical 100-watt HPS luminaire with a Type III

[1] Light pole spacing is an important factor since the general practice on residential streets is to place light poles on every third property line giving typically 150 foot spacing between light poles. Mounting heights of luminaires were simulated at 30 feet. It was assumed this would provide the worst case illuminance values.

[2] Cross-section width is based on Figure 4-9 in the September 2005 edition of City of Seattle Right-of-Way Manual. Figure 6-1 has been modified to represent the typical parking and lane configuration present at project test sites.

[3] According to the RP-8-00, areas with very low volumes (typically 10 or fewer pedestrians per hour) of night pedestrian usage is classified as "Low" Pedestrian Conflict Area. Areas with more pedestrians (typically 11 to 100 per hour) using the streets at night is classified as a "Medium" Pedestrian Conflict Area.

distribution.[4] The exception to this was the Stage I luminaire B1 that was compared against a 150-watt HPS luminaire.

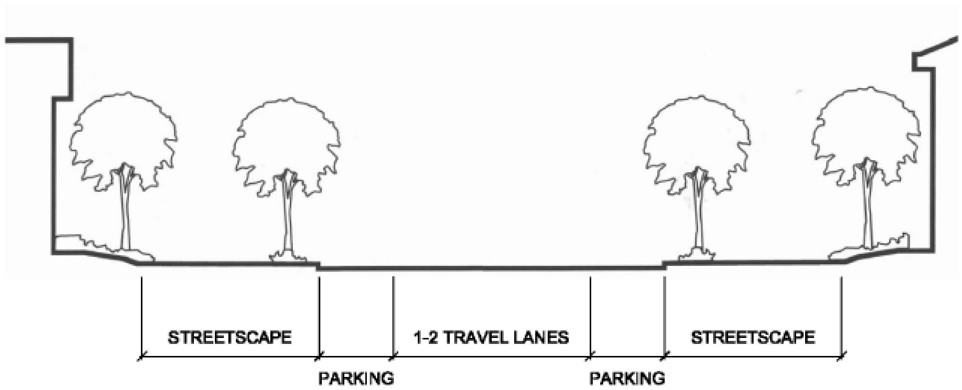


Figure 6-1 A typical residential roadway (32-foot-wide) cross section

Table 6-1 LED luminaire simulation test results for a typical residential roadway

| Description | Distribution Type | Light Loss Factor | Residential (32-foot Wide Roadway) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Medium Pedestrian Activity | | | Low Pedestrian Activity | | |
| | | | Spacing (feet) | Average Maintained Illuminance (fc) | Uniformity (Avg/Min) | Spacing (feet) | Average Maintained Illuminance (fc) | Uniformity (Avg/Min) |
| **RP-8-00 Requirements*** | | | | **0.7** | **6** | | **0.4** | **6** |
| **Existing HPS Luminaires** | | | | | | | | |
| 100W HPS Cobrahead | III | 0.62 | 117 | 0.70 | 2.50 | 134 | 0.61 | 3.05 |
| 150W HPS Cobrahead** | III | 0.62 | 153 | 0.83 | 4.15 | 154 | 0.83 | 4.15 |
| **Stage I** | | | | | | | | |
| Luminaire A1: 25LED-Type II Distribution-6000K-525mA | III | 0.95 | 82 | 0.70 | 2.80 | 103 | 0.56 | 2.80 |
| Luminaire B1**: 48LED-Type III Distribution-5500K-325mA | III | 0.88 | 47 | 0.70 | 1.25 | 83 | 0.40 | 1.54 |
| **Stage II** | | | | | | | | |
| Luminaire D1: Type II Distribution-5400K-350mA | III | 0.72 | 109 | 0.77 | 3.85 | 109 | 0.77 | 3.85 |
| Luminaire E1: Type III Distribution-6500K-311mA | III | 0.72 | 72 | 0.70 | 2.12 | 128 | 0.40 | 2.00 |
| Luminaire F1: Type III Distribution-5100K-350mA | III | 0.81 | 49 | 0.70 | 1.23 | 86 | 0.40 | 1.60 |
| Luminaire C1: 63LED-Type III Distribution-5000K-350mA | III | 0.77 | 90 | 0.70 | 2.33 | 106 | 0.60 | 3.00 |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | II | 0.77 | 98 | 0.70 | 1.79 | 117 | 0.60 | 2.86 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | II | 0.77 | 139 | o.94 | 4.70 | 139 | 0.94 | 4.70 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | II | 0.77 | 106 | 0.70 | 3.04 | 124 | 0.60 | 3.00 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | II | 0.77 | 141 | 0.70 | 3.33 | 105 | 0.68 | 3.40 |

* A minimum illuminance of 0.2 fc was required for each luminaire.
**All luminaires were compared against the 100 Watt HPS luminaire with the exception of Luminaire B1 which was compared against the 150 Watt HPS luminaire.

RP-8-00 requires a minimum average maintained illuminance level of 0.7fc for medium pedestrian activity areas and 0.4fc for low pedestrian activity areas on typical residential roadways. The uniformity ratio requirement is 6:1 for both medium and low pedestrian conflict areas. Since neither RP-8-00 nor the City of Seattle publishes a minimum allowable light level, the Washington State Department of Transportation's (WSDOT) minimum light level requirement of 0.2fc was used. The existing 100-watt HPS luminaire mounted at 25 feet resulted in an AGI32 lighting simulation spacing

[4] The current SCL practice is to light residential roadways with Type III distributions.

of 117 feet and a uniformity ratio of 2.50:1. The existing 150-watt HPS luminaire mounted at 25 feet resulted in a spacing of 153 and a uniformity ratio of 4.15:1. Of the manufacturers' candidate LED luminaires, when compared to the HPS luminaires, the following conclusions were drawn:

**Stage I**

- Luminaire A1 produced a better uniformity ratio, but with a shorter light spacing.
- Luminaire B1 produced a better uniformity ratio, but with a shorter light spacing.

**Stage II**

- Luminaire D1 produced comparable light spacing. The uniformity ratio was worse but still within RP-8-00 requirements.
- Luminaire C1 produced a better uniformity ratio, but with a shorter light spacing.
- Luminaire E1 and luminaire F1 each produced a better uniformity ratio, but with a much shorter light spacing.
- Luminaire A2 and luminaire C2 produced comparable light spacing and uniformity ratio.
- Luminaire A3 and luminaire C3 produced a longer light spacing with a worse uniformity ratio than the HPS luminaire, but still within RP-8-00 standards.

Of all the products simulated, AGI32 revealed that for a standard residential roadway Vendor A and the Vendor C Type II luminaires produced comparable spacing and uniformity to a 100-watt HPS luminaire.

## TEST SITE SIMULATION RESULTS

### Stage I - Capitol Hill Test Site Simulation Results

Table 6-2 summarizes simulation results provided by SCL for the Capitol Hill test sites. In the AGI32 simulation model, the existing HPS luminaires were replaced with the candidate LED luminaires. The average maintained illuminance levels and average to minimum uniformity ratios for roadways and sidewalks were calculated. Pedestrian activity within the Capitol Hill area was considered to be low. Light pole spacing varies under the different site conditions but typically SCL's practice is to install luminaires on utility poles placed at approximately every third property line. For Site 2, the pole spacing is approximately every 120 feet. For Site 10, the pole spacing is approximately every 100 to 140 feet. Luminaires A1 and B1 under Stage I were only analyzed for one test site rather than each of the luminaires being tested at both Stage I sites.

The results showed that luminaires A1 and B1had lower illuminance values for roadways and sidewalks at all test sites compared to the existing 100- and 150-watt HPS luminaires. Although A1 average maintained illuminance levels fell below the HPS luminaire's, they were within RP-8-00 accepted values. B1 failed to produce an illuminance level comparable to that of the existing HPS luminaire or meet the RP-8-00 requirements. The Uniformity results for Site 2 showed B1 had a better uniformity ratio than the HPS luminaire. Uniformity information was unable to be calculated for Test Site 10 because the minimum illuminance level was zero for some sample calculation points.

Table 6-2 Simulation test results for site conditions – Stage I Capitol Hill

| Site Description | Light Loss Factor | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
|---|---|---|---|---|---|---|---|
| **Site 2: Summit Ave E.** | | Roadway | | E Sidewalk | | W Sidewalk | |
| 150W HPS Type III Cobrahead | 0.62 | 1.01 | 3.37 | 0.74 | 7.40 | 0.61 | 2.03 |
| Luminaire B1: 48LED-Type III-Distribution-325mA | 0.88 | 0.27 | 2.70 | 0.23 | 2.30 | 0.17 | 1.70 |
| **Site 10: E. Mercer St. between 24th Ave E. and 25th Ave E.** | | Roadway | | N Sidewalk | | S Sidewalk | |
| 100W HPS Type III Cobrahead | 0.62 | 0.60 | NA | 0.26 | NA | 0.52 | NA |
| Luminaire A1: 25LED-Type II Distribution-525mA | 0.95 | 0.46 | NA | 0.13 | NA | 0.36 | NA |

## Stage II - South Park Test Site Simulation Results

Table 6-3 summarizes the simulation results for the field conditions at the South Park study sites. Pedestrian activity within the South Park Area was considered to be low. Typical light pole spacing under site conditions is approximately 150 feet. This corresponds to SCL's practice of installing luminaires on utility poles placed at approximately every third property line.

The following is an overall summary of the test results:

- Luminaires E1 and F1 did not have comparable average maintained illuminance levels to the 100-watt HPS nor did they meet RP-8-00 requirements for any of the test sites. Uniformity ratios for E1 and F1 where generally better than the 100-watt HPS and fell well within the RP-8-00 requirements.
- Luminaire D1 produced a comparable average maintained illuminance level to the 100-watt HPS. The uniformity ratio however was significantly worse for all test sites and did not meet the RP-8-00 requirements of 6:1.
- The Vendor A and Vendor C luminaires performed better than the Vendor D, Vendor E, and Vendor F luminaires and are comparable to the existing 100-watt HPS luminaires for both the average maintained illuminance and uniformity ratios.
- The use of the Type II distribution compared to a Type III distribution made sidewalk illuminance levels drop slightly while maintaining acceptable roadway average maintained illuminance levels. This was one of the desired outcomes of testing the Type II versus the Type III distributions.

## Table 6-3 Simulation test results for test sites – South Park

| Luminaire Description | Light Loss Factor | Site 11: S Donovan St | | | | | |
|---|---|---|---|---|---|---|---|
| | | East Approach | | NE Sidwalk | | SE Sidwalk | |
| | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| 100W HPS Type III Cobrahead | 0.62 | 0.51 | 6.38 | 0.35 | 17.50 | 0.19 | 1.90 |
| Luminaire D1: Type II Distribution-5400K-325mA | 0.72 | 0.61 | 61.00 | 0.13 | 13.00 | 0.08 | 4.00 |
| Luminaire E1: Type III Distribution-6500K-311mA | 0.72 | 0.33 | 4.71 | 0.16 | 4.00 | 0.17 | 2.83 |
| Luminaire F1: Type III Distribution-5100K-350mA | 0.81 | 0.23 | 2.08 | 0.13 | 1.86 | 0.16 | 1.78 |
| Luminaire C1: 63LED-Type III Distribution-5000K-350mA | 0.77 | 0.41 | 10.25 | 0.36 | 9.00 | 0.10 | 2.50 |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | 0.77 | 0.43 | 4.78 | 0.26 | 3.25 | 0.17 | 2.43 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | 0.77 | 0.82 | 4.56 | 0.51 | 3.19 | 0.32 | 2.13 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | 0.77 | 0.46 | 2.42 | 0.26 | 2.60 | 0.13 | 2.60 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | 0.77 | 0.60 | 2.40 | 0.34 | 2.43 | 0.16 | 2.67 |

| Luminaire Description | Light Loss Factor | Site 11: S Donovan St | | | | | |
|---|---|---|---|---|---|---|---|
| | | West Approach | | NW Sidwalk | | SW Sidwalk | |
| | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| 100W HPS Type III Cobrahead | 0.62 | 0.55 | 6.88 | 0.43 | 21.50 | 0.21 | 2.10 |
| Luminaire D1: Type II Distribution-5400K-325mA | 0.72 | 0.66 | 66.00 | 0.17 | 17.00 | 0.09 | 3.00 |
| Luminaire E1: Type III Distribution-6500K-311mA | 0.72 | 0.36 | 5.14 | 0.18 | 4.50 | 0.19 | 2.38 |
| Luminaire F1: Type III Distribution-5100K-350mA | 0.81 | 0.25 | 2.50 | 0.14 | 1.75 | 0.17 | 1.55 |
| Luminaire C1: 63LED-Type III Distribution-5000K-350mA | 0.77 | 0.46 | 9.20 | 0.45 | 11.25 | 0.10 | 2.50 |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | 0.77 | 0.46 | 4.60 | 0.31 | 3.44 | 0.19 | 1.90 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | 0.77 | 0.89 | 4.45 | 0.60 | 3.53 | 0.37 | 1.85 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | 0.77 | 0.50 | 2.38 | 0.15 | 2.50 | 0.15 | 2.50 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | 0.77 | 0.66 | 2.36 | 0.41 | 3.42 | 0.19 | 2.71 |

| Luminaire Description | Light Loss Factor | Site 11: S Donovan St | | Site 12: Alley | |
|---|---|---|---|---|---|
| | | 12th Ave S Intersection | | Btw 12th Ave & 14th Ave | |
| | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| 100W HPS Type III Cobrahead | 0.62 | 0.60 | 6.67 | NA | NA |
| Luminaire D1: Type II Distribution-5400K-325mA | 0.72 | 0.69 | 11.50 | 0.49 | 16.33 |
| Luminaire E1: Type III Distribution-6500K-311mA | 0.72 | 0.36 | 3.00 | 0.34 | 2.83 |
| Luminaire F1: Type III Distribution-5100K-350mA | 0.81 | 0.25 | 2.08 | 0.29 | 2.07 |
| Luminaire C1: 63LED-Type III Distribution-5000K-350mA | 0.77 | 0.60 | 6.67 | 0.74 | 8.22 |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | 0.77 | 0.48 | 3.43 | 0.48 | 3.00 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | 0.77 | 0.92 | 3.41 | 0.94 | 3.03 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | 0.77 | 0.50 | 3.13 | 0.57 | 2.59 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | 0.77 | 0.66 | 3.14 | 0.75 | 2.42 |

| Luminaire Description | Light Loss Factor | Site 13: S Trenton St | | | | | |
|---|---|---|---|---|---|---|---|
| | | Roadway | | N Sidewalk | | S Sidewalk | |
| | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| 100W HPS Type III Cobrahead | 0.62 | 0.66 | 4.13 | 0.32 | 3.20 | 0.42 | 14.00 |
| Luminaire D1: Type II Distribution-5400K-325mA | 0.72 | 0.56 | 18.67 | 0.09 | 3.00 | 0.12 | 12.00 |
| Luminaire E1: Type III Distribution-6500K-311mA | 0.72 | 0.30 | 3.33 | 0.17 | 2.43 | 0.16 | 3.20 |
| Luminaire F1: Type III Distribution-5100K-350mA | 0.81 | 0.21 | 2.10 | 0.15 | 1.88 | 0.12 | 1.33 |
| Luminaire C1: 63LED-Type III Distribution-5000K-350mA | 0.77 | 0.70 | 2.41 | 0.13 | 2.60 | 0.25 | 5.00 |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | 0.77 | 0.41 | 4.56 | 0.19 | 2.38 | 0.24 | 3.00 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | 0.77 | 0.79 | 4.39 | 0.37 | 2.18 | 0.48 | 3.00 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | 0.77 | 0.43 | 4.30 | 0.15 | 2.50 | 0.24 | 4.80 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | 0.77 | 0.57 | 4.38 | 0.19 | 2.38 | 0.31 | 4.43 |

The following is a summary of site specific results:

- Test Site 11: The Vendor A, Vendor C, and Vendor D luminaires produced average maintained illuminance levels comparable to the existing HPS luminaires for roadways and intersections. Among the three vendors, luminaires A3 and C3 produced illuminance levels on the sidewalk comparable to the existing lights. Although luminaire D1 produced illuminance levels for roadways and intersections comparable to the existing HPS luminaires, its uniformity ratio deteriorated dramatically; this is unacceptable in practice.
- Test Site 12: In the alleyway, the Vendor A, Vendor C, and Vendor D luminaires produced a better illuminance level than the other two products. Vendor A and Vendor C luminaires produced similar or higher illuminance levels and better uniformity ratios than the Vendor D product.
- Test Site 13: Luminaires A3, C1 and C3 produced illuminance levels for roadways comparable to the existing HPS luminaires and only C3 produced an illuminance level for sidewalks comparable to the existing HPS luminaires. Uniformity ratios of each of these three luminaires are comparable to the HPS luminaires.

## SIMULATION TEST CONCLUSIONS

Simulation results showed the Type II light distribution provided slightly greater pole spacing than the Type III light distribution for a typical residential roadway. Both Vendor A and Vendor C luminaires performed well with the Type II distributions operating at a warmer color temperature between 4100°K and 4300°K.

Vendor F luminaire had consistently low illuminance values throughout all test sites. Through further investigation into the design characteristics of the luminaire, it was found that the mounting height for optimum performance was approximately 22 feet. Vendor F luminaire was eliminated from further testing for use on residential roadways.

Vendor E luminaire, which is aimed mainly toward the decorative luminaire market, was eventually eliminated due to its consistently low illuminance values throughout the test sites. Vendor E's pricing information also indicated it would not be a competitive option for replacing the standard utility grade cobra head style luminaire.

Vendor B luminaire with a Type III distribution had lower average maintained illuminance levels of 0.27fc. This is below acceptable limits and does not meet the illuminance levels produced by the 150-watt HPS luminaire. The uniformity ratio was well within RP-8-00 values and well below that of the HPS luminaires.

Under Stage I, SCL further field tested luminaires A1 and B1 to determine actual field performance. Under Stage II, Vendor A luminaires and Vendor C luminaires with Type II distribution were recommended for further testing in the field. The final list of luminaires for field testing is shown in Table 6-4.

Table 6-4 Recommended luminaires for field testing

| Description | Field Tested Luminaires | | | | | |
|---|---|---|---|---|---|---|
| | Stage I | | Stage II | | | |
| | Luminaire A1 | Luminaire B1 | Luminaire A2 | Luminaire A3 | Luminaire C2 | Luminaire C3 |
| | Vender A | Vendor B | Vendor A | Vendor A | Vendor C | Vendor C |
| LED Array | 25 | 48 | 60 | 80 | 63 | 119 |
| Watts | 39 | 58 | 109 | 142 | 75 | 137 |
| Distribution | Type II | Type III | Type II | Type II | Type II | Type II |
| CCT | 6000°K | 5500°K | 4300°K | 4300°K | 4100°K | 4100°K |
| CRI | 75 | 72 | 75 | 75 | 75 | 75 |
| Initial Lumens Delivered | 2,070 | 2,890 | 4,968 | 6,624 | 4,701 | 9,919 |
| Efficacy (Lm/W) | 53 | 50 | 46 | 46 | 63 | 67 |
| Driver Current (mA) | 525 | 325 | 525 | 525 | 350 | 350 |
| IP Rating | 66 | 67 | 66 | 66 | 65 | 65 |
| Weight (lbs) | 10.5 | 20 | 16 | 24 | 22 | 28 |

## South Park Life Cycle Illuminance Analysis

The objective of the life cycle illuminance analysis was to evaluate the performance of the recommended luminaires over an assumed life cycle of 50,000 hours with changes in light loss factors over time. The Stage II LED luminaires recommended for field testing were evaluated using AGI32. For information purposes, Vendor A 40 LED luminaire was also evaluated. Luminaires analyzed included:

- Vendor A
  - Luminaire A2: 60LED-Type II Distribution-4300K-525mA
  - Luminaire A3: 80LED-Type II Distribution-4300K-525mA
  - Luminaire A4: 40LED-Type II Distribution-4300K -525mA
- Vendor C
  - Luminaire C2: 63LED-Type II Distribution-4100K-350mA
  - Luminaire C3: 119LED-Type II Distribution-4100K-350mA

These luminaires were tested for three scenarios:

Scenario 1 – illuminance level at initial lumen output
Scenario 2 – illuminance level at 30K lumen output (luminaire has been in operation for 30,000 hours)
Scenario 3 – illuminance level at 50K lumen output (luminaire has been in operation for 50,000 hours)

## Light Loss Factors

The total Light Loss Factor (LLF) for each luminaire at different lumens output was calculated by multiplying the two contributing factors including the Lamp Lumen Depreciation (LLD) and Luminaire Dirt Depreciation (LDD) factor. The LLD factor for LSI luminaires was 0.95 as provided by the manufacturer. The LLD factors for Vendor A luminaires were obtained from the Vendor A 525mA LM-80 Lumen Maintenance Predictions vs. Ambient Temperature Chart with an ambient temperature of 10°C. The LDD factor was obtained from the RP-8-00 Figure A5-Luminaire Dirt Depreciation Factors with a very clean ambient type per discussions with SCL staff. A cleaning cycle of every seven years was assumed. These values are summarized in Table 6-5.

Table 6-5 LLD, LDD, and LLF Values

| Scenarios | Lamp Lumen Depreciation Factor (LLD) | | Luminaire Dirt Depreciation Factor (LDD) | Light Loss Factor (LLF) | |
|---|---|---|---|---|---|
| | Vendor C | Vendor A | | Vendor C | Vendor A |
| Initial | 1.00 | 1.00 | 0.92 | 0.92 | 0.92 |
| 30K Hours | 0.95 | 0.91 | 0.92 | 0.87 | 0.84 |
| 50K Hours | 0.95 | 0.85 | 0.92 | 0.87 | 0.78 |

## Analysis and Findings

The recommended luminaires were tested for three scenarios at 30 foot mounting height. The results have been summarized in Table 6-6. City Standards for residential roadways is 0.7fc. RP-8-00 standards require a minimum illuminance level of 0.4fc for low pedestrian volumes in residential areas. The RP-8-00 uniformity ratio requirement is 6:1.

Illuminance levels produced by luminaire C2 did not meet City illuminance standards for any scenario, but met RP-8-00 standards in all cases. In addition, uniformity ratios were met for all scenarios.

Luminaire C3 produced illuminance levels that met RP-8-00 and the City's requirement under all three scenarios. Uniformity ratios were also met for all scenarios.

Luminaire A4 marginally met the RP-8-00 minimum average maintained illuminance levels for the initial set of scenario for Site 11 and 12. The RP-8-00 uniformity ratios were met for all scenarios.

Illuminance levels produced by luminaire A2 did not meet City illuminance standards for any of the scenarios, but met RP-8-00 standards in all cases. Uniformity ratios were met for all scenarios.

Illuminance levels produced by A3 met the City illuminance requirements at the initial setup and 30K scenarios for Site 11 and all scenarios for Site 12 Alleyway. RP-8-00 illuminance values were met for all scenarios. Uniformity ratios requirement were met for all scenarios.

## South Park Life Cycle Illuminance Analysis Conclusion

In summary, the Vendor A LM-80 Lumen Maintenance Predictions versus Ambient Temperature Chart provided a more realistic prediction of the expected changes in lumen depreciation between 30,000 hrs and 50,000 hrs than the standard value of 0.95 provided by Vendor C for the lifetime of the luminaire. Illuminance levels produced by luminaires A3 and C3 met City illuminance values in most but not all cases. With the exception of A4, all luminaires met the minimum RP-8-00 minimum illuminance requirements. Uniformity ratios requirement were met by all luminaires at a 30 foot mounting height.

## Table 6-6 South Park life cycle scenario analysis

| Luminaire Description | Scenarios | Light Loss Factor | Site 11: S Donovan St | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | East Approach | | NE Sidwalk | | SE Sidwalk | |
| | | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 0.51 | 4.64 | 0.32 | 3.20 | 0.23 | 1.92 |
| | 30K Lumen Output | 0.87 | 0.49 | 4.90 | 0.30 | 3.33 | 0.19 | 2.38 |
| | 50K Lumen Output | 0.87 | 0.49 | 4.90 | 0.30 | 3.33 | 0.19 | 2.38 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 0.99 | 4.71 | 0.62 | 3.26 | 0.39 | 2.17 |
| | 30K Lumen Output | 0.87 | 0.94 | 4.70 | 0.59 | 3.28 | 0.37 | 2.18 |
| | 50K Lumen Output | 0.87 | 0.94 | 4.70 | 0.59 | 3.28 | 0.37 | 2.18 |
| Luminaire A4: 40LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.37 | 2.47 | 0.21 | 2.63 | 0.11 | 2.75 |
| | 30K Lumen Output | 0.84 | 0.33 | 2.36 | 0.19 | 2.71 | 0.10 | 2.50 |
| | 50K Lumen Output | 0.78 | 0.31 | 2.38 | 0.18 | 2.57 | 0.09 | 3.00 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.55 | 2.50 | 0.31 | 2.58 | 0.16 | 2.67 |
| | 30K Lumen Output | 0.84 | 0.50 | 2.50 | 0.28 | 2.55 | 0.14 | 2.80 |
| | 50K Lumen Output | 0.78 | 0.47 | 2.47 | 0.27 | 2.70 | 0.13 | 2.60 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.73 | 2.35 | 0.41 | 2.41 | 0.20 | 2.50 |
| | 30K Lumen Output | 0.84 | 0.67 | 2.39 | 0.38 | 2.53 | 0.18 | 2.57 |
| | 50K Lumen Output | 0.78 | 0.62 | 2.38 | 0.35 | 2.50 | 0.17 | 2.43 |

| Luminaire Description | Scenarios | Light Loss Factor | Site 11: S Donovan St | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | West Approach | | NE Sidwalk | | SE Sidwalk | |
| | | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 0.56 | 4.67 | 0.32 | 3.20 | 0.23 | 1.92 |
| | 30K Lumen Output | 0.87 | 0.53 | 4.42 | 0.30 | 3.33 | 0.19 | 2.38 |
| | 50K Lumen Output | 0.87 | 0.53 | 4.42 | 0.30 | 3.33 | 0.19 | 2.38 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 1.07 | 4.46 | 0.62 | 3.26 | 0.39 | 2.17 |
| | 30K Lumen Output | 0.87 | 1.02 | 4.43 | 0.59 | 3.28 | 0.37 | 2.18 |
| | 50K Lumen Output | 0.87 | 1.02 | 4.43 | 0.59 | 3.28 | 0.37 | 2.18 |
| Luminaire A4: 40LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.40 | 2.35 | 0.21 | 2.63 | 0.11 | 2.75 |
| | 30K Lumen Output | 0.84 | 0.37 | 2.47 | 0.19 | 2.71 | 0.10 | 2.50 |
| | 50K Lumen Output | 0.78 | 0.34 | 2.43 | 0.18 | 2.57 | 0.09 | 3.00 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.61 | 2.44 | 0.31 | 2.58 | 0.16 | 2.67 |
| | 30K Lumen Output | 0.84 | 0.55 | 2.39 | 0.28 | 2.55 | 0.14 | 2.80 |
| | 50K Lumen Output | 0.78 | 0.51 | 2.43 | 0.27 | 2.70 | 0.13 | 2.60 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.81 | 2.38 | 0.41 | 2.41 | 0.20 | 2.50 |
| | 30K Lumen Output | 0.84 | 0.73 | 2.35 | 0.38 | 2.53 | 0.18 | 2.57 |
| | 50K Lumen Output | 0.78 | 0.69 | 2.38 | 0.35 | 2.50 | 0.17 | 2.43 |

| Luminaire Description | Scenarios | Light Loss Factor | Site 11: S Donovan St | | Site 12: Alley | |
|---|---|---|---|---|---|---|
| | | | 12th Ave Intersection | | Btw 12th Ave & 14th Ave | |
| | | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 0.58 | 3.41 | 0.54 | 3.36 |
| | 30K Lumen Output | 0.87 | 0.55 | 3.24 | 0.51 | 2.83 |
| | 50K Lumen Output | 0.87 | 0.55 | 3.24 | 0.51 | 2.83 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 1.10 | 3.33 | 1.06 | 2.86 |
| | 30K Lumen Output | 0.87 | 1.05 | 3.39 | 1.00 | 2.86 |
| | 50K Lumen Output | 0.87 | 1.05 | 3.39 | 1.00 | 2.86 |
| Luminaire A4: 40LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.41 | 3.15 | 0.25 | 3.57 |
| | 30K Lumen Output | 0.84 | 0.37 | 3.08 | 0.42 | 2.63 |
| | 50K Lumen Output | 0.78 | 0.34 | 3.09 | 0.39 | 2.60 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.61 | 3.21 | 0.69 | 2.65 |
| | 30K Lumen Output | 0.84 | 0.55 | 3.06 | 0.62 | 2.58 |
| | 50K Lumen Output | 0.78 | 0.52 | 3.06 | 0.58 | 2.64 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.81 | 3.24 | 0.92 | 2.49 |
| | 30K Lumen Output | 0.84 | 0.74 | 3.22 | 0.83 | 2.44 |
| | 50K Lumen Output | 0.78 | 0.69 | 3.29 | 0.78 | 2.44 |

| Luminaire Description | Scenarios | Light Loss Factor | Site 13: S Trenton St | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Roadway | | N Sidewalk | | S Sidewalk | |
| | | | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) | Illuminance (fc) | Uniformity (Avg/Min) |
| Luminaire C2: 63LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 0.5 | 4.55 | 0.23 | 2.30 | 0.29 | 3.22 |
| | 30K Lumen Output | 0.87 | 0.47 | 4.70 | 0.22 | 2.44 | 0.28 | 3.11 |
| | 50K Lumen Output | 0.87 | 0.47 | 4.70 | 0.22 | 2.44 | 0.28 | 3.11 |
| Luminaire C3: 119LED-Type II Distribution-4100K-350mA | Initial Setup | 0.92 | 0.96 | 4.36 | 0.44 | 1.10 | 0.57 | 3.00 |
| | 30K Lumen Output | 0.87 | 0.91 | 4.33 | 0.42 | 2.21 | 0.54 | 3.00 |
| | 50K Lumen Output | 0.87 | 0.91 | 4.33 | 0.42 | 2.21 | 0.54 | 3.00 |
| Luminaire A4: 40LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.35 | 4.38 | 0.12 | 2.40 | 0.19 | 4.75 |
| | 30K Lumen Output | 0.84 | 0.32 | 4.00 | 0.11 | 2.20 | 0.18 | 4.50 |
| | 50K Lumen Output | 0.78 | 0.30 | 4.29 | 0.10 | 2.50 | 0.16 | 4.00 |
| Luminaire A2: 60LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.52 | 4.00 | 0.18 | 2.25 | 0.29 | 4.83 |
| | 30K Lumen Output | 0.84 | 0.47 | 4.27 | 0.17 | 2.43 | 0.26 | 4.33 |
| | 50K Lumen Output | 0.78 | 0.44 | 4.00 | 0.16 | 2.67 | 0.25 | 5.00 |
| Luminaire A3: 80LED-Type II Distribution-4300K-525mA | Initial Setup | 0.92 | 0.70 | 4.38 | 0.24 | 2.40 | 0.38 | 4.75 |
| | 30K Lumen Output | 0.84 | 0.63 | 4.50 | 0.21 | 2.33 | 0.35 | 5.00 |
| | 50K Lumen Output | 0.78 | 0.59 | 4.54 | 0.20 | 2.50 | 0.32 | 4.57 |

# 7 Stage I and Stage II Field Tests

Luminaires identified for field testing under the simulation analysis were installed at the Stage I Capitol Hill and Stage II South Park test sites. Field tests were conducted to determine the average maintained illuminance levels and uniformity that could be achieved. Appendix C shows the locations of the HPS luminaires being replaced in Site 2 and Site 10 of the Stage I Capitol Hill area and Site 11 and Site 12 of the Stage II South Park area. The actual site limits shown in Appendix C varied slightly to accommodate the total number of LED luminaires required to conduct the appropriate tests.

A couple of important concepts to keep in mind prior to reviewing the field test results:

- Existing lighting systems are generally designed to take into account lumen and dirt deprecation over a period of time based on a maintenance cycle (cleaning) of once every four to five years. Systems are designed so that minimum illuminance levels are met at that future time which means when a new light or lighting system is installed in the field, illuminance levels are much higher than required to meet minimums. With LED luminaires, the maintenance cycle is assumed to be seven years and lumen depreciation is based on LM-80 lumen depreciation curves.
- Illuminance levels in excess of accepted values constitute wasted energy.
- With the use of LED luminaires, new dimmable drivers and light controls, a consistent lumen output can be maintained across the life of the luminaire so that the lumen output at initial installation is the same at the end of the luminaires life. In theory, this means a longer life for the luminaire since it is being driven at a lower amperage during the first few years of its life. Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries like luminaire A4 a viable and economic option.

## Stage I - Capitol Hill Illuminance Level Performance

PNNL conducted field measurements for the Stage I Capitol Hill Test Sites. The test summaries are included in Table 7-1with the full test report included in Appendix D-1.

Values summarized in Table 7-1 showed that the HPS average maintained illuminance levels were high for the residential type of roadway facility with low pedestrian activity. Uniformity ratios generally fell within acceptable ranges except for Site 10 with a ratio of 8.0. Average maintained illuminance for the LED luminaires met minimum values for the type of roadway facility being illuminated. The uniformity ratios were well within the standard of 4.0 or less. Illuminance levels along sidewalks were measured at select locations (usually one or three measurement points) for each test site. The average illuminance levels ranged between 0.1fc to 4.8fc. With only spot measurements taken on the sidewalk areas, no conclusion was drawn regarding appropriate illuminance levels other than light is being cast back to the sidewalk areas and in most cases it is near or greater than the allowed 0.2fc minimum.

Table 7-1 Capitol Hill field measurements

| Test Site/Description | | Pedestrian Activity | Luminaire Type | Characteristics | Average Illuminance (fc) | Uniformity Avg/Min Ratio |
|---|---|---|---|---|---|---|
| RP-8-00 Residential | Roadway | Low to Medium | | | 0.4 to 0.7 | 6 |
| | Walkway | | | | 0.3 to 0.4 | 6 |
| Site 2 Summit Ave E. (Thomas St. To E. John St.) | Roadway | Low | HPS (Existing) | 150W HPS Type III | 1.86 | 4 |
| | | | LED | Luminaire B1 | 0.46 | 2 |
| | Walkway | | HPS (Existing) | 150W HPS Type III | 1.21 | NA* |
| | | | LED | Luminaire B1 | 0.65 | NA* |
| Site 10 E Mercer St. (24th Ave E. to 26th Ave E.) | Roadway | Low | HPS (Existing) | 100W HPS Type III | 0.74 | 8 |
| | | | LED | Luminaire A1 | 0.37 | 4 |
| | Walkway | | HPS (Existing) | 100W HPS Type III | 0.19 | NA* |
| | | | LED | Luminaire A1 | 0.14 | NA* |

*Sidewalk illuminance levels were spot checked. Insufficient data points were obtained to calculate a uniformity ratio.

The low initial illuminance levels are reason for concern since the luminaires will experience lumen depreciation over time and many of these luminaires will replace existing installations of HPS luminaires where there is not a lot of control over the existing conditions. Simulation in Section 6 showed that assuming a seven-year maintenance cycle, luminaire B1 would have an illuminance level of 0.27fc at year seven. Luminaire A1 already shows an average illuminance level of less than the simulated value of 0.46fc.

## Stage II South Park Illuminance Level Performance

The Lighting Design Lab conducted field measurements for the Stage II South Park Test Sites. Sites 11, 12, and 13 were originally selected for field testing. Field visits revealed Site 12 and Site 13 do not have enough existing light poles to produce informative results based on the methodology plan developed for the project. Field measurements were therefore only conducted for Site 11 (see Appendix D-2) which included S Donovan St. between 14th Ave S. and 8th Ave S. Site 11 was separated into Site 11A (14th Ave S. to 12th Ave S.), 11B (12th Ave S. to 10th Ave S.), and 11C (10th Ave S. to 8th Ave S.) to better identify field measurement locations. The field test results are summarized in Table 7-2 below with the full field test report included in Appendix D-2. Uniformity ratios were not calculated for some sites because of areas with illuminance levels too low to measure, mainly due to tree foliage.

Table 7-2 South Park field measurements

| Test Site/Description | | Pedestrian Activity | Luminaire Type | Characteristics | Average Illuminance (fc) | Uniformity Avg/Min Ratio |
|---|---|---|---|---|---|---|
| RP-8-00 | Roadway | Low to Medium | | | 0.4 to 0.7 | 6 |
| Residential | Walkway | | | | 0.3 to 0.4 | 6 |
| 11A 14th Ave S. to 12th Ave S. | Roadway | Low | HPS (Existing) | 100W HPS Type III | 1.21 | 13 |
| | | | LED | Luminaire A3 | 1.14 | 4.1 |
| | Walkway | | HPS (Existing) | 100W HPS Type III | 0.35 | 3.77 |
| | | | LED | Luminaire A3 | 0.52 | 5.64 |
| 11B 12th Ave S. to 10th Ave S. | Roadway | Low | HPS (Existing) | 100W HPS Type III | 1.15 | 6.16 |
| | | | LED | Luminaire C3 | 1.75 | 18.88 |
| | Walkway | | HPS (Existing) | 100W HPS Type III | 0.39 | NA* |
| | | | LED | Luminaire C3 | 0.46 | NA* |
| 11C 10th Ave S. to 8th Ave S. | Roadway | Low | HPS (Existing) | 100W HPS Type III | 0.42 | NA* |
| | | | LED | Luminaire A2 | 0.81 | 8.68 |
| | Walkway | | HPS (Existing) | 100W HPS Type III | 0.42 | NA* |
| | | | LED | Luminaire A2 | 0.29 | NA* |

*Sidewalk illuminance levels were spot checked. Insufficient data points were obtained to calculate a uniformity ratio.

Values summarized in Table 7-2 showed that the HPS luminaires' average maintained illuminance levels were high for the roadway facility and uniformity ratios generally fell outside of the acceptable RP-8-00 standards of 6:1. In most cases the average maintained illuminance levels were two to three times greater than the minimums required. The exception to this is Site 11C where the average maintained illuminance was at 0.42fc, which is just above the accepted RP-8-00 minimum.

The HPS luminaires' average maintained illuminance levels met the standards for the sidewalk facility; the uniformity ratios however fell outside of the standards. The exception to this is Site 11A where the uniformity ratio was at 5.64:1.

Average maintained illuminance levels for the LED luminaires were generally higher than the HPS luminaires for the same roadway facility, while uniformity ratios were generally worse at those locations where uniformity could be calculated. The exception to this is Site 11A where the uniformity ratio fell well within the RP-8-00 required 6:1 ratio. A closer review of the field data showed similar performance from the LED and HPS luminaires at each test site with lower illuminance levels occurring near the midpoint (farthest distance) in between the luminaires.

For the sidewalk facilities, LED luminaires generally generated higher illuminance levels than the HPS luminaires with an exception of Site 11C where the LED luminaire produced a lower value that fell below the standard range but well above the 0.2fc minimum. Uniformity ratios for sidewalk areas were not compared due to the limited number of measured points.

In the Stage II South Park Study Area, of the eight Vendor C luminaires installed in the field, approximately 25 percent of the luminaires have failed (two out of eight). No failure has been reported for the field installed Vendor A luminaires.

## PHOTOGRAPHIC RECORD

Photographs were taken during both Stage I and Stage II studies to provide a photographic record of the study areas. See Appendix D-3. For the Capitol Hill study area, photographs were taken after the LED luminaires were installed. For the South Park study site, photographs were taken before and after the HPS luminaires were replaced with the LED luminaires.

Photographs taken at Site 11 of the South Park area are shown in Figure 7-1. The photographs provided a qualitative indication of lighting performance. Taken from the standpoint of a driver or pedestrian crossing the roadway, the photographs showed visually the LED luminaires provided comparable illuminance levels with better color rendering than the HPS luminaires.

Site 11 (Existing 100W HPS)
6/10/09 @ 12:55am
Nikon D200
ISO-400 (F-stop f/6.3, Exposure Time 2.5 sec.)

Site 11A (Luminaire A3)
12/23/09 @ 7:27pm
Canon PowerShot S5 I5
ISO-400 (F-stop f/6.3, Exposure Time 1 sec.)

Figure 7-1 Visual comparison between HPS and LED at South Park Site 11

## USER FEEDBACK

Since user feedback on the qualitative aspects of LED lighting is an essential component of the overall evaluation, SCL conducted a public survey to solicit community reaction to LED streetlights installed in the Capitol Hill neighborhood. The Capitol Hill study area consisted of a total of nine test sites as shown in Figure 4.1. Public surveys covered the nine sites, not just sites 2 and 10 being summarized in this report. The SCL survey planning team created a 16-question survey, with four optional questions to help provide a general classification of the responders. The survey was available in printed, hard copy as well as electronically on-line. The total number of completed surveys was 84. A summary of the survey results is included in Appendix D-4.

Responses to the LED luminaires were generally positive in nature. The main complaints from respondents in the Capitol Hill area concerning the LED luminaire installations included excessive brightness, increased glare, and the dismal, unwelcoming color (“too blue” or “too white”) of the lights. Nonetheless, most of the respective respondents recommended the LED streetlights to be more widely used throughout the city.

### Field Test Conclusions

The Stage I luminaire B1 with an average maintained illuminance level of 0.46fc just met minimum illuminance level of 0.4fc as required by RP-8-00 for residential streets. Luminaire A1 with an average maintained illuminance level of 0.37fc fell short of the RP-8-00 requirements. The average maintained illuminance levels did not meet those produced by the HPS luminaires under comparison.

For Stage I, the uniformity ratios of 4:1 and 2:1 respectively for luminaire A1 and B1 fell well within the RP-8-00 uniformity standard of 6:1. Uniformity ratios were better than the comparison luminaires.

The Stage II test site Vendor A and Vendor C luminaires met and exceeded the required average maintained illuminance levels of 0.4fc as published in RP-8-00 for residential streets and either met or exceed the average maintained illuminance levels produced by the HPS luminaires under comparison. Initial average maintained illuminance levels are high as to be expected since the lighting systems are designed for future years (in this case seven years). This excess lumen output is wasted energy that could be minimized by the use of dimmable drivers and control system.

For the Stage II test sites, uniformity ratios for both the HPS and LED luminaires showed poor performance. This may be due in part to the field conditions where large trees were present and in some cases luminaire arms are slightly skewed from the centerline of the roadway. These variations in field conditions created dark spots with illuminance levels too low to measure with a light meter. Because of these unknowns, it is difficult to formulate a conclusion about site uniformity.

Field observations before and after indicated that from purely an observational standpoint, the LED luminaires provided illuminance levels equal to or better than the HPS and the observers ability to see minor details was enhanced. The LED luminaires in the South Park Test Site with color temperatures of 4100°K to 4300°K created a warmer and welcoming environment than those operating at 5000°K to 6000°K in the Capitol Hill Test Site.

C2 Vendor C’s C2 luminaires were installed within the alleyway of Site 12. Because of the location and insufficient luminaire cycles, an appropriate illuminance level analysis per RP-8-00 standards was not performed. However, a visual inspection of the location indicated improved illuminance levels with a uniform light pattern.

Public feedback from Stage I installations were positive with concerns about glare, excessive brightness, and too "cold" of a color temperature. The general consensus was that the City should pursue additional installations.

Failure rate was reported as high as 25 percent for Vendor C luminaires from the Stage II South Park Area Study since the luminaires were installed in October, 2009. No failure has been reported for the field installed Vendor A luminaires.

# 8 Stage II Economic Evaluation

Energy demand and economic performance were analyzed for the Stage I and II LED luminaires. A simple payback was calculated for each LED luminaire versus the City's 100-watt HPS cobra head style luminaire for residential streets. In addition, each LED product's ability to produce a 40 percent energy savings compared to the existing 100-watt HPS luminaire was evaluated. Cost escalations were not considered in the evaluation. The factors and assumptions that went into the evaluation process have been summarized in the following sections.

## Initial Costs

The initial cost for this study is simply the time and materials required to install and energize new lighting luminaires at existing locations. SCL maintenance staff reported that maintenance crews are capable of a 20-minute removal and install process when the new LED luminaires are being placed on the same arm as the luminaire being removed. Table 8-1 summarizes the initial luminaire costs.

Table 8-1 Initial cost per luminaire

| Decription | Base System | Luminaire A2 | Luminaire A3 | Luminaire C2 | Luminaire C3 | Luminaire A1 | Luminaire B1 |
|---|---|---|---|---|---|---|---|
| Number of Luminaires | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of Lamps per Luminaire | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cost per Luminaire | $ 133.00 | $ 428.00 | $ 653.00 | $ 441.00 | $ 646.00 | $ 348.00 | $ 395.00 |
| Installation Cost | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 |
| **Initial Cost** | **$ 196.91** | **$ 491.91** | **$ 716.91** | **$ 504.91** | **$ 709.91** | **$ 411.91** | **$ 458.91** |

The initial installation costs are assumed to be equal for the HPS and LED luminaires. Both luminaires utilize the same type of mounting mechanism, are assumed to be mountable on the same arms, and wire connections can be made identical.

## Annual Operations Cost

The operation costs are dependent on energy consumption of the luminaire, the number of hours per day the luminaire will operate, and the electrical rate (cost per kilowatt hour). The City of Seattle assumes roadway and area lights are on an average of 12 hours per day. This equates to approximately 4,380 hours per year per luminaire. The current electrical rate paid by Seattle City Light is $0.053 per kilowatt-hour. Watts per luminaire takes into account the luminaire, ballast for

HPS luminaires, or drivers for LED luminaires. Table 8-2 summarizes the operating costs for the luminaires tested under this study.

Table 8-2 Annual operating cost

| Decription | Base System | Luminaire A2 | Luminaire A3 | Luminaire C2 | Luminaire C3 | Luminaire A1 | Luminaire B1 |
|---|---|---|---|---|---|---|---|
| Watts per Fixture (luminaire and ballast/driver) | 142 | 109 | 142 | 75 | 137 | 39 | 58 |
| kW per Fixture | 0.142 | 0.109 | 0.142 | 0.075 | 0.137 | 0.039 | 0.058 |
| Annual Hours of Operation (12 hrs per day) | 4,380 hrs | 4,380 hrs | 4,380 hrs | 4,380 hrs | 4,380 hrs | 4,381 hrs | 4,382 hrs |
| kW Hours per Year | 622.0 kWh | 477.4 kWh | 622.0 kWh | 328.5 kWh | 600.1 kWh | 170.9 kWh | 254.2 kWh |
| Electric Rate ($/kWH) | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 |
| **Annual Energy Cost** | **$ 32.96** | **$ 25.30** | **$ 32.96** | **$ 17.41** | **$ 31.80** | **$ 9.06** | **$ 13.47** |

## Annual Maintenance Cost

For high intensity discharge lamps, the “rated life” which is noted in terms of operating hours, is determined by operating a statistically-significant sample of lamps until 50% have failed. For white LED light sources, the “rated life” is defined as the number of hours of operation at which the light source has decreased to 70% of its initial lumen output (abbreviated as$L_{70}$).

Many LED luminaire manufacturers have estimated 50,000 to over 100,000 hours (≈12 to 29 yrs) of lamp life for their products. The driver life for LED luminaires is estimated with life spans from four years to the life of the luminaire. When compared to the HPS lamp source predominantly used within the City of Seattle, the LED lamp life is two to three times longer than the theoretical 30,000 hour (≈7 yrs) HPS lamp life. Table 8-3 is a summary of the maintenance costs for the luminaires tested under this study.

With a longer lamp life, the maintenance costs for LED luminaires will be less than for the HPS luminaires. With existing HPS luminaires, maintenance crews are scheduled to inspect, clean, and relamp the luminaire approximately every four years. Over an estimated luminaire life span of 15 years, this would equate to three scheduled maintenance cycles with the luminaire being replaced at the end of the fourth cycle. With an estimated life of 12 plus years for LED lamps, maintenance needs will consist of inspection and cleaning only. The required maintenance cycle for LED luminaires is currently recommended once every seven years. Again, if the life span of an LED luminaire is estimated to be 15 years, there is the potential for one maintenance cycle with luminaire replacement at the end of the second cycle.

The annual maintenance cost is based on scheduled relamps as provided by SCL, rather than theoretical relamps. Theoretical relamps are simply an estimate of a luminaires life divided by its lamp life. The “Annual Maintenance Cost” is made up of “Cost per Relamp/Cleaning”, normalized to an “Annual Relamp/Cleaning Cost” plus “Other Costs (Failures and Damage)” which are also normalized to an annual cost.

Table 8-3 Annual maintenance costs

| Decription | Base System | Luminaire A2 | Luminaire A3 | Luminaire C2 | Luminaire C3 | Luminaire A1 | Luminaire B1 |
|---|---|---|---|---|---|---|---|
| Fixture Life (yrs) | 15 yrs | 15 yrs | 15 yrs | 15 yrs | 15 yrs | 15 yrs | 15 yrs |
| Lamp Life (hrs)* | 30,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs |
| Lamp Life (yrs) | 6.8 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs |
| Theoretical Relamps/Cleanings Over Life of Fixture | 2.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Scheduled Relamps/Cleaning Over Life of Fixture | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| *Cost per Relamp/Cleaning (maintenance + parts)*** | $ 102.43 | $ 35.00 | $ 35.00 | $ 35.00 | $ 35.00 | $ 35.00 | $ 35.00 |
| Annualized Relamp/Cleaning Cost | $ 20.49 | $ 2.33 | $ 2.33 | $ 2.33 | $ 2.33 | $ 2.33 | $ 2.33 |
| Other Annulized Costs (Catastrophic Failure/Damage)*** | $ 29.25 | $ 11.70 | $ 11.70 | $ 11.70 | $ 11.70 | $ 11.70 | $ 11.70 |
| **Annual Maintenance Cost** | **$ 49.74** | **$ 14.03** | **$ 14.03** | **$ 14.03** | **$ 14.03** | **$ 14.03** | **$ 14.03** |

The HPS luminaires in this study were assumed to have a catastrophic failure rate of 25 percent and the LED luminaires were analyzed with an assumed catastrophic failure rate of 10 percent. Based on review of other studies and long life cycles, the 10 percent failure rate was assumed to be appropriate. A catastrophic failure is assumed to be when a luminaire fails and requires replacement. Although histories of LED failure rates do not exist for SCL, it is anticipated they will be low. For this analysis, no failures during warranty periods were assumed.

## Conservation Incentives

### Seattle City Light Conservation Resource Division (CRD)

With the installation of energy efficient streetlights, the SCL Conservation Reserve Division will pay back $0.22 per kilowatt-hour saved. When SCL submits a purchase order for a LED system to replace the traditional HPS system, the CDR will calculate the amount of energy consumed for the existing HPS luminaires and estimate the energy consumption for the future LED luminaires. The annual kilowatt-hour saved will then be multiplied by the incentive amount ($0.22 per kilowatt-hour saved) and returned to SCL as a one-time rebate. This rebate incentive is funded through the Bonneville Power Administration (BPA). SCL provides BPA with the energy savings realized during the program year for determining the rebate amount.

### Bonneville Power Administration (BPA)

BPA is a federal agency under the U.S. Department of Energy. BPA serves the Pacific Northwest through operating an extensive electricity transmission system and marketing wholesale electrical power at cost from federal dams, one non-federal nuclear plant and other nonfederal hydroelectric and wind energy generation facilities. Within the City of Seattle, SCL is the funding conduit for BPA funding.

Detailed information about BPA can be found at BPA's website, http://www.bpa.gov/corporate/. The general contact information for BPA is:

| BPA Phone Numbers | BPA Mailing Address | BPA Street Address |
|---|---|---|
| Phone: (503) 230-3000 | Bonneville Power Administration | 905 NE 11th Ave |
| Toll Free: 1-(800) 282-3713 | P.O. Box 3621 | Portland, OR 97232 |
| | Portland, OR 97208-3621 | |

## Department of Energy (DOE)

Each year, the Department of Energy (DOE) distributes funding and grants through various conservation energy programs. For instance, in 2009, the Energy Efficiency and Conservation Block Grants received $3.2 billion from the American Recovery and Reinvestment Act of 2009 (Recovery Act). Local governments can apply for formula block grants to improve energy efficiency and install renewable energy systems.

Opportunities are being updated frequently and more information can be found from the DOE's Financial Opportunity website http://www.eecbg.energy.gov/financialopportunities/default.html. One can also submit to the Office of Energy Efficiency and Renewable Energy (EERE) Financial Opportunities RSS feed to receive updates about new financial opportunities.

## Qualified Energy Conservation Bonds

Qualified Energy Conservation Bonds are issued through states or local governments for financing governmental programs to reduce greenhouse gas emissions and promote other conservation purposes. These bonds are issued with a 0% interest rate. The borrower pays back only the principal of the bond, and the bondholder receives federal tax credits in lieu of the traditional bond interest. The tax credit may be taken quarterly to offset the tax liability of the bondholder. SCL is eligible to apply for the bonds for the effort of replacing HPS streetlights with energy-efficient LED luminaires and centralized intelligent control systems. Detailed information regarding the bond can be found at the Database of State Incentives for Renewable & Efficiency's website http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US51F&currentpageid=3&EE=1&RE=1.

## Washington State Transportation Improvement Board (TIB)

TIB is an independent state agency that distributes and manages street construction and maintenance grants throughout Washington State. The funding for TIB's grant programs come from revenue generated by a three cents per gallon statewide gas tax.

TIB typically issue a call for projects each June for the next year's funding program. The TIB engineering staff provides information regarding the various funding programs and scoring criteria through workshops during the call for projects. The deadline for application submittal is typically the last business day of August. The selection of new projects is announced at the November TIB board meeting.

TIB offers funding to two different categories of programs: one is the Urban Programs and the other is the Small City Programs. With a population of over 600,000, City of Seattle is only eligible for the Urban Programs. There are three sub programs under this category:

- Urban Arterial Program (UAP): best suited for roadway projects that improve safety and mobility.
- Urban Corridor Program (UCP): best suited for roadway projects with multiple funding partners that expand capacity.
- Sidewalk Program (SP): best suited for sidewalk projects that improve safety and connectivity.

Because each program has a different intent, the evaluation criteria for each program vary. Detailed information about the criteria categories identified for each of the TIB's Urban Funding programs can be accessed at http://www.tib.wa.gov/grants/urban/UrbanCriteria.cfm. To increase scoring and project acceptance, replacement of current luminaires with more efficient LED luminaires on major arterials and corridors can be combined with other roadway projects.

Detailed information regarding the funding application process can be found at TIB's funding application website http://www.tib.wa.gov/grants/Applications.cfm.The contact information for the TIB engineering staff is:

| **TIB Phone Numbers** | **TIB Mailing Address** | **TIB Street Address** |
|---|---|---|
| Phone: (360) 586-1140 | Transportation Improvement Board | 505 Union Avenue SE |
| Fax: (360) 586-1165 | P.O. Box 40901 | Suite 350 |
| Toll Free: 1-(800) 562-6345 | Olympia, WA 98504-0901 | Olympia, WA 98501 |

## The Clinton Climate Initiative (CCI)

Launched by the William J. Clinton Foundation, the goal of the Clinton Climate Initiative (CCI) is to create and advance solutions to address the core issues driving climate change. One of CCI's objectives is to increase energy efficiency in cities. The CCI helps cities around the world improve the energy efficiency of street and traffic light systems by advising on project management, purchasing, financing, and technology. CCI works directly with cities to initiate new projects and to move existing projects forward more quickly and cost-effectively. CCI's assistance to cities for street and traffic light projects will vary based on the city's technical expertise, staffing, and experience.

Since outdoor lighting is a significant portion of a city's electrical usage, new lighting technologies such as high-efficacy LED and centralized intelligent control systems are being evaluated nationwide to assess the new technologies' capability of reducing energy use. The CCI is currently helping the City of Los Angeles replace 140,000 streetlights with LED units. SLC's on-going effort of replacing the HPS lights with energy-efficient LED luminaires is eligible to receive CCI's support.

Detailed information about the CCI and its contact information can be found at the William J. Clinton Foundation's website http://www.clintonfoundation.org/what-we-do/clinton-climate-initiative/.

## ENERGY DEMAND AND SAVINGS

Table 8-4 summarizes the annual energy demand in kilowatt hours for the 100-watt HPS cobra head luminaire and LED luminaires being tested in this study. The number of kilowatt-hours saved by replacing the 100-watt HPS cobra head luminaire (Base System) by each of the recommended LED luminaires (A1, A2, A3, B1, C2, and C3) is also included in the table.

### Table 8-4 Energy demand and savings

| Decription | Base System | Luminaire A2 | Luminaire A3 | Luminaire C2 | Luminaire C3 | Luminaire A1 | Luminaire B1 |
|---|---|---|---|---|---|---|---|
| Watts per Fixture | 142 | 109 | 142 | 75 | 137 | 39 | 58 |
| Base kWh | 621.96 | 477.42 | 621.96 | 328.50 | 600.06 | 170.86 | 254.16 |
| Savings in kWh<br>(Compared to Base System) | NA | 144.54 | 0.00 | 293.46 | 21.90 | 451.10 | 367.80 |

Although an HPS luminaire is made to consume a fixed amount of power as indicated in the product specification, the total power consumed by an HPS cobra head luminaire is higher due to the ballast and other electrical components also consuming a considerable amount of power. In this study, power consumption for the 100-watt HPS luminaire base system was estimated to be 142 watts.

## ECONOMIC ANALYSIS - SIMPLE PAY BACK

Using simple economic payback calculations and setting aside energy conservation goals of 40 percent savings over currently used HPS luminaires, LED luminaires can be an economical alternative. A simple payback calculator has been summarized in Table 8-5. As would be expected, when initial costs are high, the payback period increases. With SCL conservation rebates of $0.22 included in the overall calculation for each kilowatt-hour saved, the following payback periods were realized for the Stage I and Stage II luminaires under study:

- Small LED array luminaires
  - Luminaire A1 (39 watts) – 1.9 years
  - Luminaire B1 (58 watts) – 3.3 years
- Medium LED array luminaires
  - Luminaire C2 (75 watts) – 4.7 years
  - Luminaire A2 (109 watts) – 6.1 years
- Large LED array luminaires
  - Luminaire C3 (137 Watts) – 13.8 years
  - Luminaire A3 (142 Watts) – 14.6 years

Based on simple payback, luminaires A2 and C2 provide the best payback period and kilowatt hours saved of the luminaires tested and would be recommended for use on residential streets. However, luminaire C2 has design issues that would need to be resolved by the manufacturer due to failures in the field.

Luminaires A1 and B1 have impressive payback periods and kilowatt hours saved, they did not meet photometric requirements when tested. Luminaires A3 and C3 also have payback periods less than their anticipated life cycle, but either have no kilowatt hours saved when compared with the base luminaire tested or save only a few dollars.

When the SCL energy conservation goal of 40 percent energy savings is taken into account, a luminaire can consume up to 85 watts of energy to be considered as an option. Only luminaires A1, B1, and C2 fell into that category. However, A1 and B1 are not an option due to their photometric performance. Based on this, C2 was the only one tested to meet the 40 percent energy savings requirement. However, C2 has design issues that would need to be resolved by the manufacturer due to failures in the field.

With the efficacy of LED lamps expected to improve over the short term, both reduced costs and savings in operations costs are foreseeable. Taking advantage of new control systems with dimmable drivers is an option that can provide additional energy savings and make the luminaires with larger LED arrays a more energy efficient and economically viable option.

The economic analysis in this study was dependant on a number of assumptions that need to be reevaluated as more information becomes available:

- LED luminaire life is assumed to be 15 years.
- Maintenance cycle for LED luminaires is assumed to be once every seven years with luminaire replacement at the end of the second maintenance cycle.
- LED failure rates are assumed to be 10 percent.

## Table 8-5 Simple pay back calculator

| Decription | Base System | Luminaire A2 | Luminaire A3 | Luminaire C2 | Luminaire C3 | Luminaire A1 | Luminaire B1 |
|---|---|---|---|---|---|---|---|
| Number of Luminaires | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of Lamps per Luminaire | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cost per Luminaire | $ 133.00 | $ 428.00 | $ 653.00 | $ 441.00 | $ 646.00 | $ 348.00 | $ 395.00 |
| Installation Cost | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 | $ 63.91 |
| **Initial Cost** | **$ 196.91** | **$ 491.91** | **$ 716.91** | **$ 504.91** | **$ 709.91** | **$ 411.91** | **$ 458.91** |
| | | | | | | | |
| **Annual Operations Cost per Fixture** | | | | | | | |
| Watts per Fixture (luminaire and ballast/driver) | 142 | 109 | 142 | 75 | 137 | 39 | 58 |
| kW per Fixture | 0.142 | 0.109 | 0.142 | 0.075 | 0.137 | 0.039 | 0.058 |
| Annual Hours of Operation (12 hrs per day) | 4,380 hrs | 4,380 hrs | 4,380 hrs | 4,380 hrs | 4,380 hrs | 4,381 hrs | 4,382 hrs |
| kW Hours per Year | 622.0 kWh | 477.4 kWh | 622.0 kWh | 328.5 kWh | 600.1 kWh | 170.9 kWh | 254.2 kWh |
| Electric Rate ($/kWH) | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 | $ 0.0530 |
| **Annual Energy Cost** | **$ 32.96** | **$ 25.30** | **$ 32.96** | **$ 17.41** | **$ 31.80** | **$ 9.06** | **$ 13.47** |
| | | | | | | | |
| **Annual Maintenance Cost** | | | | | | | |
| Fixture Life (yrs) | 15 yrs | 15 yrs | 15 yrs | 15 yrs | 15 yrs | 15 yrs | 15 yrs |
| Lamp Life (hrs)* | 30,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs | 50,000 hrs |
| Lamp Life (yrs) | 6.8 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs | 11.4 yrs |
| Theoretical Relamps/Cleanings Over Life of Fixture | 2.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Scheduled Relamps/Cleaning Over Life of Fixture | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| *Cost per Relamp/Cleaning (maintenance + parts)*** | $ 102.43 | $ 35.00 | $ 35.00 | $ 35.00 | $ 35.00 | $ 35.00 | $ 35.00 |
| Annualized Relamp/Cleaning Cost | $ 20.49 | $ 2.33 | $ 2.33 | $ 2.33 | $ 2.33 | $ 2.33 | $ 2.33 |
| Other Annulized Costs (Catastrophic Failure/Damage)*** | $ 29.25 | $ 11.70 | $ 11.70 | $ 11.70 | $ 11.70 | $ 11.70 | $ 11.70 |
| **Annual Maintenance Cost** | **$ 49.74** | **$ 14.03** | **$ 14.03** | **$ 14.03** | **$ 14.03** | **$ 14.03** | **$ 14.03** |
| | | | | | | | |
| **Conservation Rebate** | | | | | | | |
| kWh Saved Compared to Base System**** | NA | 144.54 kWh | 0.00 kWh | 293.46 kWh | 21.90 kWh | 451.10 kWh | 367.80 kWh |
| **Adjustments (Conservation Rebate $0.23/kWh)** | **NA** | **$ 31.80** | **No Rebate** | **$ 64.56** | **$ 4.82** | **$ 99.24** | **$ 80.92** |
| | | | | | | | |
| **Payback (Compared to Base HPS System)** | | | | | | | |
| Adjusted Initial Cost per Fixture | $ 196.91 | $ 460.12 | $ 716.91 | $ 440.35 | $ 705.10 | $ 312.67 | $ 378.00 |
| *Rebate Adjusted* | | | | | | | |
| Annual Operations Cost | $ 32.96 | $ 25.30 | $ 32.96 | $ 17.41 | $ 31.80 | $ 9.06 | $ 13.47 |
| Annual Operations Savings | NA | $ 7.66 | $ - | $ 15.55 | $ 1.16 | $ 23.91 | $ 19.49 |
| Annual Maintenance Cost | $ 49.74 | $ 14.03 | $ 14.03 | $ 14.03 | $ 14.03 | $ 14.03 | $ 14.03 |
| Annual Maintenance Savings | NA | $ 35.70 | $ 35.70 | $ 35.70 | $ 35.70 | $ 35.70 | $ 35.70 |
| Total Annual O&M Savings | NA | $ 43.36 | $ 35.70 | $ 51.26 | $ 36.86 | $ 59.61 | $ 55.20 |
| | | | | | | | |
| **Payback Period** | **NA** | **6.1 yrs** | **14.6 yrs** | **4.7 yrs** | **13.8 yrs** | **1.9 yrs** | **3.3 yrs** |

* Current Manufacturer Claims for life of LED is 50,000 hrs to 100,000 hrs. Low end of projected life used for comparison purposes.
** LED fixtures to be cleaned only, no relamp required.
***Assumes a 25% failure rate for HPS luminaires and theoretical 10% failure for LED fixtures
****Savings shown as a positive number.

# 9 Luminaire Specification

One of the key goals of this pilot study was to develop a functional specification for use by SCL in purchasing LED luminaires. Based on the research, computer simulations and field testing, a functional specification has been developed for LED luminaires along residential roadways and has been included in Appendix E. The functional specification was written to take into account current LED luminaires available on the market. Due to the rapid advancements in LED technology, the specification should be reviewed and updated periodically. Through the course of this project, LED luminaires under study have already been updated with next generation luminaires. A review cycle of at least once every six months is recommended.

# 10 National LED Streetlight Projects Update

DOE has partnered with other agencies to conduct pilot studies to evaluate the benefits of applying LED technology to street lighting nationally. Many of these completed projects have been published on DOE's website http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html.

In the published report, "Demonstration Assessment of Light Emitting Diode (LED) Street Lighting, Phase III Continuation," DOE conducted a study in a parking lot owned by the City of Oakland. The parking lot was originally lit by HPS (100 nominal watts) luminaires which were replaced by LED (78-watts) luminaires from BetaLED in the Phase II part of the study. For the Phase III study, DOE replaced the luminaires of Phase II with the updated generation of LED luminaires (58-watts) of the same manufacturer. The results show that the lower watt Phase III LED luminaires provided adequate light levels to meet the City of Oakland's requirement except where poles were more widely spaced. The Phase III study has shown a significant increase in energy savings of 26 percent and the luminaire cost has decreased by 34 percent in 12 months. The emerging technology of LED street lighting has benefited these study sites both economically and environmentally.

In another published report, "LED Street Lighting", the DOE conducted a study of streets in a residential district in the City of San Francisco. This study replaced 100 nominal watts HPS luminaires with new LED luminaires from four companies, BetaLED, Cyclone, Leotek, and Relume. The project showed that the switch to the LED system reduced energy consumption by 50 to 70 percent. The lighting performance for these four companies varied and only two met the adequate illuminance levels with small pole spacing. The products that demonstrated an adequate lighting performance were also more economically attractive. A customer acceptance survey was conducted and responses were varied; some customers indicated they did not notice lights had been replaced.

These studies have shown that as LED products advance, lighting performance will improve and cost savings will increase. The feasibility of replacing a traditional HPS system with a LED system will depend on specific application use and wise product selection.

# 11 Conclusions

Computer simulations of Vendor A, Vendor B, and Vendor C luminaires for typical roadway sections, Stage I Capitol Hill and Stage II South Park test sites, as well as in-the-field testing of these luminaires revealed that minimum average maintained illuminance levels can be met for National RP-8-00 and City of Seattle standards for local residential streets with low to medium pedestrian activity.

For Stage I, simulations indicated average maintained illuminance levels would be below the accepted standards for luminaire B1 and at the minimum standard for luminaire A1. These simulations assumed a seven-year maintenance cycle. Actual field measurements indicated B1 meets and A1 is just below the minimum RP-8-00 Standard. This creates concern that with lumen depreciation over an estimated 15 year life cycle, the two luminaires will not perform to RP-8-00 illuminance level standards. Illuminance levels were well below the comparison HPS luminaires at each of the field locations.

For Stage II, simulations indicated average maintained illuminance values per RP-8-00 could be met for residential streets by luminaires A3 and C3 where medium pedestrian activity is present and luminaires A2 and C2 would meet minimum illuminance level standards where low pedestrian volumes are present. Actual field tests measured average maintained illuminance levels for luminaires A2, A3 and C2 at approximately twice the RP-8-00 minimums. Illuminance levels were comparable to the HPS luminaires at each of the field locations.

The RP-8-00 uniformity ratio requirements of 6:1 were met in simulations for Stage I and Stage II. Additionally, Stage I field test uniformity ratios were within RP-8-00 standards and were better than those of the comparison luminaires. Stage II uniformity values varied in the field tests. This is due largely in part to the field conditions where large trees were present and some luminaire arms were slightly skewed from the centerline of the roadway. Because of these unknowns, it is difficult to formulate a conclusion about the uniformity.

Comparison of the field measured illuminance levels of the HPS with luminaires A2,A3, and C3 indicated that the LED average maintained illuminance levels generally exceeded the HPS values. The only exception to this was A3 which was approximately 0.06fc lower than the HPS luminaires they replaced. Luminaire C2 was not able to have photometric measurements made due to the location where it was installed (Site 12: Alley) and lack of the appropriate luminaire cycles to perform a photometric measurement per the Methodology Guidelines.

The following are important findings from the computer simulation and field tests:

1. Not all luminaires met the average maintained illuminance and uniformity ratios required by National or Seattle Standards. It is important to conduct simulation and field testing of each type of LED luminaires to understand their photometric performance.

2. Changing the light distribution from a Type III pattern to a Type II pattern on residential streets minimized the amount of back lighting onto private residents. This was apparent in both the simulation and field tests.
3. In the Stage II South Park area field tests, the initial lumen output of the LED luminaires is approximately two times greater than the design year of the lighting system (in this case the design year of the system is seven years into the future). This additional lumen output is wasted energy. New control systems and dimmable drivers can be used to reduce initial lumen output and then increase it as the lamp lumen depreciation increases. In theory, this means a longer life for the luminaire since it is being driven at a lower amperage during the first few years of its life. Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries like A4 a viable and economic option.
4. Public feedback on the field installations at the Stage I test sites identified the "cooler" color temperatures from 5500°K to 6000°K created a dismal and unwelcoming environment. Subsequent installations of luminaires at the Stage II sites with a warmer color temperature from 4100°K to 4300°K created a more inviting and welcoming environment.
5. General Stage I public feedback supported the pursuit of additional installations of LED luminaires.
6. Approximately 25 percent of the Vendor C luminaires installed in the test sites have failed (two out of eight) under Stage II. There have been no failures of the field installed Vendor A luminaires.
7. A luminaire dirt deprecation factor of 0.92 was determined to be appropriate for residential streets.

This study has also shown from an economic standpoint, LED luminaires have become an economical alternative for replacement of existing roadway HPS luminaires. Using simple economic payback calculations and setting aside energy conservation goals of 40 percent savings over currently used HPS luminaires, with SCL conservation rebates of $0.22 included in the overall calculation for each kilowatt-hour saved, a payback periods of 4.7 to 14.6 years can be realized depending on the size of the LED array in the luminaire.

# 12 Recommendations

## Luminaire

Based on the analysis conducted in this study, the following luminaire has been identified as a viable option for replacement of 100-watt HPS cobra head style luminaires in residential areas. These recommendations are being made not because the luminaire meets the 40 percent energy reduction goal, but because of their economic, photometric, and maintenance performance. The following recommendation is subject to change as LED products with better photometric and economic performance are available.

**Recommendations (Luminaire):**

1. **Luminaire A2: 60LED-Type II Distribution-4300K-525mA**
2. **General Recommendations: Type II Light Distribution,**
   **Correlated Color Temperature of 4000°K to 4300°K**

Luminaire A2 has performed favorably with the following characteristics:

- Power consumption: 109-watts
- Distribution: Type II
- Initial Lumens: 4,968 (60 LED Array)
- Correlated Color Temperature: 4300°K
- Color Rendering Index: 75 minimum
- Driver Current: 525mA
- Efficacy: 46 lumens/watt
- IP Rating: IP66
- Weight: 16 lbs

As a late development in the study, Vendor A has released their new generation luminaires. The new generation luminaires are designed to provide better uniformity than the previous products. In an effort to provide up to date information, a review of the new generation luminaires showed better photometric performance with greater spacing and comparable uniformity than the previous products. It is anticipated that an economic evaluation of the new generation luminaire will yield similar results to the previous generation. The new generation luminaire should be considered as a replacement for the previous luminaire product. The new generation luminaire is as follows:

**Luminaire A2 Rev. 11/02/09: 60LED-Type II Distribution-4300K-525mA**

A portfolio of the recommended Vendor A and its newer version luminaire has been included in Appendix F.

## Specification

A functional specification has been developed for SCL to use in purchasing LED luminaires for local residential roadways and has been included in Appendix E. The specification is based on the research conducted on LED luminaires available on the market today as well as computer simulations and field testing. Since the specification was written based on currently available LED products, it is recommended that it be reviewed every six months to take into account advances in the LED streetlight technology.

**Recommendation (Specification):**
**Review specification every six months to take into account rapid advances in the LED lighting technology.**

## Luminaire Selection

LED is a new and rapidly developing technology in the roadway lighting arena. An understanding of the industry lighting standards (i.e., LM-79, LM-80, RP-8-00, and TM-15-07), manufacturing (including an understanding of heat dissipation), and testing of LED products is essential to making educated decisions on selection. Independent LM-79 and LM-80 test results of luminaire performance should always be obtained before making product selection. In addition, it is recommended to utilize a LLD factor based on LM-80 tests and a LDD factor of 0.92 for residential roadways.

**Recommendation (Luminaire Selection):**

1. **Utilize an LLD factor based on LM-80 tests.**
2. **Utilize an LDD factor of 0.92 for residential roadways.**
3. **Require independent LM-79 and LM-80 test results for all luminaire submittals.**

## Recommended Next Steps

LEDs are an instant on/instant off technology with no start-up or re-strike time. Combining LED roadway luminaires with new light control systems provide many new options for overall light control, facilitating maintenance, increasing luminaire life, and reducing operating costs. The following are benefits of incorporating lighting control systems with LED lighting technology include:

- Dimming of Lighting Circuits after Hours: This can be based on time of day or traffic volumes if connections are available to either traffic count stations or a traffic operations center. Dimming of luminaires can provide reduced energy costs and prolong the life of the luminaire.

- Step Dimming or Continuous Dimming: Lighting systems are designed to meet standard illuminance levels at a future year with a given amount of lumen and dirt depreciation incorporated into the design. This means at initial installation, more lumens are being produced than required. Step or continuous dimming of a lighting system would reduce the initial lumen output to its design standard by reducing the drive current and then gradually increase that drive current at predefined time intervals to maintain the same lumen output over the life of the system. In theory, this means a longer life for the luminaire since it is being driven at a lower amperage during the first few years of its life (See Figure 12-1). Based on the higher initial illuminance level value and not a depreciated future value if the extended life is beyond the desired period for luminaire replacement, this would make the lower wattage luminaries like A4 a viable and economic option.

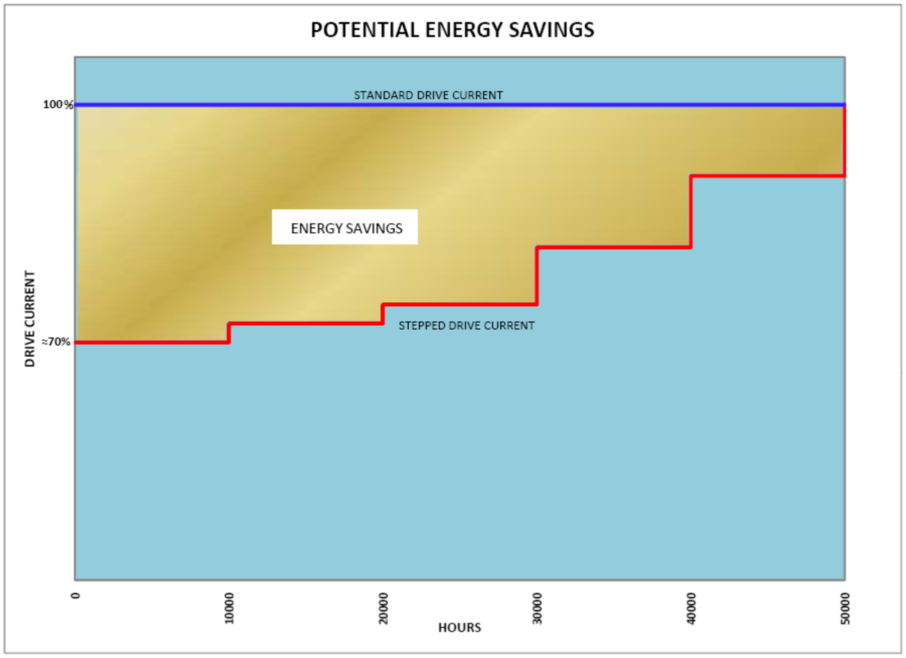


Figure 12-1 Diming energy savings

- Emergency Services Support: If lighting control systems are tied into traffic operations centers, emergency management centers, or electric utility operations centers when accidents occur illuminance levels can be increased to help facilitate emergency services and then be reduced back to normal levels when the emergency is over.

- Pedestrian or Vehicle Activated Lighting Circuits: If a lit corridor has sensors incorporated into the luminaire, lighting circuits can be turned off or dimmed until a person or vehicle is in the vicinity. Illuminance levels would rise when a pedestrian or vehicle activates the sensors and dim when the pedestrian or vehicle has passed. Dimming of luminaires can provide reduced energy costs and prolong the life of the luminaire.

- Luminaire Health Monitoring: Monitoring the health of luminaire components such as LED drivers and scheduled maintenance is based on information received from either wireless or hard wired communications between luminaires in the field and an operations center. Many benefits are available through luminaire monitoring:
    - Luminaires can be GPS located to provide maintenance with exact geographical locations reducing time in locating outages.
    - Maintenance can respond in a more efficient manner reducing the number of system wide outages and down times, improving customer service.
    - Outage patrols can be reduced.
    - Trend analysis can be conducted from information received from the field.

There are many new light control systems on the market today. Just as with LED luminaires, care needs to be taken to select the correct system to meet Agency needs. There are many different items that need to be considered both for the control system itself and the infrastructure needs to support that system. The following is a list of items that need to be evaluated to deploy a successful roadway lighting and control system:

**Control Systems Evaluation**

1) Identify SCL's Basic Needs
   a) Maintenance
   b) Monitoring
   c) Management
   d) Economics
2) Evaluate existing out-of-the-box Systems
   a) Assess the ability of the system to meet current and future SCL needs (scalability)
      i) Limitations on size of information stores
      ii) Lighting network size limitations
      iii) Dimming capabilities
   b) Identify SCL needs not supported by system and if those needs can be met
   c) Are custom applications available and who can develop the application (City, vendor, etc.)
   d) Assess how information is input from the field to the main system
   e) Assess the effectiveness of the user interface and ease of use
   f) Coordinate review of current systems in use by other public agencies and utilities
   g) Identify initial capital cost
   h) Identify ongoing upgrade and maintenance fees
   i) Recommend up to two systems for pilot field deployment
3) Assess Communications Needs
   a) What types of communications are available and effective in Seattle
      i) Evaluate the different communications options
         (1) Power line
         (2) Public radio
         (3) 900 MHz
         (4) 2.4 MHz
         (5) Others
   b) Evaluate which communications means can best be integrated into existing SCL infrastructure
   c) Evaluate Backhaul Communications
      i) Evaluate the existing backhaul communications infrastructure
         (1) City Fiber Optic Network
         (2) Public Radio Network
         (3) Fast Ethernet over Copper

(4) 3G (Cellular)
   - ii) Identify communications system sharing with other City departments
   - iii) Identify missing infrastructure needs

4) Develop and conduct field deployment
   - a) Develop field deployment methodology including measures of effectiveness (MOE)
   - b) Coordinate field installation and document deployment MOE's
   - c) Provide final recommendation to SCL of system to deploy
5) Develop System Deployment Master Plan (This may require the development of a Street Lighting Master Plan)
   - a) Identify overall coverage area for the greater Seattle Area
   - b) Integrate System into City's GIS system
   - c) Conduct area deployment test
   - d) Identify light characteristics to be included in system database
   - e) Develop grouping schemes for lights
6) Conduct an economic analysis of different systems
   - a) Initial Deployment (capital) costs
   - b) Maintenance costs
   - c) Expected component life cycles
   - d) Long Term System Upgrade and Maintenance Fees
7) Provide recommendations on a system for City wide deployment
8) System Operations Center (OC)
   - a) Determine the need for an OC
   - b) Determine OC location
     - i) Identify existing communications and computer infrastructure for OC
     - ii) Identify additional communications and computer infrastructure needs for OC
     - iii) Design OC Office Space including computer, printers, monitors, and work stations

Four control manufacturers were interviewed in this study. Meeting minutes from these interviews are included in Appendix G. It is recommended SCL pursue further study in the area of controls to better define Agency needs and the potential benefits of such a system.