GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light-Emitting Diode (LED) Roadway Lighting

Host Site: I-35W Bridge, Minneapolis, Minnesota

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

Study Participants:
Pacific Northwest National Laboratory
U.S. Department of Energy
Minnesota Department of Transportation
Federal Highways Administration
BetaLED

August 2009

Prepared for the U.S. Department of Energy by
Pacific Northwest National Laboratory

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Preface

This report documents observations and results obtained from a lighting demonstration project conducted under the U.S. Department of Energy (DOE) Solid-State Lighting GATEWAY Technology Demonstration Program. GATEWAY supports demonstrations of high-performance solid-state lighting (SSL) products in order to develop empirical data and experience with in-field applications of this advanced lighting technology. The program focuses on providing independent, third-party data for use in decision-making by lighting users and professionals. Before being extrapolated for use at other sites, this data should be considered in context with other information relevant to the particular site and application under examination.

GATEWAY evaluates and reports on the field performance of SSL products. Each demonstration typically compares one SSL product against the incumbent or otherwise standard technology used in that location. Depending on available information and circumstances, the SSL product may also be compared to alternate lighting technologies; however, the purpose of the GATEWAY program is not to provide an evaluation of all possible alternatives for a given site and should instead be considered only as a single data point for the technology(ies) specifically considered. Manufacturers and users seeking demonstrations of non-SSL products should look to opportunities in the many demonstration programs run by electric utilities, and state- and regionally-funded energy efficiency programs.

Though products demonstrated in GATEWAY have been prescreened and tested to verify their actual performance, DOE does not endorse any commercial product or in any way guarantee that users will achieve the same results through use of these products. Readers considering use of the technologies evaluated in GATEWAY reports must conduct their own due diligence before making decisions regarding selection of any particular technology, or developing expectations of the results to be achieved thereby.

Executive Summary

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology conducted in 2009 at the recently reconstructed I-35W bridge in Minneapolis, MN. The project was supported under the U.S. Department of Energy (DOE) Solid-State Lighting GATEWAY Technology Demonstration Program. Other participants in the demonstration project included the Minnesota Department of Transportation (Mn/DOT), Federal Highways Administration (FHWA), and BetaLED™ (a division of Ruud Lighting). Pacific Northwest National Laboratory (PNNL) conducted the measurements and analysis of the results.

The primary impetus for using LEDs in this particular bridge installation included the desire to maximize reliability, minimize the need for periodic lighting maintenance (such as relamping the fixtures), provide adequate illumination across the considerable roadway width while avoiding excessive energy use, and complement the state-of-the-art technological design of the bridge itself. DOE has implemented a three-year evaluation of the LED luminaires in this installation in order to develop new longitudinal field data on LED performance in a challenging, real-world environment. This document provides information through the initial phase of the I-35W bridge project, up to and including the opening of the bridge to the public and the initial feedback received on the LED lighting installation from bridge users. A final project report will be issued at the conclusion of the three-year evaluation period, providing documentation of all performance, cost and maintenance data developed over that period.

Mn/DOT has taken a bold step in implementing LED luminaires in this high-risk, highly-visible application when there is still a notable lack of field experience with the technology due to its still relatively recent introduction to general illumination applications. It is anticipated that the results from this project will continue to serve as reference for many similar future installations.

As the bridge represents new construction rather than retrofit of an existing system, the base or reference case for purposes of comparison had to be estimated through lighting simulation. Issues remain as to the precision of the base case design that are essentially unanswerable short of pursuing installation of an actual system. Nevertheless, initial findings of the evaluation are favorable, particularly for a lighting technology that is still in a relatively early stage of development. Table ES1 indicates a minimum energy savings level of 13% for the LED installation relative to the simulated base case using 250W HPS "Mongoose" fixtures.[1]

Table ES1. Energy Calculation

	Hours	Power (kW)	Energy (kWh)	Energy Saved
HPS Baseline	4,380	5.81	25,465	–
LED	4,380	5.06	22,163	13%

[1] Actual savings may be greater, depending on uncertainties with the baseline. See related discussion.

Illumination levels produced by the LED lighting compare favorably against the base case HPS installation. Table ES2 lists the actual measured values for the LED installation, along with modeled values for a conventional HPS installation. Note that, when installed in a fully horizontal or level orientation, the 250W HPS base case fails to meet Mn/DOT's uniformity criterion (indicated by the shaded cell), and that a 15° upwards tilt from horizontal is necessary to provide sufficient illumination across the entire width of the bridge roadway. The GATEWAY program believes that such a configuration would not be acceptable from either a light pollution or driver glare perspective; however, to expedite the evaluation process this design (*i.e.*, the energy that would be used by it) was accepted as the base case. What this assumption means for the associated energy savings estimate is uncertain—other than suggesting that the 13% value may be conservative, and perhaps significantly so if higher wattage HPS luminaires would in fact be required to meet the project specifications.

Table ES2. Illuminance Levels on the Bridge for Day 1

	Mn/DOT Requirements	Measured LED	Modeled[1] HPS (Level)	Modeled[1] HPS at 15° Tilt[2]
Average	0.6 – 1.1[3]	0.91 fc	1.51 fc	1.29 fc
Maximum	–	1.97 fc	5.17 fc	4.77 fc
Minimum	–	0.26 fc	0.15 fc	0.41 fc
Avg:Min	3:1 – 4:1[4]	3.51	10.07	3.15
Max:Min	–	7.58	34.47	11.63

1. Modeled values assume LLF values of 1.0 to enable an "apples to apples" comparison. Other LLF values can be applied to the modeled values as desired.
2. Modeled with a 15° luminaire tilt upwards from horizontal, in order for the 250W Mongoose simulation to meet Mn/DOT illumination requirements across the bridge roadway width.
3. Mn/DOT desired results towards the higher end of this range ≈ 0.8 – 1.0
4. Though this wasn't an absolute requirement, Mn/DOT desired more stringent uniformity ≈ 3:1.

The LED luminaires commanded a significant price premium, costing about $38,000 more than the HPS base case installation. Evaluating the investment for simple energy payback yields a lengthy payback period, given the relatively small energy savings level of 13% and low price of electricity that Mn/DOT pays for illuminating the bridge ($0.0674/kWh). The bridge contractor had offered to include the LED luminaires as part of the construction package at no additional cost, however, so that Mn/DOT's decision was primarily based on other issues.

One potentially significant benefit of the LEDs in this installation is avoiding rolling lane closures on the heavily-traveled interstate bridge for the purpose of relamping the HPS fixtures. Rolling lane closures involve multiple crew members and various maintenance and safety vehicles, diversion of traffic, as well as related administrative tasks (*e.g.*, approvals, scheduling, etc.). Mn/DOT records show an average cost of relamping fixtures along interstate roadways of between $130-150 per pole. The required frequency of relamping is affected by a number of factors, including the specific lamps used, vibration levels of the bridge from traffic and wind, power quality, and others. The previous bridge saw a lamp mortality rate of approximately 50% every two years, though an upgrade to the lamp manufactured by EYE[2] improved this somewhat, and the

[2] Specification sheet included in Appendix A.

new bridge construction has likely eliminated many of the vibration problems experienced in the previous design. Figure ES1 below illustrates the impact of various relamping cycle times on the simple payback calculation, from the assumed maximum of five years down to one year.

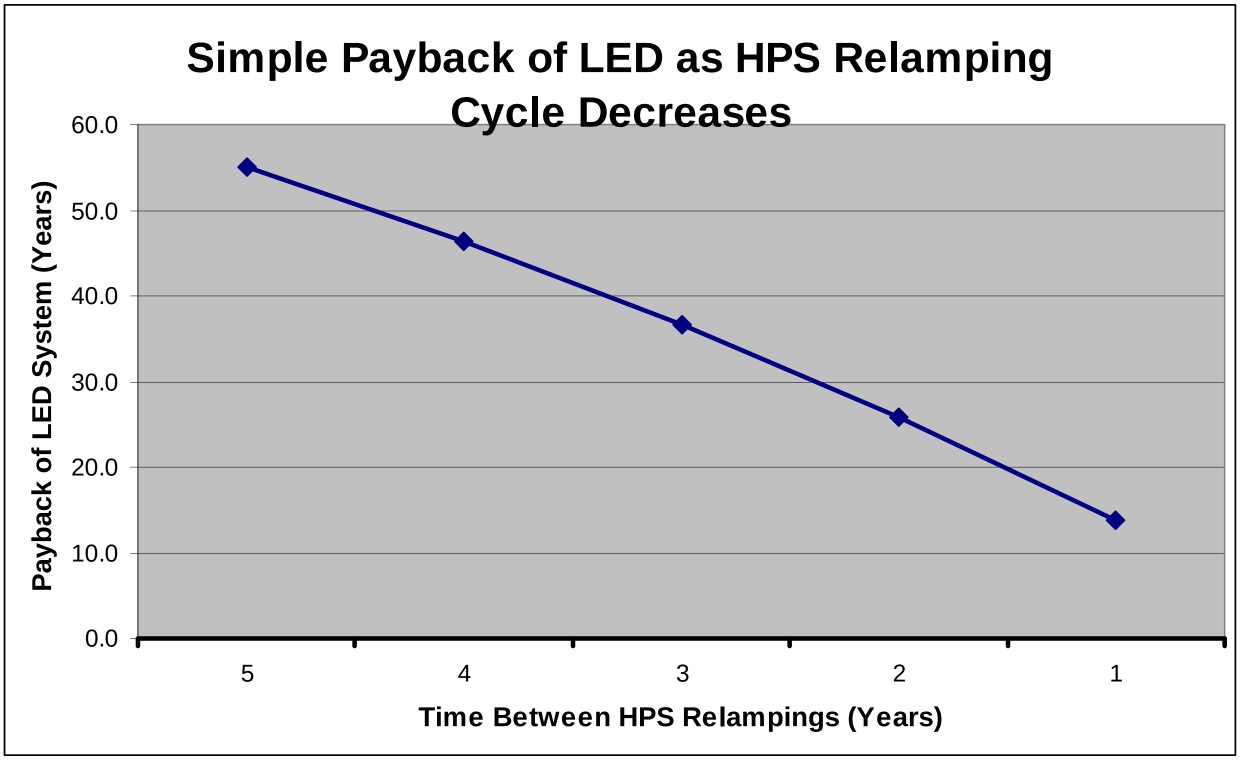

Figure ES1. Simple Payback of the LED System vs. Frequency of Relamping a Conventional HPS System on the I-35W Bridge.

Finally, the project conducted a voluntary Web-based feedback survey of nearly 500 self-described bridge users, who had driven or been passengers across the bridge during the hours of illumination. Users expressed strong preference for the LED lighting, compared to the conventional lighting installed at both ends of the bridge. In the section of the survey allowing open comments by the participants, for example, positive comments outnumbered negative ones by about five-to-one. Section 4.0 contains the feedback survey results, and all comments are listed in Appendix E.

All lighting-related experiences and expenses on the bridge will continue to be monitored over the next three years, with a final follow-up report issued at project conclusion.

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1.0 Introduction

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in a roadway lighting application conducted in 2009 in Minneapolis, MN. The project was supported under the U.S. Department of Energy (DOE) Solid-State Lighting Technology GATEWAY Demonstration Program. Other participants in the demonstration project included the Minnesota Department of Transportation (Mn/DOT), Federal Highways Administration (FHWA), and BetaLED™ (a division of Ruud Lighting). Pacific Northwest National Laboratory (PNNL) conducted the measurements and analysis of the results. PNNL manages similar demonstrations for DOE and represents DOE's perspective in the conduct of the work.

DOE supports such demonstration projects to develop real-world experience and data with SSL products in general illumination applications. DOE's approach is to carefully match applications with suitable products and form teams to carry out the needed project work. Other project reports and related information are available via DOE's SSL website at www.ssl.energy.gov/gatewaydemos.html.

The recently-reconstructed I-35W Bridge in Minneapolis, MN was designed to showcase state-of-the-art technology in all respects. In keeping with this approach, Figg Engineering Group (Figg), the design firm, included LED roadway luminaires by BetaLED in their proposal for the bridge. As LED technology is still largely unproven for such a demanding and critical application, its potential use represented a bold departure from established practice, and hence introduced an element of risk to the bridge reconstruction project. For this reason a number of the staff involved expressed reservations with regard to use of LEDs, and Mn/DOT approached the GATEWAY program to provide independent analysis and evaluation of the proposed lighting design.

One of the first concerns expressed by Mn/DOT was that the LED product, upon initial review, appeared to fail to meet a relevant Mn/DOT energy requirement. 2008 Minnesota Statute 216C.19 states:

> No new highway, street or parking lot lighting may be installed in violation of these rules. Existing lighting equipment, excluding roadway sign lighting, with lamps with initial efficiencies less than 70 lumens per watt must be replaced when worn out with light sources using lamps with initial efficiencies of at least 70 lumens per watt.[3]

Minnesota's statute focuses on the light source (in this case, the lamp) because its efficacy is easier to verify. The obvious intent of the statute is to increase the use of high-efficacy sources, but the statute neglects to also look at the other relevant characteristics of the lighting system. All of the system variables must be factored in to provide an accurate comparison of the two technologies (i.e., HPS vs LED).

The LED luminaires that were under consideration for this project possessed an efficacy of 65-67 lumens per watt (LPW), initially appearing as insufficient to meet the statute. LEDs are different in many respects from other lighting sources, however, and considering the other relevant system characteristics showed them to easily meet the intent (if not the letter) of the statute.

[3] https://www.revisor.leg.state.mn.us/statutes/?id=216C.19

In this case, conventional high-intensity discharge (HID) lamps typically offer initial efficacies well in excess of 70 LPW (source efficacy). However, the statute only focuses on the lamp and does not mention system (lamp + ballast) efficacy. HID ballasts typically have a ballast loss (power consumed by the ballast in addition to the lamp) between 10%-20% of the rated lamp wattage, reducing the efficacy of the system. By focusing solely on lamp efficacy, the statute also neglects fixture efficiency (the ratio of the light emitted by the luminaire relative to the light created by the source), typically between 65%-90% for roadway luminaires (in this particular case, 72.8%). Therefore, although the 250W HPS baseline lamp for this demonstration has an initial source efficacy of 111 LPW, when the power for the ballast and the fixture efficiency are factored into the application, the initial luminaire efficacy is reduced to 71 LPW [28,500 (initial lamp lumens) / 291W (Ballast Input Power) x 72.8% (fixture efficiency)].

Statutes are generally written around lamp efficacy because lamps are largely interchangeable and often have different efficacies. Ballast losses and fixture efficiencies can also vary greatly between products, thus a considerable range of overall luminaire efficacy is possible with conventional products depending on the specific configuration of a given luminaire. This situation contrasts with that of dedicated LED luminaires, which are photometrically measured as complete luminaires (light source [LED]+ driver + fixture), thus yielding a luminaire efficacy value from the outset. The LED luminaires in this demonstration offered luminaire efficacies of 65 and 67 LPW (distribution type III and type V, respectively), much nearer that of the baseline 250W HPS system than might be initially perceived.

In addition, no consideration is given in the statute as to the distribution or use of the lumen output. Efficient production of lumens is of little value when those lumens are sent in directions they are not wanted or not useful. Over-lighted areas (hotspots) and light trespass represent wasted light, and consequently, wasted energy. In comparison with the standard HPS lighting product, the LED system more effectively lights the task plane and thus significantly reduces such associated inefficiencies.

In the end, the results of DOE's illumination modeling showed that the LED product was more than adequate to meet the intent of the statute, which allowed the project team to move beyond this initial concern. "Early adopters" of SSL technology will likely encounter these discrepancies with regulations, codes and design specifications based on traditional light sources until they are updated.

DOE's initial concern regarding the original proposed lighting installation design was that there were no energy savings apparent from the use of LED luminaires. Subsequently, the project team determined that the proposed LED luminaires were slightly oversized. Through the use of modeling software, the project team fine-tuned the design and was able to reduce the size of most of the luminaires while still meeting all Mn/DOT illumination requirements, to achieve an anticipated energy savings level of about 13% relative to the assumed 250W HPS baseline.

After this slight adjustment in the design, DOE agreed to participate in the demonstration, which also encouraged Mn/DOT to move forward with using the LED luminaires in the installation. Mn/DOT continued to express concerns about both the performance of the luminaires as well as their longevity, however. These and other characteristics of the LED system will continue to be monitored by the GATEWAY program over the planned three-year evaluation period.

2.0 Methodology

Because the I-35W Bridge was a new construction project, the project team's lighting design and evaluation relied heavily on computer-aided design (CAD) and lighting simulation software (AGi 32). Only the main span of the bridge was to be lighted by LEDs, with the approaches and the remaining portion of the roadway lighted by conventional HPS luminaires. A site visit to the bridge was planned for the period between completion of construction and its public opening to verify that illumination levels would in fact meet Mn/DOT requirements.

2.1 Site Description

The new bridge is comprised of two separate spans 1215' long, each containing five 12' wide lanes with a 14' inside shoulder and 13' outside shoulder. The 87' overall width is somewhat larger than typical for Mn/DOT specifications. This unusual width and other factors resulted in modifications to the standard design practice.

For example, the bridge was designed with open outside shoulders as a result of a popular vote by Minneapolis residents. Instead of standard concrete barriers, the bridge has open metal guardrails which allow drivers views of the city and the river below as they cross the bridge. The open guardrails prevented the pole for the luminaires from being placed on the outside of the span as would be typical. Rather, the poles/luminaires run along the gap between the two spans (See Figure 2.1).

Next, locations of signs at the ends of the bridge and a power line at one end impacted the lighting design. In order to avoid large shadows on the roadway, the poles needed to be spaced a sufficient distance from the signs while not interfering with the routing of the overhead power line. These requirements constrained the location of the poles on either end of the bridge. Structural and aesthetic issues also influenced placement of the poles. Whereas the main span of the bridge is lighted by luminaires mounted back-to-back between the main spans of the bridge, the ends are lighted by luminaires located along the outside of the bridge.

Mn/DOT provided guidelines for their desired levels of illumination on the bridge that included an average of between 0.8 and 1.0 footcandles (fc) across the main span and an average-to-minimum uniformity ratio of between 3:1 - 4:1.

Figure 2.1. Luminaires installed on the I-35W Bridge.

2.2 Standard Luminaires

Mn/DOT provides specific information in the *Mn/DOT Roadway Lighting Design Manual* about selecting luminaires when designing a roadway. [4] These guidelines include the following information:

For roadway configurations with two or three lanes in each direction, the most common equipment used is the following:

- 250-watt HPS cobra head style luminaire
- 40-foot pole
- Spacing of the 40-foot poles is usually 240 to 250 feet, depending on the desired footcandle level and the number of lanes.

When lighting a roadway configuration with three or more lanes, the following is used:

- A mixture of 40-foot poles and 49-foot poles can be used
- 40-foot poles should be used on the ramps and loops

[4] Which can be viewed at http://www.dot.state.mn.us/trafficeng/lighting/2006%20Roadway%20Lighting%20Design%20Manual.pdf.

• 49-foot poles should be used on the through roadway

• The 49-foot poles can be roadside-mounted lighting units or median barrier-mounted lighting units

• The 49-foot pole lighting unit should have a 400-watt HPS luminaire and be spaced 280 to 300 feet apart.

Mn/DOT reports that pole heights are generally restricted to 40 feet across bridge spans to help reduce vibration and wind issues. In addition, a greater number of lanes must be closed during maintenance of higher poles because the stabilization legs (or riggers) on the bucket trucks must be spread wider, taking more space.

The pole spacing was set at 150 feet to achieve the desired lighting uniformity levels (discussed in Section 2.6); however, simulations using this pole height and spacing revealed issues with the baseline HPS system. Initial simulation of the bridge lighting indicated that the Holophane Mongoose 250W HPS fixtures could not meet Mn/DOT's desired illumination characteristics due to the long throw required to reach the outer bridge railing. Successive simulations showed that the 250W Mongoose luminaires could meet Mn/DOT uniformity requirements if they were mounted at an upwards tilt of 15 degrees from the horizontal. Such a design does not appear to be acceptable from either a glare or light pollution[5] standpoint; however, for purposes of energy use and cost/payback comparisons, a 250W HPS baseline is assumed[6]. The actual baseline lighting design using the alternative 250W HPS luminaires was never finalized since the decision was made to proceed with LED rather than conventional sources.[7]

The previously-noted HPS luminaire efficacy rating (LER) of 78 LPW represents an initial light output value. To make an accurate performance comparison over a full luminaire lifecycle, the long-term operation of the lamp needs to be considered. At 50% of the lamp's rated life of 30,000 hours, according to the manufacturer's data on Lamp Lumen Depreciation (LLD, see the cutsheet included in Appendix A), the lamp is only producing 90% of initial lumens or about 64 LPW. As this depreciation continues, near its end-of-life, the lamp will be producing roughly 85% of initial output or only about 61 LPW.

In addition, the electrical characteristics of the HPS lamp do not remain constant over its life. Arc tube voltage varies in proportion to the ratio between sodium and mercury contained within the lamp. Sodium migrates through the lamp glass through normal operation, so that this ratio changes over time. The end

[5] The June 2, 2008 meeting of the Minneapolis City Planning Commission addressed adoption of The Minneapolis Plan for Sustainable Growth, which included the following action: "Page 22, Amend Policy 10.17.1 to state, 'Provide high-quality lighting fixture designs that are appropriate to street types and land use, and that provide pedestrian friendly illumination, but minimize glare and dark sky conditions, and other unnecessary light pollution.'" See http://www.ci.minneapolis.mn.us/cped/agendas/planning-commission/2008/20080602cpc_actions.asp.

[6] It was not the purpose of this exercise to develop a robust baseline system satisfying all necessary design criteria, although the impact of not doing so may understate the actual energy savings being achieved with the LEDs (*i.e.*, stepping up to a 400W HPS baseline, if necessary to meet the illumination requirements, increases the corresponding LED savings proportionately).

[7] Successive simulations also showed that the illumination requirements could be met with a 400W HPS system (see Appendix D). However, it is not clear that an alternative 250W fixture to the Mongoose might not also have been able to meet the requirement, so the current analysis can not claim savings greater than the estimated 13%.

result is that the lamp voltage can increase 10% or more with a corresponding increase in the operating wattage over its life. Combining this increase in power with the depreciation in output of the lamp means significant decreases in performance of the HPS lamps over time.

2.3 New Luminaires

The new luminaires were manufactured by Ruud Lighting's BetaLED™ division.[8] The nominal dimensions of the luminaire are 18" wide x 30" long x 2" tall.

The LEDs and drivers were manufactured by Cree and Advanced Transformer, respectively. The LEDs are Model XR-E, generation Q5 chips.

The final design incorporated sixteen Type V distribution 10-LED array (200 LEDs total, producing nominal 16,500 lumens) luminaires across the middle span, and four Type III distribution 12-LED array (240 LEDs total producing 19,000 lumens) luminaires, two mounted on both sides of each end of the bridge. Luminaires with greater lumen output and a different distribution were required at each end due to bridge layout and geometry.

As in the case of HPS, the initial efficacy of LED luminaires does not remain constant over their lifetime. The stated efficacy values for the 10-bar Type V luminaire (67 LPW) and the 12-bar Type III luminaire (65 LPW) are initial values. The end of useful life of an LED product is typically defined as when its output reaches L_{70}, or 70% of initial lumens. Therefore, the luminaires that started out at 65 and 67 LPW respectively would have an end-of-life efficacy of 46 and 47 LPW, should the luminaires remain installed that long. At the prevailing average nighttime temperature in Minneapolis, the manufacturer projects that the luminaires would need to operate for several decades to reach this level of lumen depreciation, estimating only about a 12% loss after 20 years. However, a more likely "useful" life is anticipated to be in the range of 12-15 years, when it will have become cost-effective to replace these with the latest products available at that time even though the original luminaires are still providing adequate illumination. Despite this shorter anticipated useful life, the LED luminaires were sized in order to accommodate a 30% decrease in output and still provide adequate illumination, in the instance that they are left in place for longer than the anticipated 12-15 year period.

2.4 Installation

The LED luminaires were installed during the first week of September, 2008. Mn/DOT staff reported no difficulties in installing the luminaires or in leveling them. Consequently, no additional labor is assumed for either the base case or the LED installation.

The luminaires were set perpendicular to the horizon, rather than to the roadway surface. As the bridge surface has a slightly convex shape, sloping both from inside to outside edge and from center to either end, the luminaire faces are not oriented precisely parallel to the road surface. The impact to the illumination level of this slight angle is estimated to be negligible.

[8] BetaLED™ model numbers BLD-ARE-T5-DA-170-LED-B-UL and BLD-ARE-T3-204-LED-B-UL.

2.5 Power and Energy

The apparent power of the luminaires was measured prior to the bridge opening and the resulting values are listed in Table 2.1. All measurements were taken from luminaires located either on or nearby the bridge and all represent new product installations.

Both the HPS and LED luminaires had power factors greater than or equal to 90%. Real power values were used for the power calculations of the bridge, as presented in Table 2.1.

Table 2.1. Power Calculations for the Bridge Span

Quantity	Distribution	Luminaire Type	Luminaire Power[1] (W)	Total Power (W)
20	Type III	250W HPS	291	–
	Baseline HPS Bridge Power Sum		–	5,814
4	Type III	12- LED Array	289	1,156
16	Type V	10- LED Array	244	3,904
	LED Bridge Power Sum		–	5,060

1. Values were developed by taking apparent power measurements *in situ*, then multiplying by the respective product power factors: 250W HPS – 0.90; LED 10-Array – 0.95; LED 12-Array – 0.94.

Table 2.2. Energy Calculation

	Operating Hours	Power (kW)	Annual Energy (kWh)	Energy Saved
HPS Baseline	4,380	5.81	25,465	–
LED	4,380	5.06	22,163	13%

2.6 Illuminance

Section 4.1.1.3 of the *Mn/DOT Roadway Lighting Manual* referenced earlier provides a table of recommended illuminance values for different applications. The I-35W Bridge roadway deck falls under the Roadway classification of "Interstate and Other Freeways/Commercial" category. The roadway surface is concrete (type R1).

According to the table, the recommended illuminance values are therefore 0.6 – 1.1 fc. Though not an absolute requirement, Mn/DOT prefers the higher end of this range, or about 0.8 – 1.0 fc for the minimum average maintained illumination (E_h).

The *Manual* also provides uniformity recommendations, in the form of average-to-minimum (avg:min) uniformity ratios between 3:1 and 4:1. Though again not absolute, Mn/DOT preferred greater uniformity in this instance, looking for an avg:min uniformity ratio of 3:1.

Table 2.3 presents the simulation results for the LED and baseline HPS installations, as well as actual values measured during a site visit on the evening of September 7, 2008. For reference, the table also provides the Mn/DOT requirements from the Roadway Lighting Manual.

Table 2.3. Illuminance[4] Levels on the Bridge for Day 1

	Mn/DOT Requirements	Measured LED	Modeled[1] LED	Modeled[1] HPS	Modeled[1] HPS at 15° Tilt[2]
Average	0.6 – 1.1[3]	0.91 fc	1.03 fc	1.51 fc	1.29 fc
Maximum	–	1.97 fc	1.77 fc	5.17 fc	4.77 fc
Minimum	–	0.26 fc	0.31 fc	0.15 fc	0.41 fc
Avg:Min	3:1 – 4:1[4]	3.51	3.32	10.07	3.15
Max:Min	–	7.58	5.71	34.47	11.63

1. Modeled values assume LLF values of 1.0. Other LLF values can be applied to the modeled values as desired.
2. Modeled with a 15° luminaire tilt upwards from horizontal. The tilt of 15° was needed for the 250W Mongoose installation to meet Mn/DOT illumination requirements across the bridge roadway width.
3. Mn/DOT desired results towards the higher end of this range ≈ 0.8 – 1.0
4. Mn/DOT desired more stringent uniformity ≈ 3:1

Figure 2.2 provides an aerial view of the I-35W installation. In the photo, the uniformity of the LED system provides a marked contrast with that of the older HPS system on the adjacent, smaller bridge. Both ends of the I-35W bridge (*i.e.,* foreground and background in the photo) are lighted by closely spaced 400W HPS fixtures due to the number of conflict zones (lanes of merging traffic) in those areas.

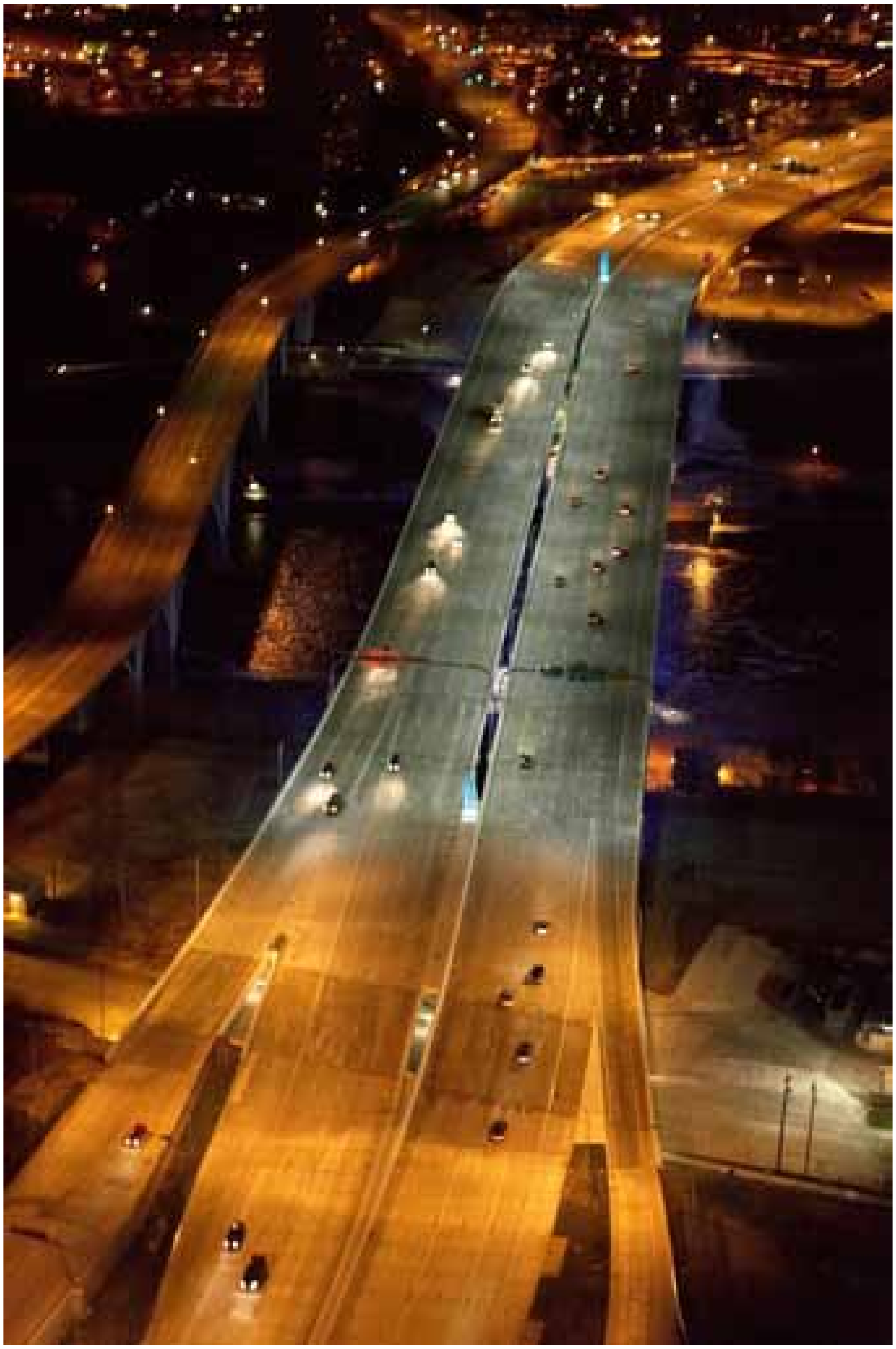


Figure 2.2. Aerial View of I-35W Bridge

2.7 Future Illuminance Measurements

Given the general lack of operating history with LED systems—particularly in harsh operating environments—future illumination levels and expected lifetimes for roadway luminaires cannot be predicted with absolute certainty. The project is employing a number of approaches to help establish a higher level of confidence that the luminaires will maintain adequate performance over their expected lifetimes.

Three of the LED luminaires were tested according to the IESNA LM-79-08 photometric test procedures prior to installation on the bridge. Two of those luminaires were subsequently forwarded to Mn/DOT for installation and the third submitted for lumen maintenance testing.

Following procedures established in IESNA LM-80-08 for investigating lumen maintenance requires a testing period of at least 6000 hours, or about 8 months of continuous operation. However, no approved method currently exists for testing *luminaire* lumen maintenance (LM-80 addresses testing individual LEDs rather than an entire luminaire). Regardless, LM-80 procedures will be followed to the greatest extent possible. PNNL will ultimately compare this LM-80 data with that from the LED manufacturer to develop an estimate of when the luminaire is likely to reach 70% (L_{70}) of initial luminous flux. This lifetime estimate is expected to be available sometime in early 2010 and, once testing is completed, the third luminaire will be returned to Mn/DOT for service as a spare.

In the meantime, and through the first three years of operation of the new bridge lighting system, the illumination levels are to be separately monitored using a mobile monitoring system developed by Virginia Tech Transportation Institute (VTTI), with support from the Federal Highways Administration (FHWA) and DOE. This system is comprised of four Minolta T-10 illuminance meters mounted on the bed of a pickup truck. In combination with a surveyor-grade GPS locator, the illuminance meters record measurements at specific points as the truck crosses the bridge. The GPS enables consistency between measurements taken over time, so that the degradation of overall illumination can be accurately measured and monitored as the luminaires age, and as any other issues such as dirt depreciation impact the amount of light reaching the roadway surface.

Separate illuminance measurements were taken on the roadway surface prior to the bridge opening and used to calibrate readings from the mobile system taken at the same time. **Error! Reference source not found.** lists the illuminance measured on the roadway surface at three locations, as noted. These values are not comparable against each other because the different areas incorporate different luminaires and spacings. The *Bridge Span* location contains 244W LED luminaires mounted at one set spacing, while the *Transition Zone* location includes both 250W (nominal, 291W including ballast) HPS and 289W LED luminaires at a second spacing and the *Approach* location has 400W (nominal, 453W with ballast) HPS luminaires at yet a third spacing. In the future, the Mn/DOT vehicle will make multiple passes across the bridge on an approximately semi-annual basis, monitoring the lighting performance without further need for corresponding ground measurements.

Table 2.4. Measured Illuminance at Three Roadway Locations

	Bridge Span **LED Luminaires Only[1]**	*Transition Zone* **HPS & LED Luminaires[2]**	*Approach* **HPS Luminaires Only[3]**
Average	0.91 fc	1.28 fc	1.69 fc
Maximum	1.97 fc	3.62 fc	3.46 fc
Minimum	0.26 fc	0.27 fc	0.92 fc
Avg:Min	3.51	4.74	1.84
Max:Min	7.58	13.41	3.76

1. 244W LED luminaires.
2. Combination of 289W LED and 250W (nominal, 291W including ballast) HPS luminaires.
3. 400W (nominal, 453W with ballast) HPS luminaires.

The mobile monitoring system not only provides information on overall system performance but will also be used to detect any individual issues as they appear, perhaps even before becoming visible to the human eye. Through this manner Mn/DOT should be able to respond to all but catastrophic failures well before issues become a serious problem.

Finally, at the end of the three-year monitoring period (that includes at least six cycles of measurements), the same two luminaires that were subjected to LM-79-08 testing prior to their installation will be removed and tested again, to provide accurate documentation of their photometric performance and electrical characteristics after three years of operation in this challenging environment. The luminaires will be tested both in their as-found condition (*i.e.*, dirty) and after being cleaned, providing useful information on expected future lumen maintenance and dirt depreciation.

3.0 Economics

3.1 Product Costs

LED luminaires remain a relatively new, rapidly evolving technology, and as such typically carry a corresponding price premium relative to their conventional counterparts. An aspect of LED lighting that is different from other lighting sources is the roughly linear correlation that exists between output of the luminaire and price. In general, increased lumen packages in LED luminaires translate into increased numbers of LEDs, along with greater use of materials needed for heat sinking and for fabricating a larger luminaire, etc. In contrast, raising the output (*i.e.,* increasing lamp wattage to produce more light) of a conventional luminaire has much less of a dramatic impact on its price.

Costs of the standard fixture and the two LED luminaires used in the project are provided in Table 3.1 below.

Table 3.1. Cost of Products for the I-35W Bridge

Product	Unit Cost	Quantity Used	Total Cost
Mongoose 250W HPS Cobra Head[1]	$440	20	$8,800
LED 10-bar Type V	$2,250	16	$36,000
LED 12-bar Type III	$2,500	4	$10,000

1. Conventional base case technology for purposes of comparison only; not installed on bridge.

The LED luminaires came at a significant price premium, about $38,000.00 more than the 250W HPS baseline. The bridge contractor offered to include the LED luminaires at no additional contract cost, however, so that Mn/DOT's decision was based primarily on other issues offered by LED technology such as the anticipated reduction in maintenance, aesthetics, potential energy savings and improved uniformity. The traditional cost-effectiveness criteria were relaxed and the project proceeded.

3.2 Maintenance

Maintenance is a significant issue for bridge lighting systems. Bridges typically have limited maneuvering room for altering the flow of traffic and thus fixture relamping and other maintenance activities usually involve lane closures and heightened safety concerns. As previously noted, reducing the number of lanes that must be blocked was one stated reason for using 40-foot rather than 49-foot mounting heights. These concerns are increased on an interstate roadway where both traffic volume and travel speeds are much higher. Given the proximity of a major metropolitan area and the need to minimize traffic disruption, such activities would typically be performed at night, which introduces additional safety concerns.

The U.S. Department of Transportation (DOT) *Manual of Uniform Traffic Control Devices*[9] (*MUTCD*) devotes considerable discussion to "mobile operations" such as utility maintenance, and the concerns related to the Traffic Transition Control (TTC) Zone, *e.g.*,

> Appropriately colored or marked vehicles with high-intensity rotating, flashing, oscillating, or strobe lights may be used in place of signs and channelizing devices for short-duration or mobile operations…
>
> During short-duration work, it often takes longer to set up and remove the TTC zone than to perform the work. Workers face hazards in setting up and taking down the TTC zone…
>
> When mobile operations are being performed, a shadow vehicle equipped with an arrow panel or a sign should follow the work vehicle, especially when vehicular traffic speeds or volumes are high. Where feasible, warning signs should be placed along the roadway and moved periodically as work progresses. Under high-volume conditions, consideration should be given to scheduling mobile operations work during off-peak hours…
>
> Reduced visibility inherent in night work impacts the performance of both drivers and workers. Because traffic volumes are lower and congestion is minimized, speeds are often higher at night necessitating greater visibility at a time when visibility is reduced. Finally, the incidence of impaired (alcohol or drugs), fatigued, or drowsy drivers might be higher at night…
>
> Because typical street and highway lighting is rarely adequate to provide sufficient levels of illumination for work tasks, temporary lighting should be provided where workers are active to supply sufficient illumination to reasonably safely perform the work tasks. Temporary lighting for night work should be designed such that glare does not interfere with driver visibility, or create visibility problems for truck drivers, equipment operators, flaggers, or other workers. Consideration should also be given to stationing uniformed law enforcement officers and lighted patrol cars at night work locations where there is a concern that high speeds or impaired drivers might result in undue risks for workers or other drivers.

Clearly, maintenance is not only costly but of great safety concern on a bridge (or similarly, in a tunnel), and any means of minimizing the amount of required maintenance carries a significant value beyond the dollar cost of actually conducting the activity. LED products are anticipated to offer great benefits in this aspect and thus underscore some of Mn/DOT's interest in their use for the I-35W Bridge.

Estimating the precise dollar value of avoided maintenance on the bridge is complicated by the fact that Mn/DOT negotiates an overall rate that combines all of the lighting maintenance into a single contract. Incremental costs of labor and other vehicles and signage suggested from the *MUTCD* excerpts above are not separately accounted for, and are thus not as explicit as might be the case were a contract to be established for the bridge by itself.

The values in Table 3.2 comprise assumptions of costs that might be incurred for the twenty 250W HPS Mongoose base case fixtures across I-35W Bridge. The resulting total cost per relamped fixture falls into the range provided by Mn/DOT of $130-150 per fixture; though note this estimate represents an average across all interstate lighting covered by their lighting maintenance contract.

[9] Available from http://mutcd.fhwa.dot.gov/.

Table 3.2. Assumptions for Estimation of Maintenance Savings

Number of Lamps changed per hour		4.00
Total Hours to complete job (20 luminaires at 4 per hour)		5.00
Hourly cost of bucket truck	$	50.00
Hourly cost of trailing signage vehicle	$	25.00
Total number of staff for relamping interstate bridge		4.00
Hourly Labor rate per staff member	$	50.00
Transit time to and from (hours)		2.00
Relamp Materials per lamp	$	41.00
Equipment (Truck) Cost per lamp	$	18.75
Relamp Labor per lamp	$	50.00
Total cost in transit*	$	550.00
Total Cost per fixture relamped	**$**	**137.25**
Total site cost for relamp	$	2,745.00
Relamp cycle (# of years)		5.0
Annualized relamp cost	**$**	**549.00**

*Cost of labor and equipment getting to and from the site.

Another issue for consideration is the expected relamp cycle, which in Table 3.2 is simply the standard lifetime of the HPS lamps (24,000 hours for a standard lamp, 30,000 hours for the upgraded model used on the previous I-35W bridge) divided by the annual usage (4380 hours/year), multiplied by the IES recommended replacement schedule of 70% of rated life, or roughly 5 years overall. Standard lamps experience significantly shorter life due to excessive vibration on bridges of steel truss construction (*e.g.,* such as the previous I-35W bridge). The previous bridge reportedly experienced a standard lamp failure rate on the order of 50% every two years.[10] The newly-constructed bridge is of pre-stressed concrete, which greatly dampens the level of vibration transmitted from vehicle traffic and would thus be expected to relieve most or all of the previous elevated mortality rate. Table 3.2 therefore assumes a lamp replacement schedule of 5 years for purposes of a base case comparison, and all lamps are assumed to be replaced at the same time (*i.e.*, no interim spot replacements).

Maintenance for the LED product is assumed to be zero over the expected practical lifetime of the luminaires (~15 years), based on information provided by the luminaire manufacturer. As no actual field data exists for LED streetlight products over this duration, the accuracy of this assumption is uncertain. For example, the unit is designed to be self-cleaning: however, the effectiveness of this design feature remains to be proven in actual long-term operation. One planned element of the ongoing demonstration project involves retrieving two of the luminaires after three years and resubmitting them for photometric testing. The luminaires will be tested in an as-found condition, then manually cleaned and tested again, to measure the

[10] Personal communication with Greg Brandt, Mn/DOT Metro Lighting Project Manager. Upgrading to the improved (and more expensive) EYE lamp on the bridge reportedly helped this problem. See Appendix A for lamp specifications.

effectiveness of the self-cleaning design. Any other maintenance necessary over the three-year period is to be documented and reported at the conclusion of the overall effort.

3.3 Simple Payback

In order to meet most users' requirements for acceptable return on investment, the current price premium of LED technologies generally requires that, in addition to energy savings, a monetary value of their other attributes be assigned to/accounted for in the calculation. The most obvious of these is typically derived from the longer life/lower maintenance aspect of LEDs compared to the conventional product they are replacing. A full in-depth life-cycle cost analysis might also consider other factors such as savings from the enabled reductions in wire gauge or additional design changes resulting from the different luminaires (though that information was not available for this particular evaluation). Finally, ancillary attributes, such as resistance to vibration, instant-on/instant-off, dimming capability, etc., may also have intrinsic value and encourage an investment that might otherwise be rejected if based on the value of electricity savings alone.

In this case, the electricity savings achieved from the use of LEDs on the bridge, relative to the assumed HPS base case, amounts to about 13% of total use. Coupled with the fact that Mn/DOT pays a fairly low rate for electricity for roadway lighting ($0.0674/kWh), the resulting dollar value of these savings is small, on the order of $180 total per year for the twenty luminaires combined. Even an assumed doubling of the rate paid for electricity only marginally impacts the payback calculation due to the small percentage savings.

The majority of economic savings in this instance thereby comes from the elimination of maintenance that would have otherwise been required for a standard HPS installation. As a consequence, the frequency of relamping assumed for the HPS base case is also a major driver of the economics of the installation. Table 3.3 lists the estimated payback for the bridge installation for several different relamping cycles. The shorter relamping cycles are more relevant for bridge lighting applications where vibration or related issues decrease the usual expected lifetime of the lamps.

Table 3.3. Simple Economic Payback for I-35W Bridge for Different Relamping Cycles

Relamp Cycle (years)	5	4	3	2	1
Total Annual Relamp Savings	$549.00	$686.25	$915.00	$1,372.50	$2,745.00
Electricity Savings	$180.67	$180.67	$180.67	$180.67	$180.67
Grand Total Annual Savings	$729.67	$866.92	$1,095.67	$1,553.17	$2,925.67
Payback (years)	**55.1**	**46.4**	**36.7**	**25.9**	**13.7**

The values in Table 3.3 are illustrated in Figure 3.1 below.

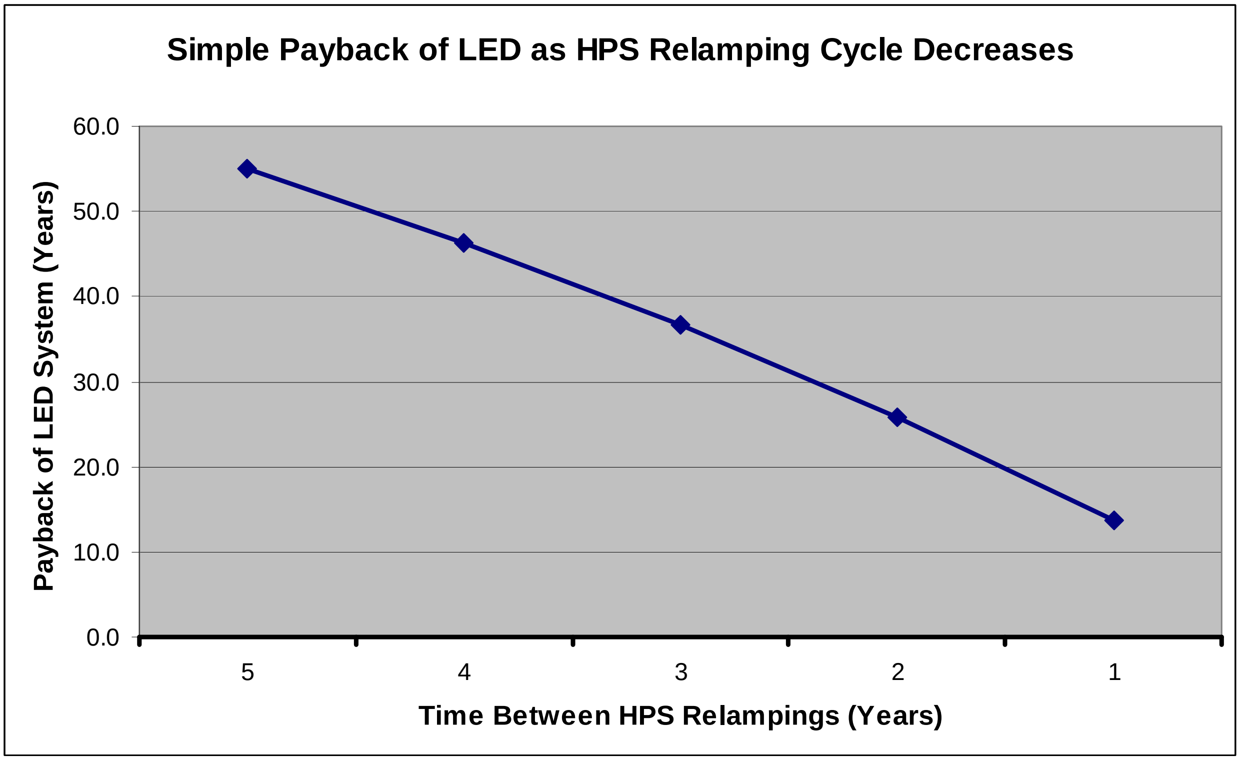


Figure 3.1. Simple Payback of the LED System vs. Frequency of Relamping a Conventional HPS System on the I-35W Bridge.

4.0 User Feedback

A key component of evaluating the effectiveness of a lighting system substitution is collecting user feedback on the acceptability of the new technology. LEDs cannot be considered a successful replacement if users believe it diminishes lighting quality and/or related aspects (*e.g.,* appearance, impressions of safety and security, etc.).

Due to the pioneering nature of this installation, being the first of its kind in the United States, the GATEWAY program determined that a special effort should be undertaken to convene a group of outdoor lighting experts on the bridge prior to its opening to the public. Results from both sets of reviews are discussed below.

4.1 Lighting Expert Review Panel

Prior to the bridge opening, more than a dozen outdoor lighting experts and other involved staff from Mn/DOT and other agencies visited the site to review the lighting quality provided by the LED luminaires. The participants were free to walk about the bridge and to take notes, measurements and photographs. The following morning, the majority of the group reconvened to discuss their impressions of the LED lighting system.

Without exception, participants in the review expressed overall favor with the quality of illumination provided by the luminaires, although a few concerns were also raised (described below). Horizontal illuminance was perceived to be adequate across the width of the bridge (5 lanes plus 13- and 14-foot shoulders), even at the outside rail (farthest from the light poles). The most common observation pertained to the visibly uniform illumination; one participant remarked that the bridge appeared as though lighted by a full moon on a clear night. More than one participant noted that they had previously been skeptical concerning the expected illumination, but in the end came away impressed.

Despite some concern expressed prior to the visit, none of the participants expected afterwards that glare would be a problem from the LED luminaires for drivers on the bridge. In fact, more glare was perceived from other existing HPS luminaires in the near distance than from the LED luminaires. The luminaires do appear bright when observing them from a low angle (*i.e.,* below the luminaire), but this is not a practical concern for drivers nor is it different from conventional lighting sources. One participant suggested that such glare might be an issue for boats passing underneath the bridge, though another noted there would be a similar problem with any light source due to the luminaire location in relation to the bridge and the river below.

A few additional concerns were raised about the illumination of the LED system that may be worth further attention. Two of the experts expressed some apprehension that the bridge might be illuminated too uniformly, *i.e.*, a lack of variation in the lighting would prevent drivers from identifying objects on the roadway. The Small Target Visibility (STV) metric outlined in IESNA RP-8 places more value on less uniform lighting systems. However, the STV contrast is measured irrespective of light spectrum (color) and only focuses on luminance. "Too great of uniformity" is not a commonly heard criticism of lighting systems, but this could be because most traditional systems cannot as easily achieve the same levels of uniformity offered by LED technology. A more scientifically rigorous study of this issue may be warranted.

A second potential concern regarded the anticipated rate of lumen depreciation, and whether the illumination might fall below the Mn/DOT required illumination levels during the expected practical lifetime of the luminaires (~15 years). [11] As noted earlier, PNNL is currently testing a luminaire from the same production batch as those installed, adapting IESNA LM-80-08 (Approved Method: Measuring Lumen Maintenance of LED Light Sources) for testing lumen maintenance of the luminaire. In addition, actual illumination levels on the bridge are also to be systematically monitored over the next three years. The results of both of these procedures will be carefully evaluated to estimate what illumination levels will be maintained over the operating lifetime of the luminaires.

Overall, achieving the anticipated lifetime with little or no required maintenance was the greatest remaining question in the minds of Mn/DOT staff present at the meeting. As noted previously, uncertainty remains with respect to maintenance needs (*e.g.*, cleaning/power washing of the luminaires, required replacement of power supplies, etc.) and lifetime because no LED roadway lighting products have been installed anywhere near these kinds of timeframes. But participants in the review meeting were cautiously optimistic and considered the present LED illumination a success. Performance of the LEDs will be closely monitored over the next three years.

4.2 Driver Questionnaire

In an effort to obtain a sense of driver's perception of the quality of lighting on the new bridge, a brief survey was administered to 3,384 recipients November 12 - 21, 2008. The survey was sent via email to a Mn/DOT distribution list populated by users who signed up requesting email updates on the new bridge. Although such a self-selecting audience is by definition not an entirely independent survey sample, its size and convenience significantly outweighed any concerns regarding absolute statistical rigor.

Out of the total mailing, 671 responses were received, roughly a 20% response rate. Of those, 489 (14% of all recipients) indicated that they had either driven or been a passenger across the bridge while the lighting system was operating. Table 4.1 summarizes the findings from these 489 respondents, each beginning with the question and subsequent survey result (questions are listed in the survey order).

[11] At the manufacturer's anticipated rate of lumen depreciation (~ 0.5% per year based on the prevailing average night time temperatures in Minneapolis), this would not be an issue during the expected lifetime, though the actual rate of lumen depreciation for this product has not yet been established.

Table 4.1. Responses from User Feedback Survey

"Compared to the lighting on the approaches to the bridge, how would you characterize the roadway lighting on the bridge?"

Response	Chart	Frequency	Count
Extremely different		19.1%	89
Somewhat different		**65.2%**	**303**
Not different		10.3%	48
No opinion		5.4%	25
		Valid Responses	**465**
(Respondents could only choose a **single** response)		**Total Responses**	**465**

"The quality of lighting on the new bridge _____ my ability to see the roadway and objects that are on it."

Response	Chart	Frequency	Count
Greatly enhances		23.9%	108
Enhances		**53.9%**	**243**
Has no effect on		17.3%	78
Inhibits		4.7%	21
Greatly inhibits		0.2%	1
Not Answered			2
		Valid Responses	**451**
(Respondents could only choose a **single** response)		**Total Responses**	**453**

"The new bridge lighting creates _____ glare than other roadway lights."

Response	Chart	Frequency	Count
Much less		21.7%	97
Somewhat less		33.3%	149
No noticeable difference in		**38.5%**	**172**
Somewhat more		5.6%	25
Much more		0.9%	4
		Valid Responses	**447**
(Respondents could only choose a **single** response)		**Total Responses**	**447**

"The lighting level on the new bridge is _____."

Response	Chart	Frequency	Count
Too dim		2.9%	13
Somewhat dim		21.7%	96
Just right		**64.8%**	**287**
Somewhat bright		9.9%	44
Too bright		0.7%	3
Not Answered			1
		Valid Responses	**443**
(Respondents could only choose a **single** response)		**Total Responses**	**444**

"The quality of the bridge lighting makes it seem ______ to drive under."

Response	Chart	Frequency	Count
Very safe		28.0%	123
Safe		**45.5%**	**200**
Neither safe nor unsafe		23.4%	103
Unsafe		3.0%	13
Very unsafe		0.2%	1
Not Answered			2
		Valid Responses	**440**
(Respondents could only choose a **single** response)		**Total Responses**	**442**

"I _________ recommend use of this type of lighting elsewhere."

Response	Chart	Frequency	Count
Would definitely		37.2%	164
Would		**41.0%**	**181**
May or may not		17.2%	76
Would not		3.4%	15
Would definitely not		1.1%	5
		Valid Responses	**441**
(Respondents could only choose a **single** response)		**Total Responses**	**441**

"Year of birth."

Response	Chart	Frequency	Count
1983 – 1989		10.7%	60
1978 – 1982		**16.0%**	**90**
1973 – 1977		11.2%	63
1968 – 1972		8.0%	45
1963 – 1967		10.3%	58
1958 – 1962		8.4%	47
1953 – 1957		9.4%	53
1948 – 1952		8.9%	50
1943 – 1947		7.3%	41
1933 – 1942		8.0%	45
1932 or earlier		1.8%	10
Not Answered			3
		Valid Responses	**562**
(Respondents could only choose a **single** response)		**Total Responses**	**565**

"Gender"

Response	Chart	Frequency	Count
Male		**74.6%**	**419**
Female		25.4%	143
Not Answered			3
		Valid Responses	**562**
(Respondents could only choose a **single** response)		**Total Responses**	**565**

The age demographic was fairly well distributed. A correlation analysis was conducted to determine if there were any identifiable patterns associated with age (*e.g.*, do older drivers perceive the lighting differently than younger drivers?). The analysis revealed no age-related correlation for any of the questions.

5.0 Discussion

The goal of the GATEWAY demonstration program is to demonstrate solid-state lighting products in general illumination applications that: save energy, match or improve the quality of illumination, and that are genuinely cost-effective for the user. Together these three criteria present a formidable challenge, particularly the hurdle of achieving cost-effectiveness after the first two criteria have been adequately met.

In the I-35W Bridge installation, some level of energy savings has been achieved, though assessing the ultimate degree is complicated by the fact that there was not an earlier conventional product in place and therefore the baseline can only be established through use of computer simulation. Initial simulation of the bridge using the 250W HPS Mongoose fixture indicated a failure to meet Mn/DOT's required uniformity. The simulation was able to improve the uniformity to an acceptable degree by modeling a 15° upward mounting angle for the fixture, which projects more light to the outer edges of the bridge deck, raising the minimum illumination level. Yet while this approach achieves the required uniformity, evaluation of the consequent light distribution (see corresponding BUG Analysis in Appendix C) suggests that tilting the HPS luminaires would not be acceptable from either a glare or light pollution perspective.[12] If the tilt is in fact not acceptable, larger wattage fixtures, such as the 400W models used on the bridge approaches, could potentially be required and the baseline energy use (along with the savings relative to it) would be much greater than currently estimated. However, in the end this study did not establish with certainty that another 250W HPS luminaire could not meet the illumination requirements, being outside the main focus of the effort. For the sake of expediency, the 250W HPS Mongoose luminaire (with tilt) was assumed to be acceptable for purposes of the evaluation, adding a degree of conservatism to the results.

According to the comments received from the public user survey, the LED lighting installation was preferred over the HPS lighting on either end of the bridge by a large margin of relevant comments (approximately 5 to 1 in favor[13]; see the actual comments compiled in Appendix E). Of the comments that were unfavorable, many express the opinion that the lighting under the LEDs is too dim. The average illuminance under the LEDs is in fact significantly lower than the approaches on either side (0.91 vs. 1.67 fc), which are lighted by closely spaced 400W HPS fixtures due to the number of conflict zones (lanes of merging traffic) in those areas (see photo in Figure 2.2). Given the abrupt transition to the lower illumination levels once on the bridge, this perception is not unexpected.

Comments from the expert panel review were also generally favorable. The lighting uniformity was particularly noted, and glare was not perceived to be an issue even by those who had previously expected it. Considering the results from both the experts and the driver survey, it appears justified to conclude that the second criterion, to match or improve illumination quality, has also been accomplished in this location.

The final and most difficult criterion for this installation is achieving cost-effectiveness. The value of estimated energy savings is not significant, given only a roughly 13% savings in energy use over the assumed baseline and a relatively low price of electricity. Thus the cost-effectiveness of the I-35W Bridge installation

[12] Furthermore, the Mongoose fixtures used by Mn/DOT are what was previously classified as "full cutoff," a designation that is defeated by tilting the luminaire.

[13] One commenter stated, for example, "The LED lighting makes the bridge a treat to drive across as opposed to the typical freeway lighting I'm used to. It's [*sic*] 'cool' coloration really makes things easier to see and less harsh on the eyes. I wish more of this lighting was used on the approaches." See Appendix D.

relies heavily on the value of avoided maintenance, which was one of the underlying drivers for selection of LED products at the outset.

Lighting system maintenance in limited-access installations like bridges and tunnels can be quite expensive because it generally requires lane closures, and the work must be carried out in close proximity to moving traffic. Safety issues increase as the speed of travel and traffic volume increase, both of which are significant at this bridge location. The actual annualized cost of having to relamp HPS fixtures would depend both on the number of vehicles and staff involved to close the lane and conduct the work, and the required frequency of maintenance activity. Unfortunately, it is difficult to find documentation of bridge-specific costs since roadway lighting contracts are typically issued all-inclusive, and thus reflect average costs over a much larger set of roadways. Furthermore, not all issues can be directly monetized, such as the difficulty in scheduling lane closures on a major freeway bridge located in a large metropolitan area. Even with these clear maintenance advantages, simple payback periods estimated at more than a decade, as in the case here, continue to present a formidable obstacle to adoption of SSL technology for roadway lighting.

Aside from performance of the product itself, success of a given installation largely depends on the particulars of the site and the specific information included in the evaluation. In the case of the new I-35W Bridge, energy is being saved and illumination has been qualitatively improved, though at a relatively high economic cost. Continued evolution of SSL technology should only improve these results.

Appendix A

Lamp, Ballast and Meter Information

Appendix A

Lamp, Ballast and Meter Information

Meter Information

Manufacturer: PhotoResearch
Type: LiteMate III
Model: 504
Sensitivity Range: 0.01 – 19,990 fc
Measurement Uncertainty: 1.8%
Calibrated: 11/2007

Luminaire Information

Manufacturer: Holophane
Model: "Mongoose" G250HP MC L WF H GB
Nominal Dimensions: 37" long x 17" wide x 12" tall
Maximum Weight: 50 lbs
EPA: 2.05 square feet

Ballast Information

Manufacturer: Holophane
ANSI Code: S50
Type: Constant-Wattage Autotransformer
Input Wattage: 305 watts
Power Factor: 90% HPF
Minimum ambient starting temperature: -40° F

Lamp Information

Manufacturer: Eye
ANSI Code: S50
Product Code: 60012
Description: Ignitron™ EN LU250/I/EN
Bulb Designation: ET18
Base: Mogul (E39)
Initial Lumens: 28,500
CCT: 2100
Chromaticity (x, y): 0.532, 0.422
Color Rendering Index: 25
Rated Life: 30,000 hours

TECHNICAL BULLETIN
HIGH PRESSURE SODIUM

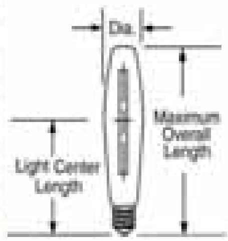
Ignitron™ EN LU250/I/EN

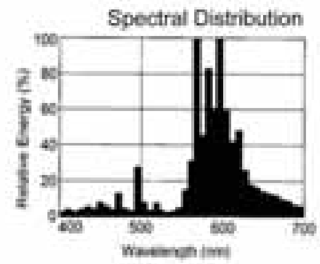
ANSI Code: S50 | **Product Code: 60012**

Features:	• Eliminates the need for replacement ignitor • EPA TCLP compliant for non-hazardous waste • FEC protects lighting system components • Dependable long life	• Universal burning position • Eliminates possible damage to ballast

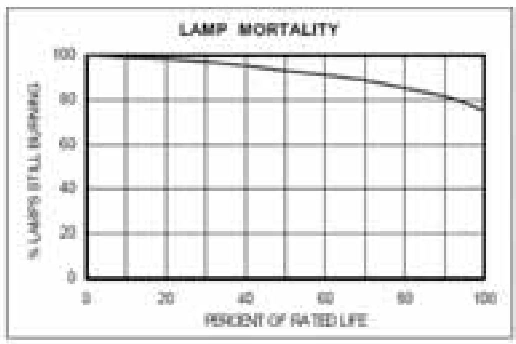
EPA TCLP Compliant	Yes

PERFORMANCE DATA		
Initial lumens at rated watts after 100 hours operation	28500	lm
Mean lumens at 10 hours/start	25600	lm
Rated average life	30000	h
Warm up time (90% lumens)	5	min
Correlated color temperature	2100	K
CIE chromaticity	0.532, 0.422	x, y
Color rendering index	25	
Operating Position	Any	
Hot Re-strike time	15	min

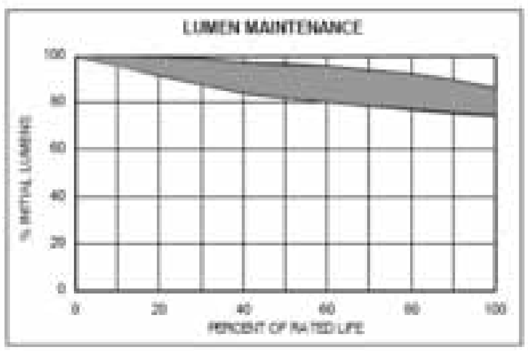




ELECTRICAL CHARACTERISTICS		
Nominal lamp wattage	250	W
Nominal lamp voltage	100	V
Nominal lamp current	3.0	A_{rms}
Current crest factor (max.)	1.8	
Max. starting current	4.5	A_{rms}
Min. starting current	3.0	A_{rms}
Ballast requirements	Use with ballast rated for S50 lamps	
Open circuit voltage		
-40°C (-40°F)	169 (235)	Vrms (Vpeak)
Pulse requirements	External pulse not required	
Pulse Height/Number of pulses	Not Applicable	kV
Pulse Width	Not Applicable	µs
Socket rating	4	kV



PHYSICAL DESCRIPTION		
Maximum overall length	248 (9.75)	mm (in)
Light center length	146 (5.75)	mm (in)
Bulb diameter	57 (2.25)	mm (in)
Base to bulb eccentricity (max.)	3	Degrees
Maximum base temperature	210 (410)	°C (°F)
Maximum bulb temperature	400 (752)	°C (°F)
Bulb designation	ET18	
Bulb material	Borosilicate (Hard Glass)	
Arc tube material	PCA	
Arc length	64 (2.52)	mm (in)
Bulb finish	Clear	
Base designation	Mogul (E39)	



ISO 9001:2008 Certified ISO 14001:2004 Certified OSHAS 18001:2007 Certified ISO 17025:2005 Accredited

EYE LIGHTING INTERNATIONAL OF NORTH AMERICA, INC.
A SUBSIDIARY OF IWASAKI ELECTRIC CO., LTD.
Address: 9150 Hendricks Rd., Mentor, OH 44060
Phone: 888-665-2677 Fax: 800-811-7395 e-mail sales@eyelighting.com
Phone: (440) 350-7000 Fax: (440) 350-7001 Web: www.eyelighting

EQS-N-52-78-60012 November 19, 2008

EYE	**TECHNICAL BULLETIN** **HIGH PRESSURE SODIUM**	**Ignitron™ EN** **LU250/I/EN**

⚠WARNING

RISK OF ELECTRIC SHOCK:

- Turn power off before inspection, installation or removal.
- Protect lamp from direct contact with liquids to avoid breakage from thermal shock.

RISK OF FIRE:

- Keep combustible materials away from lamp during operation.

UNEXPECTED LAMP RUPTURE MAY CAUSE INJURY, FIRE OR PROPERTY DAMAGE

- Do not exceed rated ballast voltage.
- Do not use lamp if outer glass is scratched or broken.
- Do not use beyond rated life.
- Do not turn on lamp until fully installed.
- Use only with fixture and ballast rated for this product.
- Electrically insulate any metal to glass support in fixture.

⚠CAUTION

RISK OF BURN:

- Allow lamp to cool before handling.
- Contains sodium – Avoid skin contact with broken pieces.

LAMP MAY SHATTER AND CAUSE INJURY IF BROKEN

- Do not use excessive force when installing lamp.
- Dispose of lamp in an enclosed container.
- Wear safety glasses and gloves when installing lamp.

LAMP OPERATING INSTRUCTIONS

IGNITRON LAMPS CONTAIN AN INTERNAL IGNITOR.
TO INSURE PROPER LAMP OPERATION AND MAINTAIN UL FIXTURE LISTING, DISABLE THE FIXTURE IGNITOR AS PER INSTRUCTIONS LOCACATED ON OUR WEBSITE: www.eyelighting.com, "Luminaire Conversions Retrofit Instructions."

Hg-LAMP CONTAINS MERCURY

Manage in Accord with Disposal Laws
See: www.lamprecycle.org or 1-888-665-2677

ISO 9001:2008 Certified ISO 14001:2004 Certified OSHAS 18001:2007 Certified ISO 17025:2005 Accredited

EYE LIGHTING INTERNATIONAL OF NORTH AMERICA, INC.
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Phone: (440) 350-7000 Fax: (440) 350-7001 Web: www.eyelighting

EQS-N-52-79-00012 November 19, 2008

Appendix B

Luminaire Photometric Testing Results

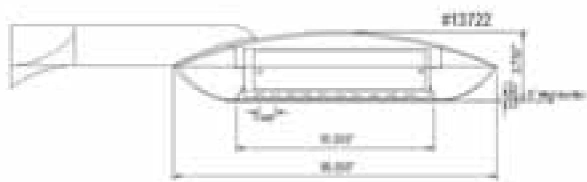
Appendix B

Luminaire Photometric Testing Results

LTL LUMINAIRE TESTING LABORATORY, INC.

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

LTL NUMBER: 13722 DATE: 08-20-2008
PREPARED FOR: PACIFIC NORTHWEST NATIONAL LABORATORY/BATTELLE
CATALOG NUMBER: TD 08-88
LUMINAIRE: CAST ALUMINUM HOUSING, EXTRUDED ALUMINUM HEATSINKS, NO ENCLOSURE.
LAMP: 240 WHITE LEDS WITH CLEAR PLASTIC OPTICS BELOW EACH.
LED POWER SUPPLY: TWO ADVANCE LEDINTA0350C425F
ELECTRICAL VALUES: 277.0VAC, 1.0878A, 289.3W
LUMINAIRE EFFICACY: 65.3 LUMENS/WATT
NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY.*



IES CLASSIFICATION: **TYPE III**
LONGITUDINAL CLASSIFICATION: **SHORT**
CUTOFF CLASSIFICATION: **SEMI-CUTOFF** **

FLUX DISTRIBUTION

LUMENS	DOWNWARD	UPWARD	TOTALS
HOUSE SIDE	6812.13	0.00	6812.13
STREET SIDE	12070.12	0.00	12070.12
TOTALS	18882.25	0.00	18882.25

Approved By: ____

*DATA WAS ACQUIRED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY. A UDT MODEL 211 PHOTODETECTOR AND UDT MODEL S370 OPTOMETER COMBINATION WERE USED AS A STANDARD. A SPECTRAL MISMATCH CORRECTION FACTOR WAS EMPLOYED BASED ON THE SPECTRAL RESPONSIVITY OF THE PHOTODETECTOR AND THE SPECTRAL POWER DISTRIBUTION OF THE TEST SUBJECT.

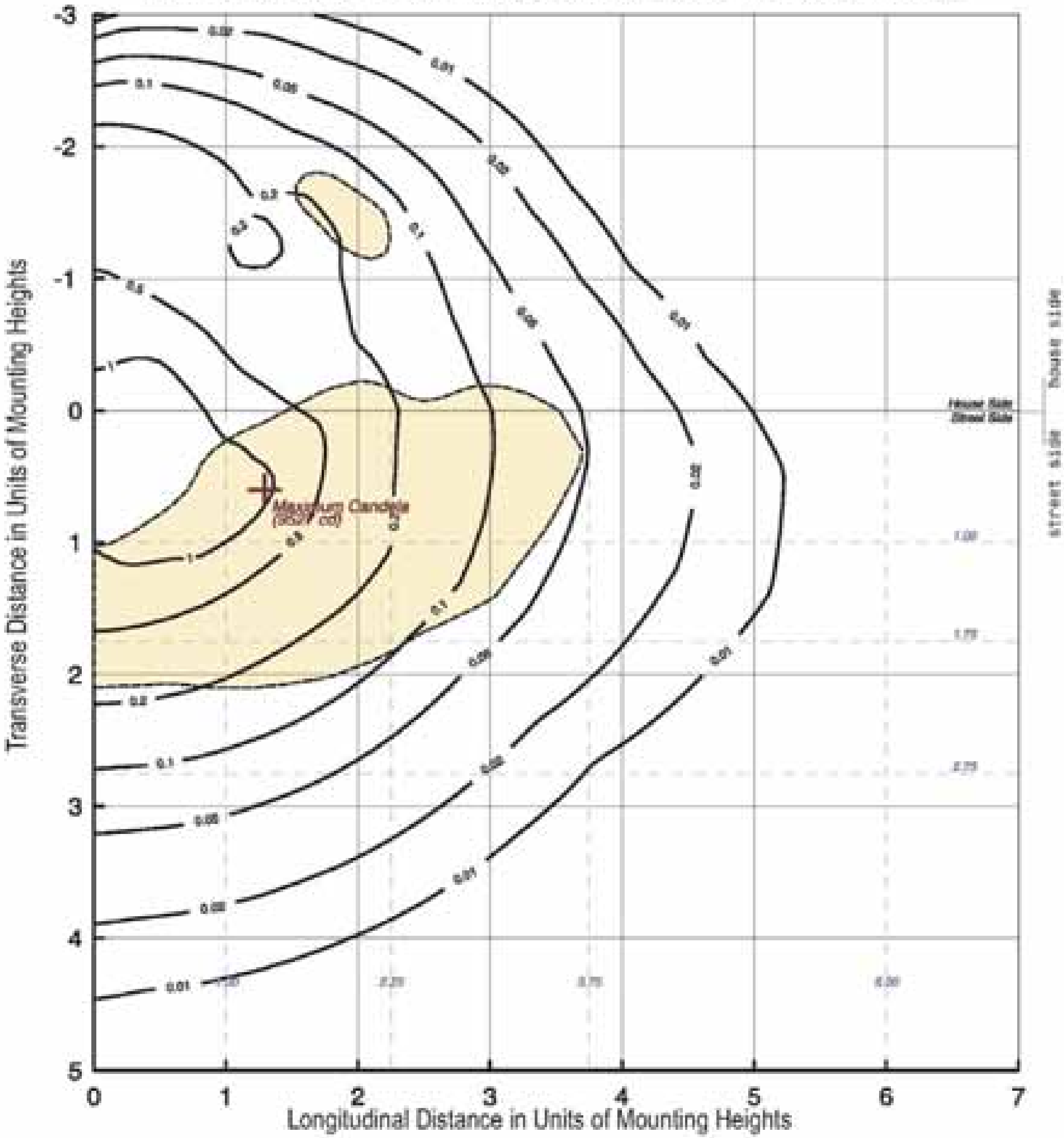
TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.
TEST ANGULAR INCREMENTS AND REPORT FORMATTING WAS BASED ON IES LM-31-95.

LTL LUMINAIRE TESTING LABORATORY, INC.

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

VALUES BASED ON 40.00 FOOT MOUNTING HEIGHT

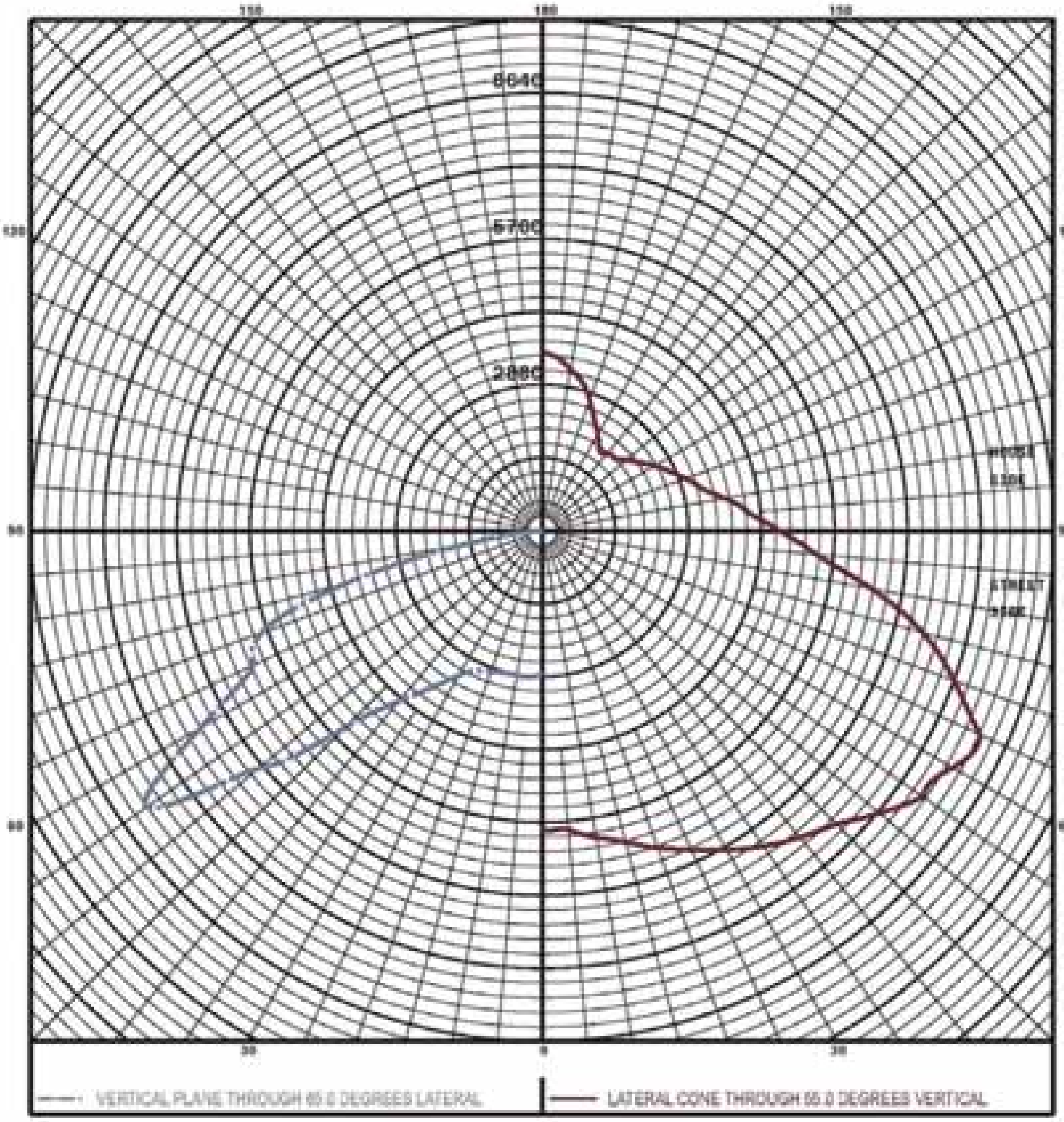


PAGE 2-LTL NUMBER 13722

LTL LUMINAIRE TESTING LABORATORY, INC.

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

MAXIMUM PLANE AND CONE PLOTS OF CANDELA



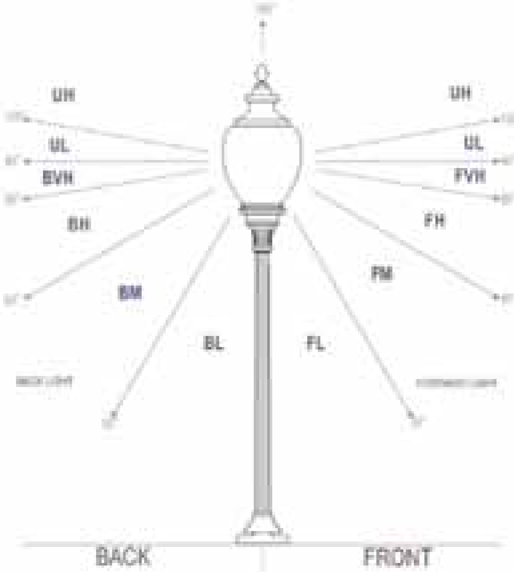
PAGE 5-LTL NUMBER 13722

LTL LUMINAIRE TESTING LABORATORY, INC.

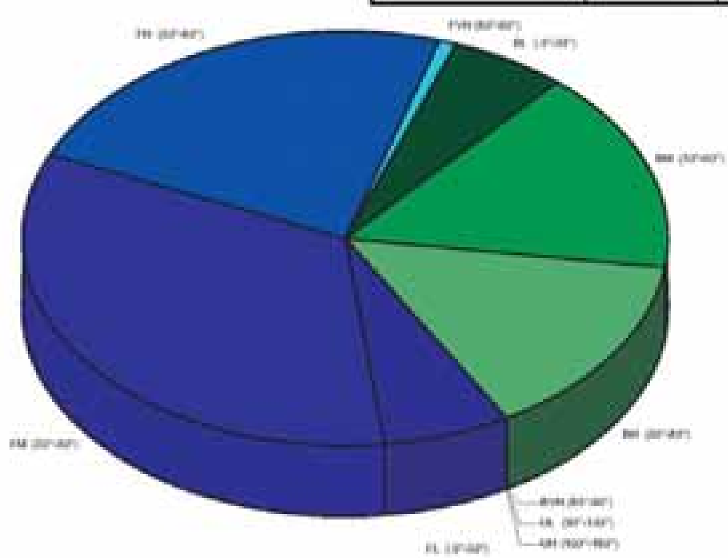
FOUNDING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



ZONE	FLUX: LUMINAIRE LUMENS	FLUX: % OF LUMINAIRE LUMENS
FORWARD LIGHT	12070	63.9
FL (0°-30°)	1228	6.5
FM (30°-60°)	6318	33.5
FH (60°-80°)	4345	23
FVH (80°-90°)	179	1
BACK LIGHT	6812	36.1
BL (0°-30°)	1076	5.7
BM (30°-60°)	3004	15.9
BH (60°-80°)	2707	14.3
BVH (80°-90°)	24	0.1
UPLIGHT	0	0
UL (90°-100°)	0	0
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



LTL LUMINAIRE TESTING LABORATORY, INC.

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

LTL NUMBER: 13721 DATE: 08-18-2008

PREPARED FOR: PACIFIC NORTHWEST NATIONAL LABORATORY/BATTELLE

CATALOG NUMBER: TD 08-87B

LUMINAIRE: CAST ALUMINUM HOUSING, EXTRUDED ALUMINUM HEATSINKS, NO ENCLOSURE.

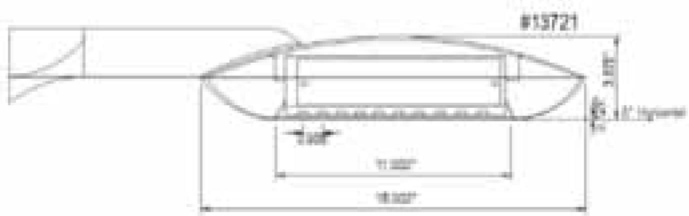
LAMP: 200 WHITE LEDS WITH CLEAR PLASTIC OPTICS BELOW EACH.

LED POWER SUPPLY: TWO ADVANCE LEDINTA0350C425F

ELECTRICAL VALUES: 277.0VAC, 0.9242A, 242.5W

LUMINAIRE EFFICACY: 68.0 LUMENS/WATT

NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY.*



IES CLASSIFICATION: **AREA LIGHT**

CUTOFF CLASSIFICATION: **CUTOFF****

**[illegible]

FLUX DISTRIBUTION

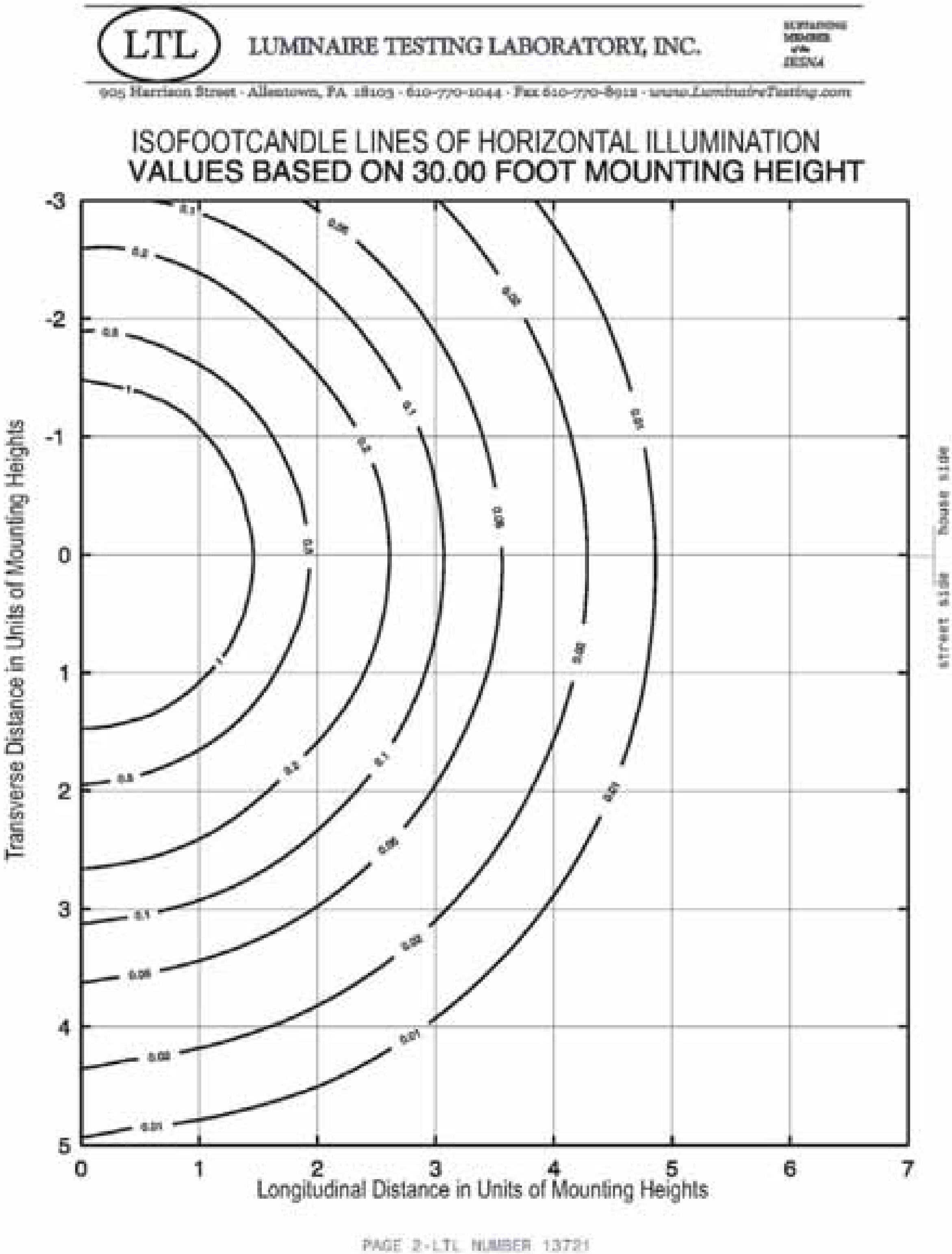
LUMENS	DOWNWARD	UPWARD	TOTALS
HOUSE SIDE	8185.16	0.00	8185.16
STREET SIDE	8296.94	0.00	8296.94
TOTALS	16482.10	0.00	16482.10

Approved By: KG

*DATA WAS ACQUIRED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY. A UDT MODEL #211 PHOTODETECTOR AND UDT MODEL #S370 OPTOMETER COMBINATION WERE USED AS A STANDARD. A SPECTRAL MISMATCH CORRECTION FACTOR WAS EMPLOYED BASED ON THE SPECTRAL RESPONSIVITY OF THE PHOTODETECTOR AND THE SPECTRAL POWER DISTRIBUTION OF THE TEST SUBJECT.

TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.

TEST ANGULAR INCREMENTS AND REPORT FORMATTING WAS BASED ON IES LM-31-95.

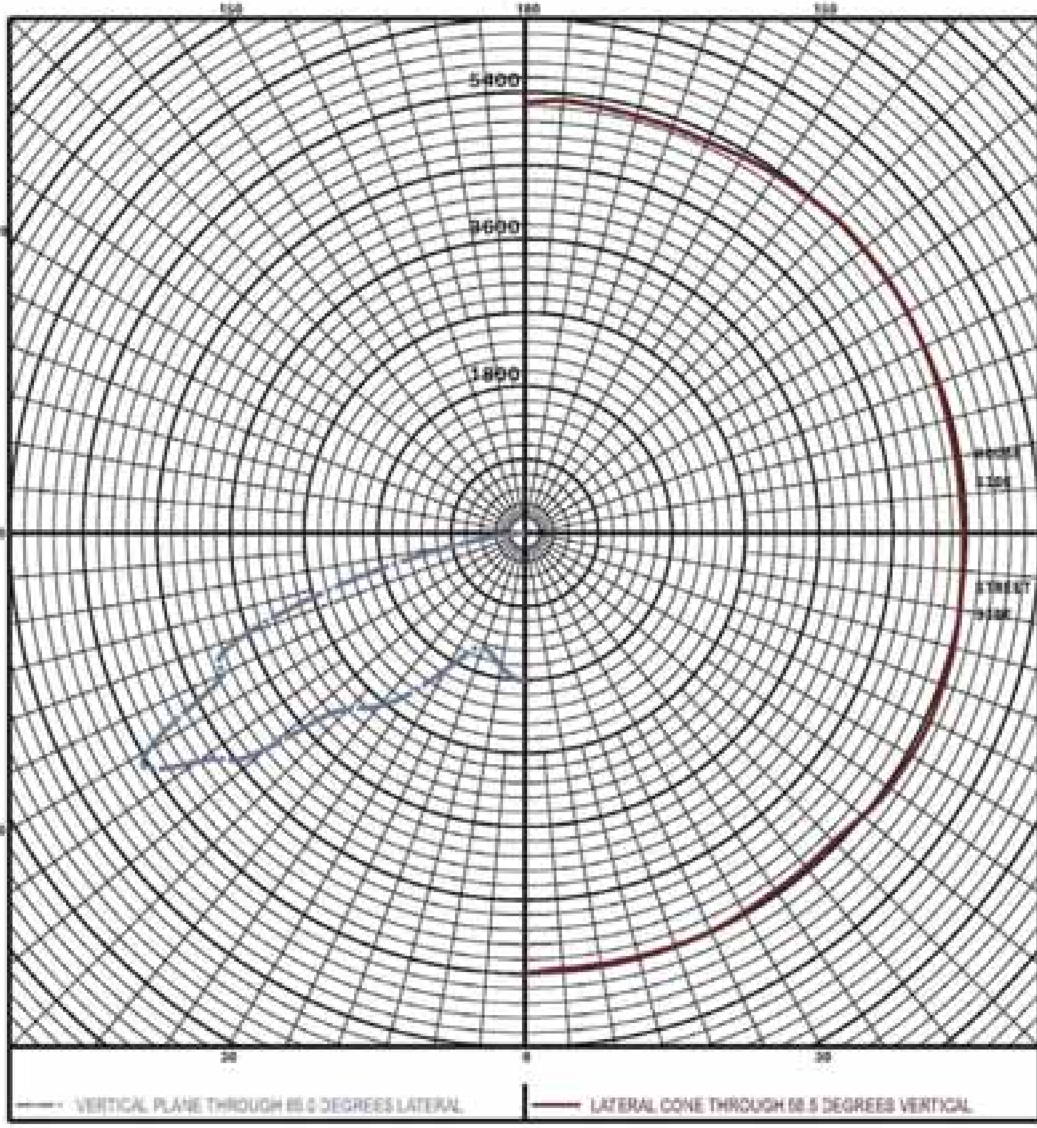


LTL
LUMINAIRE TESTING LABORATORY, INC.
905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com
ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION
VALUES BASED ON 30.00 FOOT MOUNTING HEIGHT
Transverse Distance in Units of Mounting Heights
Longitudinal Distance in Units of Mounting Heights
house side
street side
PAGE 2-LTL NUMBER 13721

LTL LUMINAIRE TESTING LABORATORY, INC.

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

MAXIMUM PLANE AND CONE PLOTS OF CANDELA



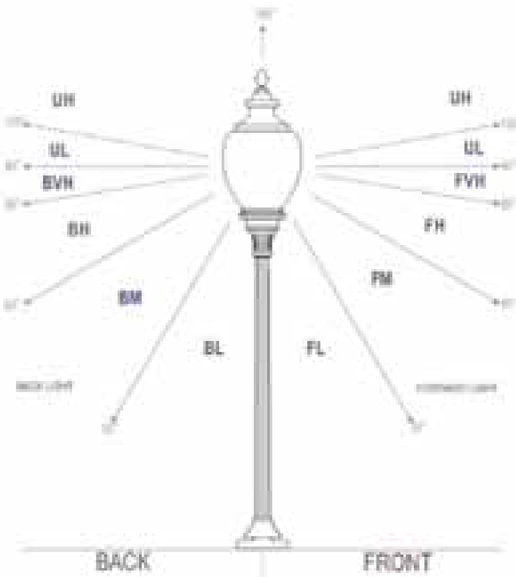
PAGE 5-LTL NUMBER 13721

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

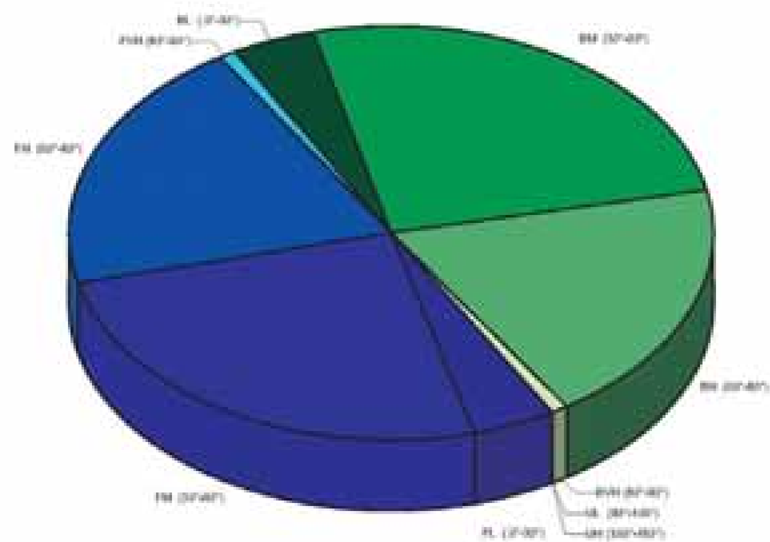
905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



FLUX

ZONE	LUMINAIRE LUMENS	% OF LUMINAIRE LUMENS
FORWARD LIGHT	8297	50.3
FL (0°-30°)	690	4.2
FM (30°-60°)	4179	25.4
FH (60°-80°)	3295	20
FVH (80°-90°)	133	0.8
BACK LIGHT	8185	49.7
BL (0°-30°)	689	4.2
BM (30°-60°)	4205	25.5
BH (60°-80°)	3165	19.2
BVH (80°-90°)	126	0.8
UPLIGHT	0	0
UL (90°-100°)	0	0
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



PAGE 8-LTL NUMBER 13721

Appendix C

BUG Analysis of 250W Mongoose Fixture

Mongoose – No Tilt BUG Ratings:

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	2001.3	7.1	9.8
FM (30-60)	7072.7	25.3	34.5
FH (60-80)	4557.6	16.3	22.2
FVH (80-90)	48.4	0.2	0.2
BL (0-30)	1768.8	6.3	8.6
BM (30-60)	3658.3	13.1	17.9
BH (60-80)	1322.7	4.7	6.5
BVH (80-90)	55.3	0.2	0.3
UL (90-100)	0.0	0.0	0.0
UH (100-180)	0.0	0.0	0.0
Total	20485.1	73.2	100.0
BUG Rating	**B3-U1-G3**		

Mongoose – With 15° tilt BUG Ratings:

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	1848.3	6.6	9.0
FM (30-60)	6009.6	21.5	29.3
FH (60-80)	6643.1	23.7	32.4
FVH (80-90)	1146.0	4.1	5.6
BL (0-30)	1513.5	5.4	7.4
BM (30-60)	2756.4	9.8	13.5
BH (60-80)	525.9	1.9	2.6
BVH (80-90)	6.0	0.0	0.0
UL (90-100)	36.5	0.1	0.2
UH (100-180)	1.2	0.0	0.0
Total	20486.5	73.1	100.0
BUG Rating	**B3-U3-G5**		

BetaLED Type V – Independent Results

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	689.5	N.A.	4.2
FM (30-60)	4131.2	N.A.	25.2
FH (60-80)	3283.3	N.A.	20.0
FVH (80-90)	133.9	N.A.	0.8
BL (0-30)	695.1	N.A.	4.2
BM (30-60)	4195.5	N.A.	25.6
BH (60-80)	3145.9	N.A.	19.2
BVH (80-90)	122.0	N.A.	0.7
UL (90-100)	0.1	N.A.	0.0
UH (100-180)	0.0	N.A.	0.0
Total	16396.5	N.A.	100.0
BUG Rating	**B4-U2-G4**		

BetaLED Type V – Independent Results

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	690.5	N.A.	4.2
FM (30-60)	4177.7	N.A.	25.3
FH (60-80)	3296.6	N.A.	20.0
FVH (80-90)	133.8	N.A.	0.8
BL (0-30)	689.0	N.A.	4.2
BM (30-60)	4204.7	N.A.	25.5
BH (60-80)	3163.3	N.A.	19.2
BVH (80-90)	125.5	N.A.	0.8
UL (90-100)	0.2	N.A.	0.0
UH (100-180)	0.0	N.A.	0.0
Total	16481.3	N.A.	100.0
BUG Rating	**B4-U2-G4**		

BetaLED Type III – Independent Results

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	1228.7	N.A.	6.5
FM (30-60)	6300.6	N.A.	33.4
FH (60-80)	4337.3	N.A.	23.0
FVH (80-90)	178.1	N.A.	0.9
BL (0-30)	1076.7	N.A.	5.7
BM (30-60)	3019.8	N.A.	16.0
BH (60-80)	2723.0	N.A.	14.4
BVH (80-90)	26.2	N.A.	0.1
UL (90-100)	0.1	N.A.	0.0
UH (100-180)	0.0	N.A.	0.0
Total	18890.5	N.A.	100.0
BUG Rating	**B4-U3-G4**		

Table 5 - BUG Absolute Lumen Values for Glare

Glare Ratings for Asymmetrical Luminaire Types					
	G0	G1	G2	G3	G4
FVH	10	250	375	750	>750
BVH	10	250	375	750	>750
FH	660	1800	5000	12000	>12000
BVH	110	500	1000	5000	>5000
Glare Ratings for Symmetric Luminaire Types					
	G0	G1	G2	G3	G4
FVH	10	250	375	750	>750
BVH	10	250	375	750	>750
FH	660	1800	5000	12000	>12000
BH	660	1800	5000	12000	>12000

Appendix D

Summary Simulation Results of 250W and 400W Mongoose Luminaires

MnDOT Requirements

			Avg	Max	Min	Avg/Min	Max/Min	# Pts
			0.6-1.1			3:1-4:1		

250W Mongoose Type III-No Tilt

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	1.51	5.17	0.15	**10.07**	34.47	264

250W Mongoose Type III-15-degree Tilt

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	1.29	4.77	0.41	**3.15**	11.63	264

400W Mongoose Type III-Option 1

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	1.55	4.26	0.48	**3.23**	8.88	264

400W Mongoose Type III-Option 2

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	1.47	4.12	0.64	**2.3**	6.44	264

400W Mongoose Type III-Option 3

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	2.06	8.19	0.55	**3.75**	14.89	264

400W Mongoose Type III-Option 4

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	2.36	8.75	0.74	**3.19**	11.82	264

Measured illuminance

			Average	Max	Min	Avg:Min	Max:Min	# Pts
Measured Points	Illuminance	Fc	0.91	1.97	0.26	**3.51**	7.58	280

LED System - AGi 32 Calculations

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min	# Pts
Measured Points	Illuminance	Fc	1.03	1.77	0.31	**3.32**	5.71	264

Appendix E

I-35W Bridge Survey Comments

Appendix E

I-35W Bridge Survey Comments

This appendix contains a sorted listing of text comments provided during a website survey of users of the I-35W Bridge undertaken during the period November 12 - 21, 2008. A total of 489 valid responses were obtained during the survey, though not all volunteered comments.

The bridge contains multiple lighting systems, including the roadway luminaires, an undercarriage lighting system and another system that illuminates two “wave” sculptures on either end of the bridge. As the bridge was opened to the public before all of the operational issues with the latter two systems had been worked out, their operation had been intermittent up to and during the period of the survey. Numerous comments were received on this issue despite the fact the survey was intended to focus exclusively on the roadway lighting system. Those comments and others about the bridge itself are included in an “Unrelated Comments” section at the end of the document.

Also of note are several comments related to the concrete surface of the pavement and a lack of visibility between it and the lane striping. Many of these note this lack of contrast exists during the daytime, which indicates that it is independent from the bridge lighting. These comments are also separated into their own section, “Pavement/Lane Striping Comments.”

Finally, while many comments can be clearly categorized overall as “Favorable” or “Unfavorable,” others may be more difficult to classify or may contain both positive and negative comments in roughly equal measure. Comments of this type are also placed into their own category.

Approximately half of the comments received fall into the overall “Favorable” category, versus about 10% in the “Unfavorable” category and the remainder spread among the other categories. Other than their categorization, the comments are unedited to prevent any further possible errors of misinterpretation.

NOTE: Several comments mention LED lighting and related associations with energy efficiency or environmental benefit. The survey itself made no mention that the bridge lighting system contained LEDs nor did it reference energy efficiency, energy use or any other aspect of costs or benefits associated with LEDs. The survey is very carefully worded so as not to introduce any such bias on the part of the respondents; however, it cannot control information obtained through other avenues.

Favorable Comments:

- I love that it is a white light instead of the standard, yellow/orange street lights. It seems much more natural and it is easier to see the details of the roadway.
- Love the new lights on the bridge. Much brighter and more consistent lighting across the bridge. Why can't the highways be lighted like this?
- I like them and feel any support other than the general consumer for more energy efficiency products will be very helpful. Thank you for installing them on this bridge.

- It seems much brighter and the lights make the bridge more attractive.
- The lighting is great! It’s bright and makes it very easy to see.
- The lighting is GREAT! As someone who wears glasses and has trouble seeing while driving at night, the new, bright lighting is a great thing.
- The LED lighting makes the bridge a treat to drive across as opposed to the typical freeway lighting I'm used to. It's "cool" coloration really makes things easier to see and less harsh on the eyes. I wish more of this lighting was used on the approaches.
- 1st time over at night was very impressed with the lighting; seemed brighter than other bridges and created an impression of better visibility
- Expand this lighting to other areas in the Twin Cities area - its GREAT!
- It is beautiful.
- The lighting is very calming and nice.
- Love it, and I hope the LEDs provide enough energy savings to justify this lighting installation on all highways.
- I love the Bridge and the Design of the lighting Plus it is Eco Friendly
- I like the lighting and the bridge. I tend to squint at some lighting street lighting and I noticed that the lights on the bridge did not bother my eyes or make me squint.
- Bridge is great. Lighting is good and not distracting, which I assume to be one of the more important parts of lighting a bridge. In other words, subtle and well-lighted.
- It feels very "high tech". The bridge has a nice clean feel to it as you pass over it. The blue accent light adds to this feel, but ultimately the overhead lights make the driving experience good.
- Lighting seems very even across and along roadway. While glare is better with these lights, it could still be improved. Color change indicating "the river crossing" is a nice touch. Color much better than with Sodium lights.
- Roadway lighting works very nicely. I find the colored under-lighting very entertaining and look forward to seeing the variety of displays, for example Maroon & Gold for Gopher events, Purple and Yellow for Vikings, etc. Thank you.
- I really love the new LED lighting. I wish we could replace all of our highway lights with those of this type!
- It is very attractive and it pleases me whenever I drive over the new bridge. I feel I have a better view of the bridge, the river and the cityscape.
- I like the color - it's like a daylight color.
- The look very nice from the adjacent bridge.
- It’s like high definition lighting when I cross at 2:45 am every morning.
- The energy efficiency of the LED light fixtures is terrific. The fixtures produce more light then I would expect from this type of luminaire. LED technology will continue to improve but these are definitely as good or better then any other LED fixtures currently available.
- I actually like the "difference" in lighting on the bridge, as it enhances the experience of being ON the bridge as opposed to the road and/or approaches. Eye catching, yet without being distracting.
- I'd like to add that the lights are great because of their energy efficiency.

- The light seems to be more evenly spread, instead of the lighting in other areas which alternates from bright to shadow to bright to shadow...
- It’s about time we utilize this technology.
- It has a much more calm feeling to it than the harsh orange-ish color of other lights and has a much more natural look. It also has less contrast to other dark colors at night making it easier on the eyes.
- Looks great. Love the bridge. Fantastic work! Thank you!!!
- Love it! I work at the Guthrie and it's absolutely gorgeous from here.
- LED is energy efficient also. A win-win.
- I was pleasantly surprised at the coverage of the new lights. There don't seem to be big gaps of darkness. I also like the new lights because they don't shine upward, contributing to night time light pollution.
- LOOKED GOOD TO ME AND I AM IN THE ELECTRICAL CONSTRUCTION BUSINESS
- I think it is a great system. I hope Mn/Dot uses it in other locations in the state.
- It is great in the center of the bridge but it gets a bit dark on the outer edges. Overall I would say the LED lighting is a success and a plus for the environment.
- The first time that I went over the bridge at night, I was struck by the noticeable difference in the lighting. It was much softer than any other type of highway/street lighting than I'd ever experienced. For me it presents a sense of calm for whatever that's worth.
- Yes, I like the new lighting. However, I am sorry to see that the blue lighting for the (wave) monuments on both ends of the bridge failed after less than two weeks and have not been repaired.
- Just that it looks really nice!
- I think the lighting fits the environment of the new bridge, use of it elsewhere would depend on the location.
- I could read the signs on the bridge, the lighting is streamlined and not on the edges of the bridge - this makes the bridge design less cluttered.
- It's great, and I love using the bridge.
- I feel much safer driving over the new bridge than I did over the previous bridge...even with the "hump" that prevents seeing all the way across as one begins crossing.
- I really like it. It makes everything look cleaner and overall brighter.
- Just a fantastic Bridge all around!
- Is it LED? I hear this type of lighting is cheaper to maintain/pay for--I think that we should be looking at places to be friendlier to the environment and if it is cheaper--it is a plus.
- I think the use of the new lighting makes it a more appealing structure as well as very functional. I can't wait until the bike lane is constructed below the surface to allow for crossing at the same point in the same lighting.
- With the additional lanes and the updated lighting it is easier and safer for me to travel over the bridge in the early mornings. Thanks and keep up the great work.
- I like the lighting on the new bridge

- Lights are bright and soft to me. Seems to be a bit dimmer from a long distance. What I'm trying to say is the lights focus seems more isolated to a certain focal point and not a wide angle.
- It is well lit, yet it doesn't interfere with my night vision, I crossed it several times on my motorcyle, and most lights glare on the fairing and helmet visor, but it seemed to be well thought out.
- The light seems to be more evenly distributed than light from bulb-type luminaires.
- I love the new lighting on the bridge; the bridge lighting is perfect; there is a sense of security.
- The lighting looks really modern and goes well with the design of the bridge. Also, if they are more energy efficient and cost effective than their alternatives, that is especially beneficial.
- Easier on the eyes for driving, and very pleasant for the overall appearance of the new bridge.
- I like it, you are conscious of the surroundings, of passing over the Mississippi. It feels more open and less claustrophobic. Before, it was like traveling through a tunnel of glaring light.
- I like that it is energy efficient. I wish it was less "blue."
- I like it makes it easy to see the road bed at night.
- I am very pleased with the lighting and the overall appearance of the bridge and the approaches and ramps to and from the bridge. Again, though, the lights are great.
- The lighting looks and works great. Keep it up.
- Very bright, crisp and clean. Looks great.
- I am aware that the new lighting uses LED technology. I feel that whatever complaints that people have is overshadowed by the obvious advantages of the LED lighting.
- It feels like there is more space on the bridge.
- It's a little different, but I like it. And I believe they are efficient LED's. Which only make the case stronger for their use.
- The lights are much better than the other style. It's like the difference between xenon headlights and regular headlights. Good work!
- I like the WHITENESS of the light, as opposed to sodium lights, which I find difficult to drive under. How is the efficiency when compared to sodium lights? Is this a green lighting scheme?
- Light output is surprisingly even compared to most sodium roadway lights. It may appear slightly dimmer on average, but if it's truly saving energy, that's a good thing. More of these should be installed. As public gets used to them, perceived disadvantages will disappear.
- I think that a new bridge calls for new, state-of-the-art lighting which enhances safety and visual appeal.
- I like the new look.
- The lighting on the sides of the bridge should stay on for a better look overall but the roadway lights are great.
- Seems so weird to have the "old" lights then the blue diamond style lights. It's so lit up! Still wonder what the decorative squiggle things are on either end...were the old ones broke?
- I really like the lights. I thought it was for effect of going over the water with the cooler color light. It would be nice to see more lighting like this. I heard the bridge was supposed to be lit like a rainbow or blue, but have not seen this...is this going to happen? All and all it is beautiful.

- It seems softer and might even take some of the "edge" off typical lighting, also, it might not be as harsh.
- The LED lighting permits a pleasant and comfortable driving condition that is easy on the eyes. I would like to drive under this type of lighting more often. Moreover, it looks much nicer than sodium bulbs.
- When I first saw the lights and location I thought that there would be a lot less light on the bridge, but it really is quite effective and equivalent to driving on other stretches of lighted freeway.
- Only went over the bride once at night. The lighting was fine ... and better than other bridges.
- The first time I drove across the bridge one of the first things I noticed is how easy it is to see the road and lanes on the bridge because of the great lighting.
- I feel it is the safest bridge in the country.
- I think the lighting is adequate, and would save taxpayers a lot of money in the long run if they convert all the sodium vapor lighting on the roadways.
- It's aesthetically pleasing, blends in with the surrounding concrete surface, and makes it so much of a pleasure to drive on the bridge! I urge PNL to consider such lighting in more of Mid-West. Keep it up!
- THE FIRST THING MY HUSBAND AND I COMMENTED ON WAS THE GREAT LIGHTING!!
- Great Lighting.
- I would hope the LED lights use less energy than other lights. It seems that the lights have a more broad broadcast than other lights, which is a good thing. I would call the lights less light on surfaces, but the coverage seems more even. Driving over the bridge, with rain the LED lights where much better than the orange lights normally used.
- I like the softer, yellowish lighting. I also think the guard rails are too low, and perhaps some lighting on them would provide additional safety.
- GREAT IMPROVEMENT.
- The color temperature is much more pleasing to look at than typical "orange" streetlights. It also makes the illuminated surroundings look the "right" color, rather than bathed in an orange glow.
- I like the LED lighting on the bridge, I wish all road lighting was LED gives a cleaner bright look to the road and more efficient in the end.
- I like them. Hopefully they are energy saving and can be put on the rest of the system!!!
- The lights illuminate the whole width of the bridge without leaving dark spots.
- I like the new lights. The light is much easier on the eyes. After I saw that there was a survey I made note of the lights before I filled it in.
- It seems good but I am not an Engineer so I hope you talk to a few of them as well!
- It looks great. Things seem more crisp under the new lighting, and doesn't have that dirty yellow light.
- Plan and simple it easy to see the roadway very clearly even in rainy weather with the lighting.

Unfavorable Comments

- I like that the bulbs are more efficient, but they need to be brighter.
- More light.
- The lighting could be a little brighter on the roadway.
- The one time that I have driven across the bridge at night, I almost felt blinded by the intense lighting on the bridge as compared to the approaches.
- The lighting seems shadowy.
- Seems a bit low.
- The far right northbound lanes seem dim and perhaps lights on the outside of the bridge is also necessary. The lanes immediately adjacent to lights are fine but the further away you are the less impact they seem to provide although I'm sure they are supposed to be lighting it.
- Can use more lighting.
- Compared to other bridges, this one seemed to dark for me. Not sure if I am just used to the bright orange lights or what. But I did like the lighting at either end of the bridge.
- It’s distracting to have the color change over the bridge. I like having the lights in the center to look out at the river but could you to have a color that match that of sodium vapor. I googled the bridge and lights (as I assumed they were new) and found the BetaLED PDF. I like everything except the harsh white. I would put my two cents on putting in the 3500K color LED's. Keep the white lights under the bridge, but for driving a yellowish light would work better for the driver.
- Seems like the spacing of light poles is not adequate to maintain a consistent level of light (*e.g.*, midway between light poles is a lower intensity of light)
- Maybe make it a little brighter?
- It seems somewhat too bright (more than absolutely necessary) which creates some glare.
- I think more lighting is needed, and not only on the bridge but many other places around the system, spend more money on lighting dark areas and less on metering ramps that don't need to be metered.
- I travel on it at 6 a.m. during the week. It seems like its indirect lighting? And seems darker then it should be especially when it is raining, but maybe I just need to get used to it.
- It seemed that I went from very bright lighting to ultra-dim lighting and that caught me up short and made me slow down and feel less sure of my driving and what was around me. I was uncomfortable. The decorative lighting was lit the first time, but not the second time I drove over it. I WANT to love the bridge, but feel uncomfortable with it at night.
- It lights up the inner lanes much better than the outside. Not so good for those on the outside lanes. The biggest problem with the bridge - it has no class. It looks like the cheapest quickest put together bridge you can find. It's ugly.
- Color of the light and the surroundings seemed odd.

Neither Favorable Nor Unfavorable, or Contain Aspects of Both

- I am curious how the light will reflect off the Snow.
- I'm still getting used to the blue color of the lighting.
- The white lighting is good for seeing better, but it's so bright that it's a bit of a shock to the eyes. Just tone it down a bit & that will be fine. I'm wondering how the white light will be perceived during fog and while it's snowing...
- I hope it does not provide too much light pollution into space
- It seemed dim to me, but its illumination is actually better than other lighting. I think it just feels dim.
- It's just enough to allow one to see the skyline view and also see other motorists as they are passing.
- The change of color (white as opposed to yellow) is noticeable but not necessarily distracting.
- It looks whiter than the lighting on the neighboring 10th Ave bridge. I hate the decorative lighting on the side in blue or turquoise.
- Did not notice the lights, only the poles, and they looked fine.
- Its fine! Why would anyone over think it! As long as it does not make it fall down, don't question it.
- More lighting on the bridge roadway on a bridge this large is welcomed. The approach gateway lighting is weak at each end for a bridge this large.
- The more the better, I hate dark streets/dark bridges.
- I like when the water design is lit. It seems just a bit dark but otherwise all the lanes are visible.
- It prompts one to slow down and get their bearings.
- I noticed that they must be LED lights by the bluish tint. I was wondering if the middle centerpiece that is sometimes lit up is supposed to symbolize the water below?
- It should be dark-sky approved lighting, and minimize light dispersion into the sky and to the sides.
- I like that the light standards are in the center of the bridge thus helping to differentiate the bridge itself from its approaches.
- I think that the fact that I haven't noticed any problems with the lighting , indicates that for me the lighting on the bridge works. I don't notice any difference between the approaches and the bridge itself.
- The lighting is different then I am used to seeing, seems darker then normal but that may be because all other lighting that we drive under is the harder glaring light from the old lamps. I do like it but I believe the light should have been alternated from center to outside with a few more lights involved; the outside lanes appear much darker.
- I think it is beautiful and well-lit from the pictures I've seen.
- More lighting of the same type can be installed, perhaps on the sides. I have bad night vision.
- I actually forgot that LED lighting was being used on the bridge until I got this survey.

- Besides the color of the light, the big difference seems to be the brightness between the darkest spot between the lights and the brightest spots under the lights. The light doesn't seem to fill the dark spots as well as the traditional lights. On the other hand, the lights seem brighter so it could be an illusion. The bridge is very small relative to the length of a typical drive, so it would be worth having these lights over longer distances and studying how people feel about them.
- The lighting seems some what lower in the outer lanes. This maybe to avoid having a huge glow overpowering drivers or a design flaw? The clarity is better than the old fixtures. I still think there should be some bright or directional lighting for outer lanes.
- The left lane is much brighter than the right lane, but they are much easier on the eye's, and don't seem to be as harsh as regular lights.