PHASE 1: MOGUL BASE LED REPLACEMENT LAMPS
Report Summary

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A Report of BPA Energy Efficiency's Emerging Technologies Initiative

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This report summary was condensed
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Abstract

Mogul base LED replacement lamps are being marketed as equivalent replacements for incumbent HID lamps. LRC characterized the HID marketplace and conducted photometric and electrical testing on 18 mogul base LED lamps to inform the DesignLights Consortium (DLC) on these products' performance in consideration of them being added to the Qualified Products List (QPL). LRC found that 4 of the 18 lamps met the minimum tested DLC QPL criteria for retrofit kits when the lamps were placed in area lighting and roadway luminaires. The wall pack and high bay luminaire combinations did not meet the applicable tested retrofit kit criteria. Additional testing will be conducted in Phase 2 of this project to better inform the DLC on these lamps' performance.

This report summary includes an Executive Summary of 2 pages, a main body of 15 pages, and an Appendix.

An Emerging Technologies for Energy Efficiency Report

The following report was funded by the Bonneville Power Administration (BPA) as an assessment of the state of technology development and the potential for emerging technologies to increase the efficiency of electricity use. BPA is undertaking a multi-year effort to identify, assess and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is the world's leading center for lighting research and education. Established in 1988 by the New York State Energy Research and Development Authority (NYSERDA), the LRC has been pioneering research in energy and the environment, light and health, transportation lighting and safety, and solid-state lighting for more than 25 years. Internationally recognized as the preeminent source for objective information on all aspects of lighting technology and application, LRC researchers conduct independent, third-party testing of lighting products in the LRC's state of the art photometric laboratories, the only university lighting laboratories accredited by the National Voluntary Laboratory Accreditation Program (NVLAP Lab Code: 200480-0). LRC researchers are continuously working to develop new and better ways to measure the value of light and lighting systems, such as the effect of light on human health. The LRC believes that by accurately matching the lighting technology and application to the needs of the end user, it is possible to design lighting that benefits both society and the environment.

Acknowledgments

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Project Background

In December 2013, Washington State University Energy Program (WSU) / Bonneville Power Administration (BPA) requested that the LRC create a work plan for market characterization and performance testing of mogul base LED replacement lamps to support cost-effective LED retrofits for multiple types of lighting applications, particularly high bay and decorative post top, also including wall pack, yard light and cobra head.

The LRC proposed that the project be broken into three phases. The first phase (the subject of this report) consisted of market characterization and pilot photometric testing of representative mogul base LED lamps alone and in luminaires, in order to develop a testing plan to ensure application equivalency. The second phase, in progress, consists of additional performance testing of mogul base LED replacement lamps in representative luminaire types and analyses. The third proposed phase would consist of field demonstrations to determine real-world performance and acceptability.

Six tasks were completed in Phase 1. This report describes results for each task.

- **Task 1**: Market characterization of installed luminaires with mogul base sockets by application type and wattage.
- **Task 2**: Market survey of available mogul base LED replacement lamps, mogul base LED replacement retrofit kits, and application-relevant LED luminaires.
- **Task 3**: Literature review of projects, pilot studies and demonstrations implementing mogul base LED replacement lamps.
- **Task 4**: Specifier survey to determine specifier concerns and relevant luminaire performance characteristics for various lighting applications, to support the development of a performance testing plan.
- **Task 5**: Pilot testing of select mogul base LED replacement lamps and representative luminaires to further develop performance testing plan. (purchase of up to 18 lamps and 6 luminaires)
- **Task 6**: Write report, including a lamp testing plan for Phase 2.

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Executive Summary

Task 1: Mogul Base Socket Market Characterization

- Mogul base high intensity discharge (HID) lamps are used in:
    - Exterior lighting: roadways (30% of sockets), parking lots (20%), building exterior (14%),
    - Interior lighting: commercial interior (24%), industrial (10%), misc. (2%).
- The 144 million mogul base sockets in the US comprise 2% of all lamp sockets in the US.
- HID lamps used 26% of lighting energy in the US in 2010, and most HID lamps over 150W have mogul bases. The only lamp type that consumes more energy in the US is linear fluorescent. Retrofits from HID to LED would likely yield energy savings, concentrated in a relatively small number of units.
- Mogul bases are frequently used for high wattage (150W to 1000W), high light output HID lamps, which may pose a heat management challenge for mogul-base LED replacement lamps.
- Other types of replacement lamps [pulse start metal halide (MH), T5HO, HPT8] are mature, highly efficacious technologies and pose a challenge for penetration of mogul base LED replacement lamps.
- Labeling and lists are important drivers for incentives, and thus replacement opportunities.
- In commercial and industrial applications, the majority of the incumbent HID technology is comprised of MH, rather than poor color rendering HID sources such as high pressure sodium (HPS) or mercury vapor (MV). This implies that white light and improved color rendering (which LED lights can deliver) are preferred for commercial and industrial applications.

Task 2: Mogul Base LED Market Survey: Lamps, Kits & Luminaires

- The lighting characteristics for about 200 mogul base LED replacement lamps, 760 LED retrofit kits and 90 integral LED luminaires were summarized during Q1 2014.
- On average, most mogul base LED lamps on the market in Q1 2014 were relatively low power (average 54W across all products, with a few products over 100W), while integral LED luminaires for comparable applications were available over a broader range of wattages (average 100W, with a few products over 200W).
- Among the compared products, integral luminaires have lower average rated efficacy compared to bare mogul base LED lamps. However, in Task 5 the efficacy of the mogul base LED lamps decreased when installed in luminaires, as expected.
- The average price of mogul base LED lamps was very roughly 30% of the average price of integral LED luminaires. However, pricing information was not readily available for many products, and this ratio may be different if volume pricing is used.
- Detailed specification information was not found for many of the products.

Task 3: Mogul Base LED Replacement Lamp Case Studies

- Many of the reviewed case studies for mogul base LED replacements focus on energy savings and economics. Most of these studies lack quantitative lighting information such as average illuminance values, uniformity ratios, and color metrics, so specifiers may not be able to determine if the replacements are indeed equivalent to or better than the original lighting.
- In some case studies, the illuminated area was over lit by the incumbent lighting technology. Energy savings attributed to the replacement LED technology may largely be due to reduced lighting levels. A sensitivity analysis comparing the LED replacement lamps to incumbent HID systems when both are designed to meet target light levels would be very helpful to specifiers, but is absent from most case studies, including those in this report.
- Several case studies reported payback periods of less than 5 years.
- No case studies included comprehensive evaluations conducted by an independent third party.
- Most case studies are based on manufacturers' claims and/or municipal publicity. Until comprehensive quantitative and qualitative evaluations are published, caution is warranted regarding these lamps' suitability as equivalent replacements.

Task 4: Specifier Survey

- An online survey was sent to about 5000 contacts in February 2014. Of 304 respondents, 191 were not employed by lighting manufacturers or their agents. 22% of respondents are consulting engineers, 10% are lighting designers, 7% are building owners or managers and less than 1% are architects.
- About 30% of the non-manufacturer respondents had evaluated, specified or installed mogul base LED lamps in the past 12 months.
- Four luminaire types were listed most often: flood lights, decorative post top, outdoor area lights and high bays. (Three of these applications were covered in Task 5 testing, however decorative post top luminaire tests were delayed by late delivery from the luminaire manufacturer.)
- "Cylinder" and "half-cylinder" shaped mogul base LED lamps were evaluated or specified more than any other types.
- Light output, intensity distribution, and size questions were ranked as the most important considerations for mogul base LED lamps.
- The LEDtronics brand was mentioned most often, followed by Philips, GE, Light Efficient Design, Bbier, Toshiba, MaxLite and Global Tech. Philips, GE and Toshiba do not manufacturer mogul base LED lamps so it is unclear why these brands were mentioned.
- Most respondents were located in the US from 19 different states.

Task 5: Mogul Base LED Replacement Lamp Test Results

Although most of the lamp-luminaire combinations tested did not meet the current DLC QPL performance criteria for retrofit kits, a few passed.

- 57% (4 of 7) of the area light and roadway lamps met the tested DLC criteria for retrofit kits for these applications.
- No tested high bay or wall pack lamps met the DLC criteria for retrofit kits for these applications.
- The luminous efficacy criterion is the hardest criterion to meet for these lamps. Less than 30% of the tested mogul base LED lamps met the DLC efficacy criteria for retrofit kits for approved applications.
- The measured luminaire efficacy for the yard light combinations were among the highest results measured.
- Life testing was not a part of this research program and no conclusions are being drawn as to the lifetime performance of these products.
- All of the measured lamp-luminaire combinations passed the DLC total harmonic distortion (THD) criterion except for the yard light containing the Evluma lamp (YL4).
- Phase 2 will focus on testing additional lamps that are installed by bypassing the magnetic ballast. Also, another sample of LED-8030M42 (109463) will be purchased and tested in Phase 2, since the sample tested in Phase 1 would not stabilize.

Task 6: Phase 2 Test Plan

Further tests will be conducted.

- Due to concerns about persistence of energy savings, only LED replacement lamps that bypass the ballast will be tested; "plug and play" products using the existing ballast will not be tested.
- HID lamps will be installed in converted sockets, to address concerns about savings persistence and safety.
- More products will be tested to DLC retrofit kit specifications, including more samples of products that did not stabilize in Phase 1.
- To address concerns about light distribution at various mounting heights, Luminaire System Application Efficacy (LSAE) calculations will be conducted at various mounting heights.
- To address luminance equivalence, perceived brightness will be calculated and compared to HID.
- To address concerns about performance degradation at high temperature, a few products will be tested at high temperature.

Task 1: Mogul Base Socket Market Characterization

Background

Task 1 describes: 1) which types of lamps have a mogul base, 2) the size of the market in the USA, and 3) relevant sectors (e.g., industrial, outdoor, etc.) for this technology.

Mogul Base Lamps

Mogul ("E39/E40") screw bases are larger than medium ("E26" or "Edison") screw bases. Mogul base sockets are used mostly for high-intensity discharge (HID) sources, usually greater than 175 W and less than 1650 W. With some exceptions, medium screw bases are standard for HID lamps less than 150 W. As shown in the following figure, the average wattage for most types of HID lamps is high enough that mogul bases are more common than medium bases.

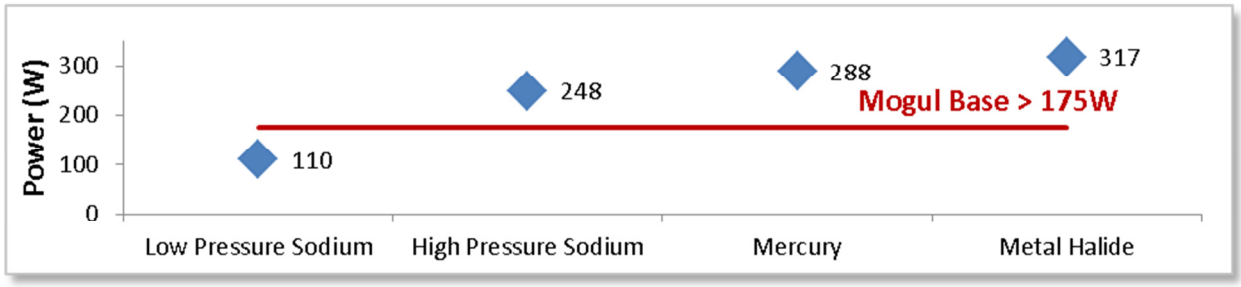

Figure 1: Average Wattage of HID Lamps in the USA. (Adapted from US DOE/Navigant 2012[1])

The average power for incandescent, halogen, and compact fluorescent (CFL) lamps in the USA is less than 150 W, so any mogul base non-HID lamp types are out of scope for this report.

Market Size and Energy Impact of HID Lamps

There are 144 million HID lamps in the USA, representing 2% of the installed lamp inventory. While the number of HID lamps is small compared to other types of lamp, HID lamps have a large impact on energy use. The figure below shows that annual HID energy use (183 terawatt-hours ([TWh]) is second only to linear fluorescent lamps (294 TWh). HID lamps use 26% of the annual lighting energy in the US.

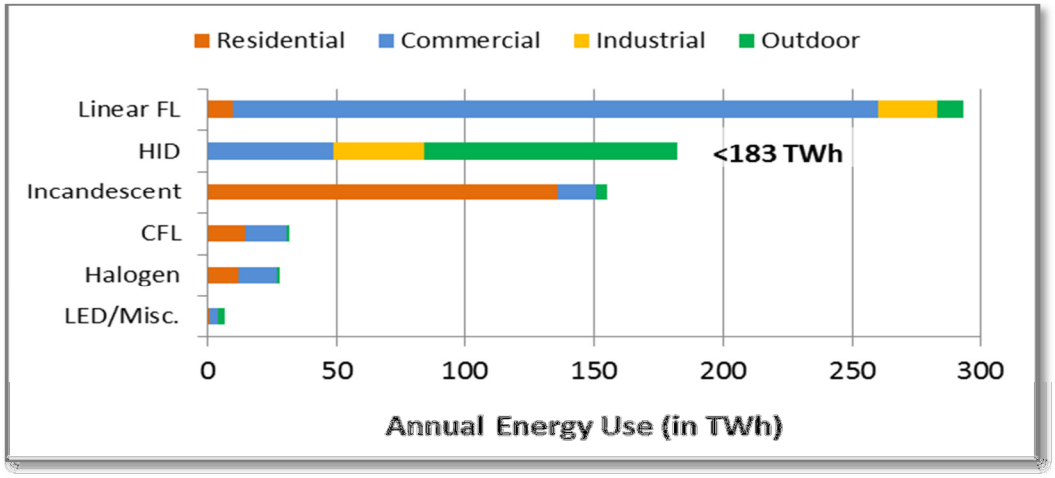

Figure 2: Estimated US Energy Use (2010) by Lamp Type and Sector. (Adapted from US DOE/Navigant 2012)

[1] U.S. Department of Energy/Navigant Consulting. 2012. *2010 U.S. Lighting Market Characterization*.

Sectors Using Mogul Base Lamps

In the USA, most HID luminaires use either MH or HPS lamps (Figure 3). As shown below, HPS is mostly used in outdoor environments. MH is used in commercial, industrial, and outdoor sectors. Low pressure sodium (LPS) and mercury (MV) lamps do not make up a significant portion of the incumbent HID market.

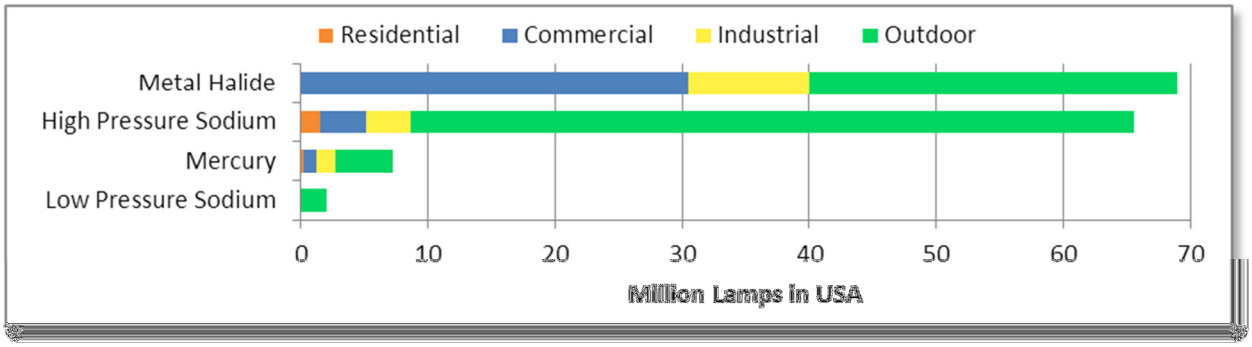

Figure 3: HID Lamp Inventory by Sector and Lamp Type. (Adapted from US DOE/Navigant 2012)

Figure 4 below shows use of HID lamps in the US by sector. About 65% of HID lamps are used in outdoor applications such as roadways, parking lots and building exteriors. Commercial interior applications comprise 24% of the US HID market, and industrial applications comprise 10%.

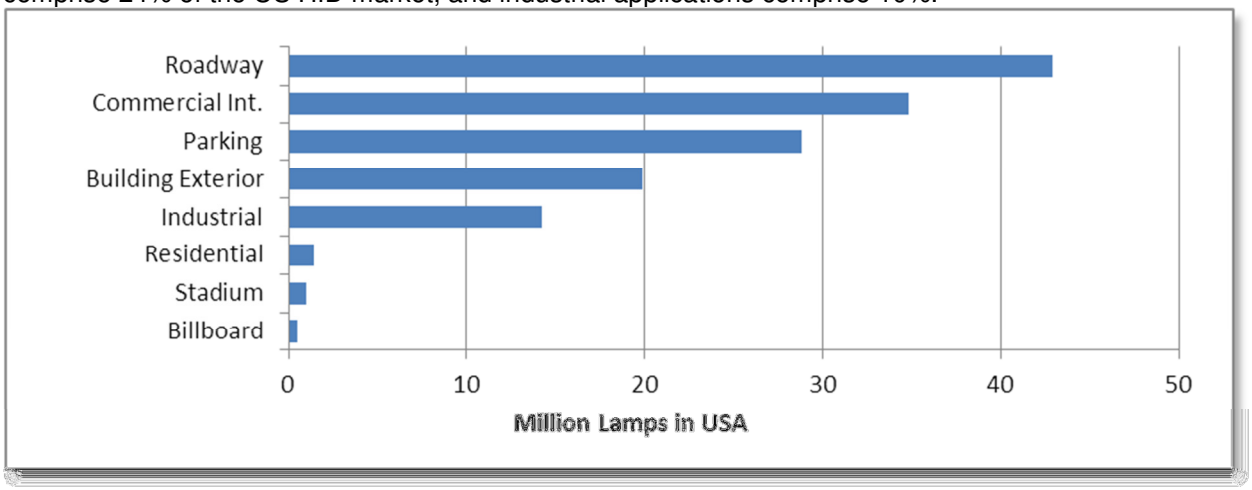

Figure 4: HID Lamp Inventory by Application Type. (Adapted from US DOE/Navigant 2012)

Based on this information, for Task 5 testing, the LRC used roadway, high bay, parking, and building exterior luminaires specified by DLC for testing retrofit kits.

Task 2: Mogul Base LED Market Survey: Lamps, Kits & Luminaires

Background

For Task 2 the LRC conducted a market survey, searching for product specifications for mogul base LED replacement lamps, retrofit kits and a sample of integral LED luminaires to create a product matrix snapshot of the marketplace as of Q1 2014. The product matrix was used to select 18 lamps to be purchased for photometric and electrical testing in Task 5.

Methods

LRC used 3 resources to search for mogul base LED replacement lamps: product advertisements in lighting trade journals from Q3 2013 – Q1 2014; the DOE Lighting Facts website; and Google.
LRC created a spreadsheet for each product type (replacement lamp, retrofit kit and integral luminaire). Within each spreadsheet, a template was created for the specifications that were sought for each product, as summarized in Table 1 showing how often (%) the required information was listed for each product.

Most mogul base replacement lamps include a driver within the lamp assembly, while some products include an external LED driver. In comparison, retrofit kits are hardwired into the luminaire housing.

Table 1: Product characteristics sought for mogul base LED replacement lamps.

	Specification	Information available for mogul base lamps %	Information available for DLC listed retrofit kits[2] %	Information available for unlisted retrofit kits %	Information available for integral LED luminaires %
DLC Related Criteria	DLC Qualified	6%	100%		89%
	Manufacturer	100%	100%	100%	100%
	Model No.	100%	100%	100%	100%
	Brand Name				
	Warranty	81%	14%	57%	80%
	Lifetime	94%	12%	90%	86%
	Total Harmonic Distortion	14%	13%	17%	0%
	Light Output - Rated	95%	13%	88%	99%
	Efficacy - Rated	80%	13%	67%	99%
	Wattage - Rated	99%	13%	88%	99%
	CCT - Rated	96%	13%	90%	89%
	CRI - Rated	78%	13%	81%	75%
	Power Factor - Rated	56%	13%	67%	0%
Additional Information	Dimmable	31%	-	24%	2%
	Claimed Lamp Equivalent	67%	-	45%	61%
	Beam Distribution	73%	-	71%	7%
	Dimensions (inches)	90%	-	74%	51%
	Weight (lbs.)	49%	-	43%	28%
	ANSI Base Nomenclature	94%	-	57%	-
	UL	36%	-	24%	8%
	RoHS compliant	58%	-	48%	19%
	LM-79, 80, 82	12%	-	10%	25%
	TM 21	4%	-	2%	0%
	IP Rating/NEMA Enclosure	29%	-	45%	22%
	Cost ($US)	28%	-	19%	57%
	Recommended Applications	76%	-	14%	94%

For luminaire-based testing, the LRC selected luminaires approved by DLC to test retrofit kits for mogul sockets (Table 2). The preapproved wall pack luminaire is only available with a medium base socket so a similar wallpack with a mogul base socket was selected. Except for the high bay luminaire, which was only preapproved in a 400W HPS version, all purchased luminaires were 150W HPS or MH.

[2] Based on downloaded DLC QPL spreadsheet.

Table 2: Preapproved DLC luminaires purchased for Phase 1 testing.

Category (Pre-Approved luminaire types)	Pre-approved Manufacturer / Model Number	Socket type	Purchased for testing
Cobrahead	GE M250R2	Mogul	M2RC_15_S_0_A_1_G_MC2
Shoebox	Lithonia KAD Contour Series	Medium for 70-150M. Mogul for ≥175M, 70-400S	KAD 150S R3 TB SPD04 LPI
Outdoor Decorative - Acorn	GE Patriarch	Mogul standard where lamp is available in mogul (Medium otherwise)	GE PTRX-15-S-1-A-1-1CB-A-BLCK (delivered July 2014)
Outdoor Wall-Mounted Area Luminaires	Lithonia TWF1 100S	Medium	Cooper Lighting WPS15C with a mogul base
High-Bay Luminaires	Lithonia THD 400S A15 TB	Mogul base	THD 400S A15 TB LPI

LRC used the lamp brands mentioned on the specifier survey (see Task 4) and three characteristics from the replacement lamp spreadsheet to down select the lamps. First, the mogul base LED lamp had a claimed lamp equivalency equal to 150W HID or higher (or 400W HID for the high bay). This characteristic was used (rather than light output) because the claimed lamp lumens varied greatly, and most lamps that claimed equivalency did not produce rated lumens equivalent to a 150W HPS or MH lamp. Second, the lamp dimensions had to be smaller than the interior dimensions of the selected luminaires. Most luminaire manufacturers do not specify the interior dimensions of their luminaires, so LRC contacted the manufacturers directly to obtain this information. Finally, the recommended application for the lamp was applicable to the luminaire selected (e.g. a base-down only lamp could not be used in a horizontal socket).

Results

More detailed versions of the following summary tables are included in the Appendix.

Replacement Lamps

LRC found 194 mogul base LED replacement lamps by the end of Q1 2014. Several of these lamps imply that they are DLC listed, as a DLC logo appears in the specification literature. However, DLC does not have a mogul base screw-in lamp category.

Most of the mogul base LED lamp manufacturers include basic lamp information required by specifiers such as power, light output, efficacy, and physical dimensions as well as other criteria required by DLC such color correlated temperature (CCT), color rendering index (CRI), and lifetime. However more than 30% of the products did not include information regarding power factor (PF), total harmonic distortion (THD), claimed lamp equivalency, dimming, or weight.

Table 3: Summary of mogul base LED lamps as of April 2014.

# of Models	Avg. Claimed HID Wattage Equivalency	Avg. Rated Power (W)	Avg. Rated Light Output (lm)	Avg. Rated Efficacy (lm/W)	Avg. Rated CCT (K)	Avg. Rated CRI	Avg. Lifetime (1000 h)	Avg. Cost ($US)
194	**207**	**54**	**5064**	**91**	**4640**	**77**	**55**	**$186**

About 5% of the products were listed on the LED Lighting Facts web site[3]. About 10% of the products indicated that they include a fan for active cooling. About 5% of the products indicated that they were not recommended for use in enclosed luminaires. About 4% of the products indicated that they had a universal orientation position.

While some products included built-in surge protection, several products came with a recommendation that an additional surge protection device be installed; for a few exterior installations this additional surge protection device is required to maintain the warranty.

[3] LED Lighting Facts. http://www.lightingfacts.com/

For some manufacturers, the specification sheet (in PDF format) sometimes conflicted with the technical specifications web page in terms of product information, such as light output and/or product dimensions.

Most products were eliminated from testing consideration due to lack of information (claimed lamp equivalency or lamp dimensions) or their size; many of the lamps that claimed to be equivalent to 150W HID lamps were too long to fit into the luminaire.

Retrofit Kits

LRC found 721 retrofit kits listed on the DLC QPL list as of April 2014, as shown in Tables 4 and 5. A few products appear to have a screw-in mogul base.

Table 4: DLC QPL-listed retrofit kits as of April 2014.

High-Bay Luminaires	Large Area & Roadway Luminaires	Area & Roadway Luminaires	Outdoor Decorative Luminaires	Outdoor Wall-Mounted Area Luminaires	Blank	Total # of Models
4	30	620	57	8	2	721

In addition, LRC found 41 products not listed on the DLC QPL, marketed as retrofit kits from various manufacturers, as shown in Table 5. Seventeen of these products come with an E39 or E40 mogul base, an additional 7 products are available with a medium (E26) base or E39 mogul base.

Table 5: Characteristics of retrofit kits as of April 2014.

DLC Listed?	# of Models	Avg. Rated Power (W)	Avg. Rated Light Output (lm)	Avg. Rated Efficacy (lm/W)
Yes	721	89	7296	81
No	41	76	6546	83

Luminaires

In order to characterize the market in which these products compete, LRC included 88 integral LED luminaires in its review focusing on luminaires with “lower” price points and for the following applications: area and roadway lights, decorative streetlights, yard lights, wallpacks, high-bays, as well as canopy / parking garage lights (Table 6). Some of the products were listed on the DLC QPL.

Table 6: Sample integral LED luminaire characteristics as of April 2014

# of Models	Avg. Rated Power (W)	Avg. Rated Light Output (lm)	Avg. Rated Efficacy (lm/W)	Average Cost ($US)
88	100	8604	81	$576

Among the compared products, integral luminaires have the lowest average rated efficacy. However, the efficacy of the lamps and retrofit kits will decrease when they are installed in a luminaire. As expected, the results from Task 5 show this effect.

This data suggests that most mogul LED lamps on the market in Q1 2014 were relatively low power (average 54W, with a few products over 100W), while integrated LED luminaires for comparable applications were available over a broader range of wattages (average 100W, with a few products over 200W)

Task 3: Mogul Base LED Replacement Lamp Case Studies

Background

This section summarizes case studies where mogul base LED lamps were used to replace incumbent HID lamps. Of 15 case studies found, five described acorn streetlights, and four or five described high bay installations. Five claimed payback of less than 3 years, and at least five commented on a preference for the whiter color of LED's compared to the incumbent. Most of these case studies were posted on manufacturers' websites, except for Differential Energy Global. A description of each case study is included in the Appendix, with a reference website.

Ideally, case studies should include comprehensive quantitative and qualitative evaluations conducted by an independent third party. Most of the case studies are based on manufacturers' claims and/or municipal publicity. Until comprehensive quantitative and qualitative evaluations are published, caution is warranted regarding these lamps' suitability as equivalent replacements.

Table 11: Demonstrations and Case Studies

Brand	Application	Old Lamp Watts	New Lamp Watts	Notes
Differential Energy Global	Acorn streetlight	70, 100	~70	Wattage is adjustable up to 148W. Broad rollout is waiting for a lower wattage product.
EIKO	Acorn streetlight	175	30, 45	Payback 3.5 years
EIKO	Acorn streetlight	150	30	Payback 2.2 years
Evluma	Security fixture	100	50	Perceived brightness of white light was well received. A new mounting bracket made space for the long lamp inside the luminaire.
Evluma	Acorn streetlight	250	50	White color is well received; the space was previously overlit, so lower light output is ok.
LEDtronics	Pendant post top	50, 70	20	Perceived better, safer lighting with lower light pollution.
LEDtronics	Parking garage	150	41	Perceived brighter, safer look. 2.5 year payback with incentive.
Light Efficient Design	Furniture store	400	100	Better color rendering
Lunera	Manufacturing	400	"Jr"	Payback under 1 year with $0.10/kWh electricity
Lunera	Grocery Produce	175	"Pro"	Payback under 1 year with $0.12/kWh electricity
Lunera	University Gym	400	"Pro"	Payback 1.5 year with $0.12/kWh electricity
Neptun Light	Acorn streetlight	150, 175	40	

The case studies summarized above were found on vendors' websites. The only case study found with an independent evaluation, showed a less optimistic appraisal of one vendor's mogul base LED products when installed in wall packs. See Wall Pack, BPA Maintenance Study case study in Appendix for more details.

Task 4: Specifier Survey

Background and Summary

An online survey was conducted in February–March, 2014, seeking specifiers' opinions on mogul base LED lamp characteristics and comparisons with traditional HID lamps. This information was used to inform the project team as to which mogul base LED lamps to purchase for further testing and to identify specifiers who had field experience with these products and would be willing to share those experiences with the project team.

Among the 191 respondents who did not work for manufacturers or manufacturers' representatives, 54 respondents had experience with evaluating or specifying mogul base lamps. Among lamp types, exterior area lighting was addressed most frequently, followed by high bay and decorative post top. Tables 8 and 9 below contain comments by respondents, both positive and negative.

Methods

LRC used Survey Monkey to create an online survey that was sent to approximately 5000 email addresses obtained from people who had previously downloaded National Lighting Product Information Program (NLPIP)[4] reports from the LRC website. The survey included 10 questions and an additional comment box. The survey was designed to take less than 10 minutes for a respondent to complete, and personal information was not collected unless it was voluntarily provided.

Most of the questions included multiple-choice responses as well as an "other" comment box allowing user-input. Multiple choice responses were randomized using Survey Monkey to minimize order effects. Specifiers were required to answer all questions, and could answer "prefer not to respond" to any question.

Results

Q1: Do you consent to having your answers included anonymously in a future publication?

In total there were 334 respondents (about 8% of the survey list). 304 of these consented to have their answered included in the survey and answered follow-up questions. The survey ended at this point for specifiers who did not consent to have their answered included.

Q2: Please specify your affiliation.

245 respondents answered this question. Those that indicated they were manufacturers or manufacturer's reps continued with the survey. Their answers were recorded, but are not included in this report. In total, 191 non-manufacturer respondents are included in this report.

Q3: Have you evaluated, installed or specified mogul base LED lamps in the past 12 months?

189 of the 191 non-manufacturer respondents answered this question. Of these, only 29% had evaluated, installed or specified mogul base LED lamps in the past 12 months. These 54 respondents continued with the survey. The survey ended for the other 133 respondents.

Q4: Select the types of luminaires for which you have evaluated or specified mogul base LED lamps. Select as many as applicable.

Of the 54 respondents with experience with mogul base LED lamps, 50 provided responses to the types of luminaires they used with these lamps. Respondents could list multiple luminaire types. Four luminaire types were listed by more than 33% of the respondents: outdoor area lights, flood lights, high bays and decorative post top (shown in Figure 5 below). Respondents who provided "Other" responses indicated

[4] National Lighting Product Information Program. http://www.lrc.rpi.edu/NLPIP/

they had evaluated or specified “domestic ceiling oysters and table lamps”, “Public lighting”, “A-line LED lamps, which did not fit into your categories”, “Indirect Indoor Tennis Lighting” and “residential wall mount”. It is unclear whether the respondents had actually evaluated mogul base LED lamps for these applications, or some other LED technology.

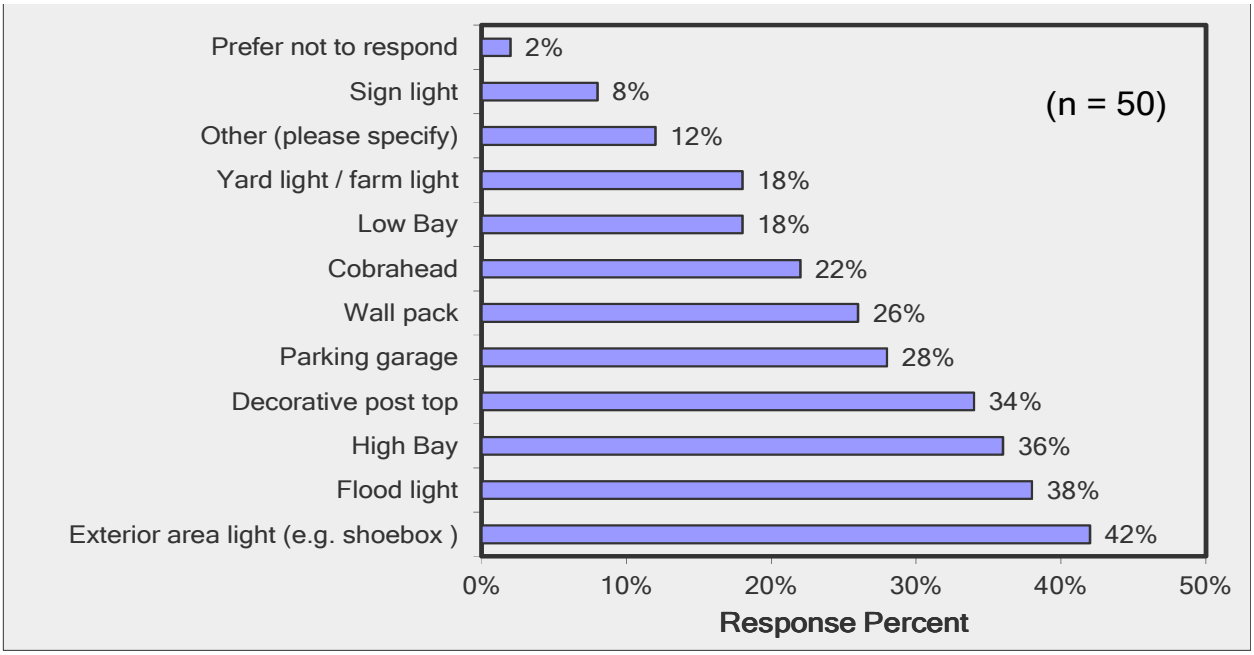

Figure 5: Types of luminaire where mogul-base LED lamps were specified or evaluated

Q5: Select the types of mogul base LED lamps that you have evaluated or specified in the last 12 months for interior / exterior commercial / industrial applications. Select as many as applicable. Images shown are examples of such products.

Sample lamp images that were displayed in association with the multiple choice answers for this question are shown in Table 7. 42 respondents answered this question. The responses showed that “cylinder and “half-cylinder” mogul base lamps were evaluated or specified more than any other types (Figure 6 below).

Table 7: Sample lamp images shown as examples of mogul base LED lamps. Lamp images were used with permission from the respective manufacturers.

LED “cylinder” / post top mogul lamp 	LED PAR mogul lamp 	LED “garden”/yard light mogul lamp 
LED mogul lamp for wallpack / roadway / area lighting 	LED mogul lamp for high bays/canopies 	LED mogul lamp for parking garages 

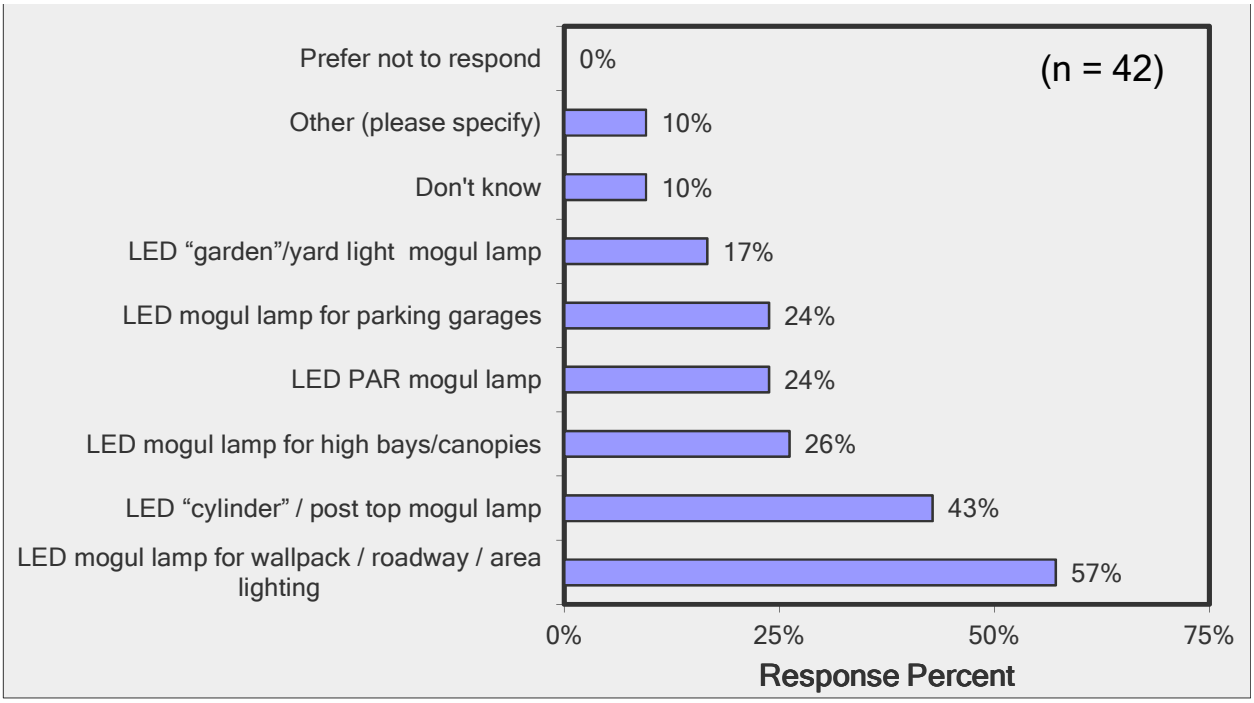

Figure 6: Responses to Question 5. Respondents’ selection of mogul base LED lamps types. Respondents who provided “Other” responses indicated they had evaluated or specified “Cree A19 60w” lamps and “Global Tech LED heads”. One respondent indicated that the lamps they had evaluated or specified was “unlisted” but gave no other information. Another indicated they had evaluated “No LED Mogul based lamps”, but had earlier indicated that they had (response to Question 3).

Q6: Rank in order the following questions about mogul base LED lamps. The most important answer should be ranked as # 1, other less important answers should be ranked in descending order of importance (2-8) or N/A. If you prefer not to respond to this question, assign #1 to "prefer not to respond" and N/A for the other questions.

39 respondents answered this question, rank-ordering mogul base LED lamp considerations in order of importance. Light output, intensity distribution, and size questions were ranked as more important than questions about cost, temperature and weight.

Q7: Please list three brands and models of mogul base LED lamps that you have evaluated or specified in the last 12 months.

29 respondents answered this question. LEDtronics lamps were mentioned more than any other brand, followed by Philips, GE, Light Efficient Design, Bbier, Toshiba, MaxLite, Global Tech, and EYE Lighting. Note that GE, Philips and Toshiba do not manufacture mogul base LED lamps so it is unclear why these brands were mentioned. The following brands were each mentioned once: Aamsco, Bulbrite, Cree, Duraguard, EIKO, Enigma, ETI, Evluma, FES, Green Firefly, LED Inc, Litetronics, Martek, Mobern, Neptune, Satco, Sylvania (includes OSRAM), VIVID, and Wattman.

Q8: If you have direct experience with mogul base LED lamps and would like to share information about an installation, please provide comments

Anonymized responses are shown in Table 8.

Table 8: Responses to Question 8. Respondents' experience with mogul base LED lamps.[5]

I think the mogul LED lamp needs the suitable reflector for protection of light pollution
The equivalent light output mogul base LED lamps would not fit into our Wall packs.
Most cost-effective way to add LED to a site
400 watt MH recessed can. F can ballast removed lamp by pass ballast wired 277 volt to lamp holder 18ft ceiling. Good cover of light
Pricing versus quality make many clients unhappy with these products as well as their output and the overall design
Https://www.youtube.com/watch?V=guizomkbfi0 Please view the installation video on youtube
I did extensive independent market research for the company and feel the alterlume trufit Mogul base LED replacement lamp surpasses any other product on the market in quality, reliability and ease of installation heat distribute, light distribution and fit for most replacements of HID lamps. It is designed and assembled in the U.S. in San Jose, CA
These lamps are not true retro fit, due to their size they produce different luminaire performance / distributions so have been discounted as a viable option to consider.
The lamps were used in a 175 watt MH enclosed fixture, the bulbs have a pancake fan for cooling, the concern is heat dissipation in an outdoor rated fixture, the heat transfer is the biggest problem for a retrofit verse a design that incorporates heat dissipation. Fixture design and led design must be developed together for the bulb or led component to have the longevity given by bulb and fixture manufacturer.
Forget replacement about lamps and kits use an integrated LED luminaire
I've heard stories about 'corn-cob' replacement lamps that have been attracting insect and spider nest inside of the heat-sink areas. The property managers were advised to put nylons or panty-hose over top of the lamps to keep the insects out. I'm wondering what effect on light output such shielding would have.

Q9: Where are you located?

63 respondents answered this question. As shown in Figure 7, 70% (44) of the respondents are located in 19 states across the US. No single state was overrepresented in the survey.

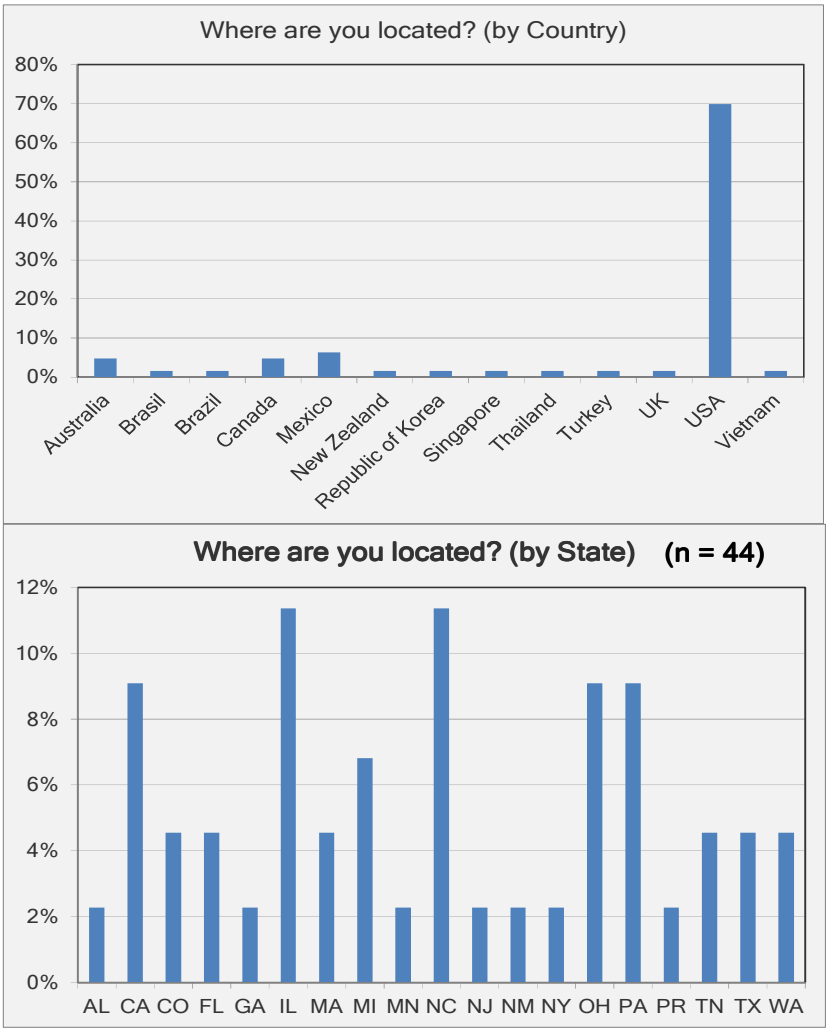

Figure 7: Responses to Question 9. Respondents' location by country and by US state.

Question 10: Thank you for your time and attention. If you have additional comments, please let us know in the comment box below.

Comments are shown in Table 9.

Table 9: Responses to Question 9. Additional responses regarding mogul base LED lamps.

Thank you for your guide
See previous question, if these lamps are to be viable they need to have the same size and location of light source as the lamp they are replacing for them to work optically in a luminaire.
Your research and articles are a great resource to the industry.
I prefer 4000K for streetlighting in this application, although other CCT's may be appropriate elsewhere.
I am very skeptical about this category and the viability of it as an acceptable solution. That said, it would be nice to have some standards and minimum performance requirements in this category.

Task 5: Mogul Base LED Replacement Lamp Test Results

Background and Summary

This chapter describes test methods and results for the 18 bare lamps and 18 lamp-luminaire combinations tested in Phase 1.

Only 4 of the 14 (28%) lamp-luminaire combinations passed all of the applicable DLC performance criteria, primarily because the remaining 10 products did not meet the minimum luminaire efficacy requirement (including all of the wall pack and high bay luminaire combinations). One of the 14 combinations did not meet the required CCT criteria and two of the 14 combinations did not meet the PF performance criteria (both tested with the magnetic ballast).

Products Selected and Tested

Depending on the screw-in mogul LED lamp manufacturer, some products simply replace the HID lamp, while others require the removal of the magnetic ballast, and rewiring of the line voltage to either an external LED driver /surge protector, or directly to the socket to for an internal driver within the LED lamp.

Most of the mogul base LED lamps tested were claimed to be equivalent to 150W HID, and these were selected based on the following considerations. As previously noted, HID lamps of less than 175W typically use a medium base. Yard lights often use 100W HID medium base lamps and wall packs often use 150W medium base HID lamps. Decorative streetlights are often mounted on short poles, so they do not need high light output, and these typically include HID lamps of 150W or less. Cobraheads and shoeboxes are frequently mounted on taller poles using 250W or 400W HID lamps.

One of the challenges with picking equivalent mogul base LED lamps has to do with their typically longer dimensions than the HID lamps they replace. Frequently, the luminaire manufacturer does not publish interior dimensions for their luminaires, only exterior dimensions. This is not an issue for HID lamps because their dimensions are standardized. According to the manufacturer, the Lithonia area light selected has 7.75 inches clearance from end of socket to end of the opposite interior surface, and the GE cobrahead has 9 inches (± 0.5 inches) clearance. LRC measured the clearance in each luminaire received and found that the area light had 9.5 inches clearance, the cobrahead had 8.9 inches clearance and the wallpack had 12.5 inches clearance. The mogul socket depth was 1.75 inches. This is sufficient room to accommodate a 7.75 inch (Maximum overall length (MOL) including base) 150W HPS lamp, and a 9.75 inch (MOL) 250W HPS lamp but too short for many of the LED 150W and 250W equivalent lamps that are currently available in this half-cylinder or cylinder configuration.
In the selected Lithonia high bay luminaire, 400W equivalent LED lamps were tested. This high bay luminaire has 9.75 inches of clearance from the end of the socket to the open end of the reflector. High bay mogul base LED lamps with an axial light intensity distribution, such as HB1 and HB3, are able to emit higher light output without exceeding the length of 9.75 inches. Because this luminaire type in not enclosed, a mogul base LED lamp could protrude beyond the 9.75 inches open bottom of the test luminaire, although that may produce undesirable glare and aesthetics.

Photographs of all the lamps and luminaires are included in the Appendix.

Test Methods

During the Phase 1 testing, the mogul base LED lamps were tested in a preapproved luminaire as well as in open air in an integrating sphere. Open air testing is not required by DLC, but was conducted to compare the lamps' measured performance to the rated performance, and to determine the performance impact of the luminaire. Testing the lamp inside the luminaire increases the ambient temperature around the lamps, decreases its light output and decreases its efficacy. Luminaire test results are charted below. Details about test methods, numerical results and bare lamp results are included in the appendix.

Luminaire Results

Figures 8-10 show the integrating sphere results for the tested luminaire-lamp combinations. All of the lamps tested in one luminaire are grouped within one pastel overlay color. 16 of the 18 luminaire-lamp

combinations were able to be measured and provided stable, accurate results[6]. Two of the luminaire-lamp combinations would not stabilize to the tolerances allowed in LM-79-08 and measurements for these products cannot be accurately determined.

Light output and CRI for the 16 luminaire-lamp combinations exceeded (e.g. passed) the minimum applicable (or comparable) DLC performance criteria.

For CCT, most lamps were between 4000K and 4500K, and all but one lamp met the DLC requirement. Two lamps exceeded the threshold by a small amount, within the tolerance for error.

For luminaire lumen output, all lamps met the DLC requirements. However, in order to generate this much light, most of the lamps used more power than would be allowed by the DLC efficacy requirement.

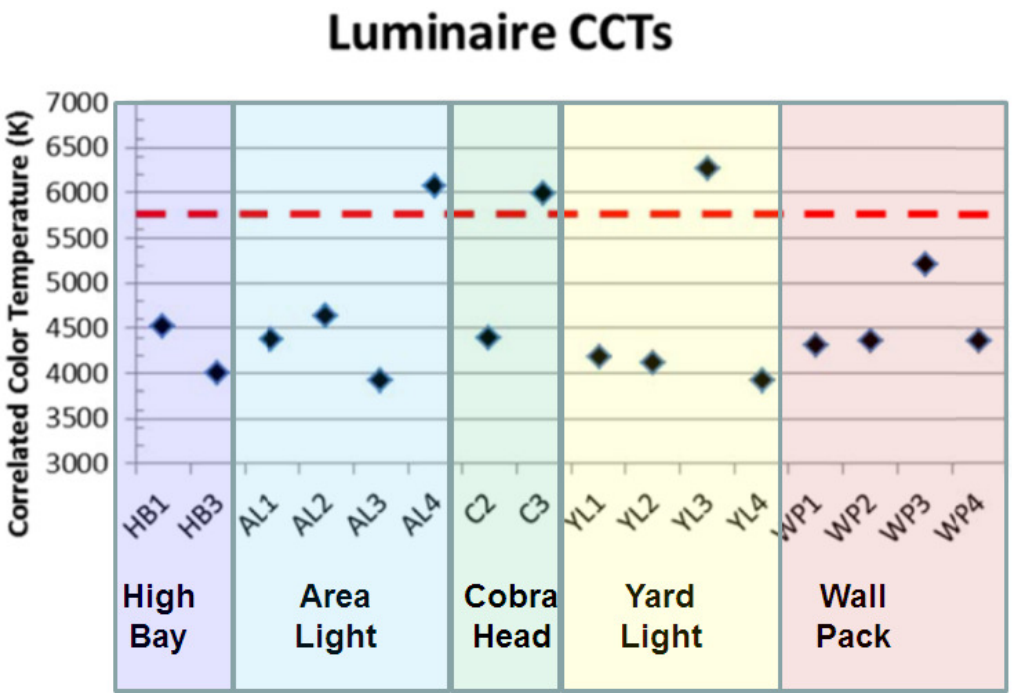

Figure 8: Measured CCT for 16 luminaire-lamp combinations.
The dashed red line indicates the maximum CCT retrofit criteria for that application (tolerance around the limit is not shown). For the yard lights (YL1 – YL4), the maximum CCT is for retrofit kits for outdoor pole-mounted area lights.

[6] The Lunera lamp-luminaire combination (HB3) ceased to be operational after we tried to operate the lamp without a ballast to determine the lamp characteristics. Zonal lumen density and THD measurements could not be conducted on this product.

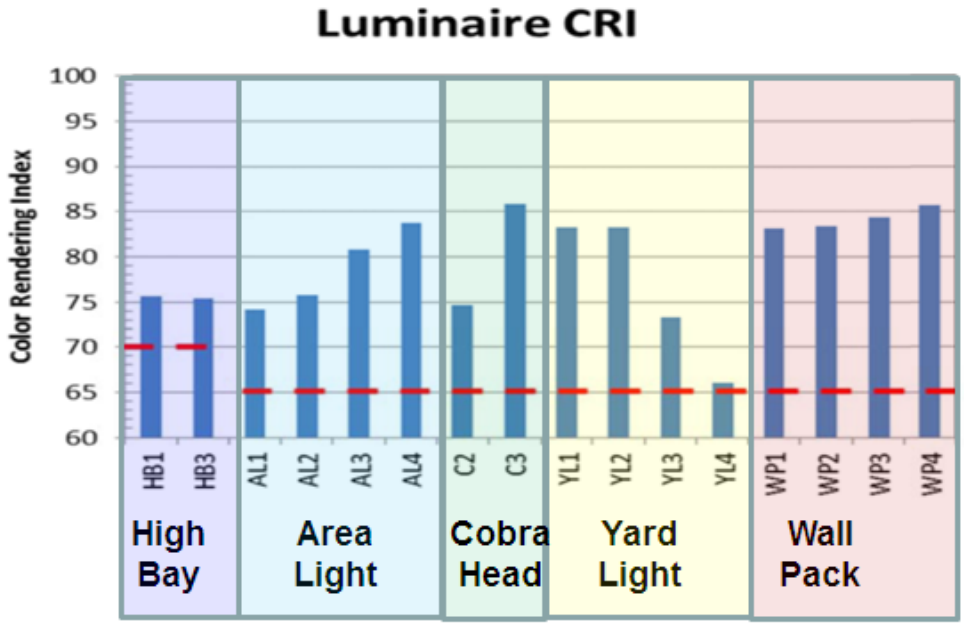

Figure 9: Measured CRI for 16 luminaire-lamp combinations.
The dashed red line indicates the minimum CRI for retrofit kits for that application. For the yard lights (YL1 – YL4), the minimum CRI is for retrofit kits for outdoor pole-mounted area lights.

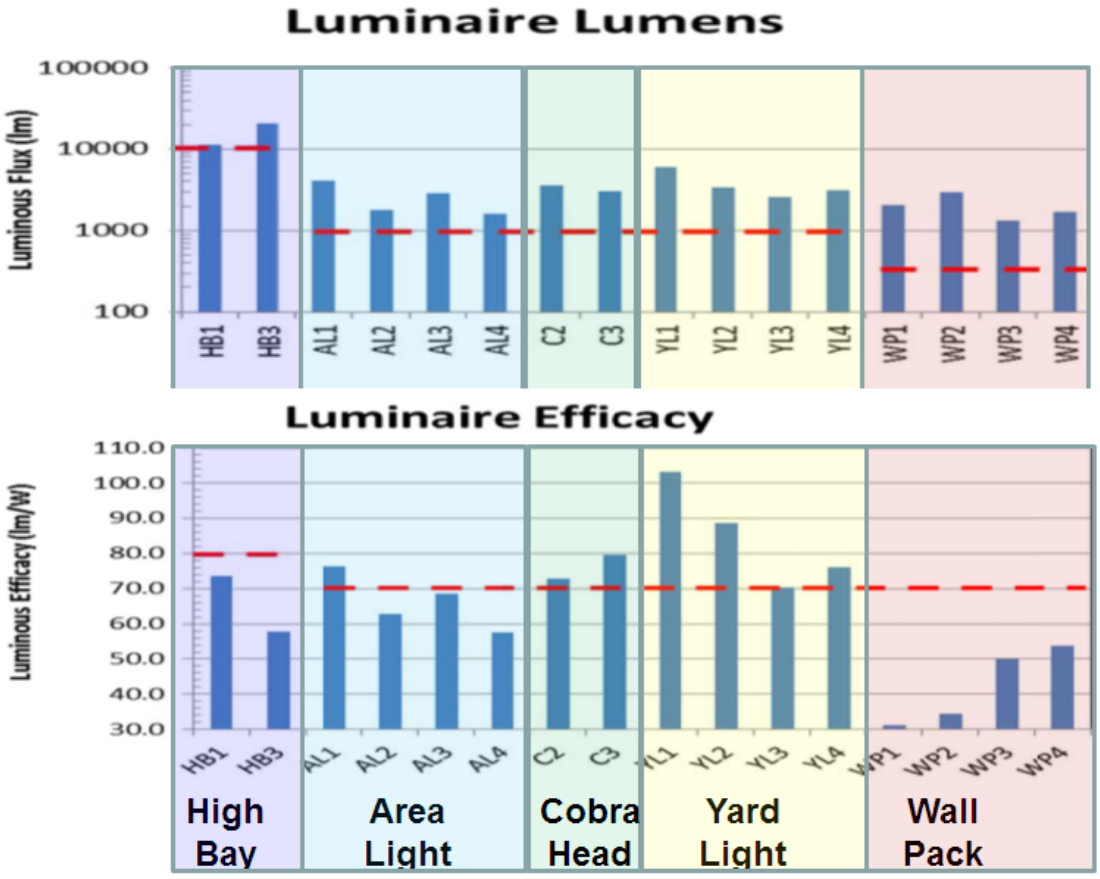

Figure 10: Measured light output and luminaire efficacy for 16 luminaire-lamp combinations.
The dashed red line indicates the minimum light output for retrofit kits for that application. For the yard lights (YL1 – YL4), the minimum light output and minimum efficacy are for retrofit kits for outdoor pole-mounted area lights.

DLC Electrical and Photometric Technical Requirements for Retrofit Kits

For retrofit kit categories/products, DLC requires that the retrofit kit is tested inside a pre-approved luminaire. Electrical and photometric testing is conducted per the LM-79 test method and an LM-79 report is submitted with the product application. In addition, an IES file is submitted to confirm that the product is compliant with the zonal lumens requirements. DLC also requires UL proof of safety certification to be part of the application.

Table 10 shows the DLC requirements and tolerances for retrofit kits. These requirements will be used as the basis for comparison in Phases 1 and 2.

Table 10: DLC Technical requirements for Retrofit Kits.

Metric	Minimum Required Value	Tolerance (%)
Power Factor	>= 0.9	-3%
THD	<= 20%	+5%
Light Output	Depends on category (300 – 10,000 lumens)	-10%
Luminaire Efficacy	Depends on category (60 – 85 lm/W)	-3%
CCT	Depends on category (<= 5000K or 5700K)	Defined by ANSI C78.377-2011
CRI	Depends on category (65-80)	-2
Zonal Lumens	Depends on category	Per Table 5[7]

Task 6: Final Phase 2 Testing Plan

Phase 2 Work Plan (July 2014 – January 2014)

Measure persistence is a concern where a mogul base LED replacement lamp operates on the existing magnetic ballast because the conventional lamp could be returned to the luminaire during the next relamping if the magnetic ballast is still operational. Therefore, only mogul base LED lamps that operate without a magnetic ballast, heretofore referred to as “bypassed lamps,” will be tested in phase 2.

Phase 2 Task 2: HID Persistence Testing

To address concerns about persistence and safety because the bypassed LED replacement lamp could be eventually replaced with a conventional HID lamp, LRC will purchase and test HID lamps, using line voltage provided directly to the socket to determine if the lamps will light without a magnetic ballast in line. The mogul base HID lamps tested will include 70W and 400W HPS lamps, 175W and 400W probe-start and pulse-start metal halide lamps. The line voltage applied will be 120V and 277V.

ANSI HID lamp standards will be purchased for guidance on starting and operating voltage requirements.

Phase 2 Task 3: Expanded DLC Testing

To increase the number of lamp/luminaire combinations sampled in phase 1 DLC testing, the LRC will test more bypassed mogul base LED replacement lamps. The measured lamp-luminaire performance will be evaluated against DLC requirements for retrofit kits. In this task, 12 additional mogul base LED replacement lamps will be purchased and tested in their applicable luminaires, including at least 1 mogul base LED lamp from EIKO, and at least one 250 W equivalent mogul base LED lamp for use in the high

[7] DesignLights Consortium. *Technical Requirements Table*. http://www.designlights.org/Content/QPL/ProductSubmit/CategorySpecifications.

bay luminaire. In addition, up to 5 additional samples of bypassed lamps that did not stabilize and did not produce measurable results during the initial testing in phase 1 will be purchased and tested under phase 2. Five mogul base LED replacement lamps for decorative streetlight applications (including 3 purchased under phase 1) will be tested in an acorn luminaire at LTL using their goniophotometer, in addition to sphere testing within this luminaire which will be completed at the LRC.

Phase 2 Task 4: Application Efficacy Calculations

To address the concern that mogul base LED replacement lamp performance is equivalent to HID performance at a limited range of mounting heights, the LRC will conduct Luminaire System Application Efficacy (LSAE) calculations to analyze the application efficacy at various mounting heights for each of the 6 applications. Based on IES files from phases 1 and 2, the LRC will create LSAE charts for 30 lamp-luminaire combinations.

Phase 2 Task 5: Brightness Calculations

To address the question that brightness perception can be used to determine equivalency between mogul base LED replacement lamps and HID lamps, in addition to light output comparisons, the LRC will compute the predicted brightness values using spectral power distributions (SPDs) for 30 lamp-luminaire combinations for each of the 6 applications from phases 1 and 2.

Phase 2 Task 6: Photometric Testing Under High Temperature Ambient Conditions

To address the concern that mogul base LED replacement lamp performance will degrade under high temperature ambient conditions, such as those that occur in unconditioned spaces and summer temperatures, the LRC will pilot test the relative light output for 6 lamp-luminaire combinations, including 3 high-bay combinations, as well as 3 other combinations.

Phase 2 Task 7: Write Report

The LRC will produce a report summarizing the test methods and measured results for tasks 2-6. The report will include recommended modifications to the DLC specifications including a discussion of additional information required to incorporate mogul base LED replacement lamps into the retrofit kit category.

Appendix

Acronyms and Appreviations

CCT	Correlated Color Temperature
CFL	Compact Fluorescent
CRI	Color Rendering Index
DOE	United States Department of Energy
HPS	High Pressure Sodium
LED	Light Emitting Diode
lm	Lumens
LPS	Low Pressure Sodium
MH	Metal Halide
MOL	Maximum Overall Length
NEMA	National Electrical Manufacturers Association
PAR	Parabolic Aluminized Reflector
PF	Power Factor
QPL	Qualified Products List
THD	Total Harmonic Distortion
TWh	Terawatt Hours
UL	Underwriters Laboratory
W	Watts
WSU	Washington State University Energy Program

Appendix: Task 3 Case Studies

Several published case studies were found on manufacturers' websites and in news media.

Differential Energy Global

The University of Washington Tacoma (UWT) is using lamps from DEG in decorative acorn streetlights in two building applications.[8] A follow-up telephone interview with Hugh Smith, resource conservation manager at UWT was conducted on May 13, 2014, plus a conversation by Levin Nock with Roger Peery of Tacoma Power on August 6, 2014. Over one hundred 15-foot tall decorative acorn luminaires use a mixture of 70W and 100W HPS lamps, with a mixture of medium and mogul base. The existing King luminaires are at least 25 years old, and sometimes fill with water because the gaskets are failing. While the university has clean power, the incumbent HID lamps are replaced every 1-1.5 years when they fail. The rapid failure rate may be due to water penetration. A replacement lamp/ballast kit is installed each time the lamps fail at a cost between $275 and $500 per kit. [Notes are unclear: $275 might be for materials, and $500 includes labor?]

The university sought a screw-in option to replace their HID lamps and they were not aware of the DLC QPL retrofit product list at the time they were considering replacement options. A contact at Tacoma Power recommended they consider this lamp.

The existing HID lamp and ballast are removed and the new LED lamp, external LED driver and surge protector are installed while the luminaire is in their maintenance shop. They use the same mounting hardware and mounting locations so that their UL rating is not affected.

They used a dimmed 400W-equivalent LED replacement lamp (DEG 325400 lamp) to replace 100W HPS lamps in 10 acorn luminaires. They chose this lamp because they were not sure of the LED lamp's light output. The lamp has a potentiometer that can be used to dim the lamp once it is screwed into position, ranging from 14W (0% light output) to 148W (100% light output).[9] For this installation, the potentiometer is dimmed more than 50% (between positions 1 and 2) to yield a system power demand of 70W. The preferred light level selected was based on perception, not on measured light levels. They prefer the "white" light the LED lamps provide over the yellowish light of the HPS lamps.[10] They also believe the "white" light will also make students feel safer.

The University plans to replace the remaining HPS lamps as they fail with the dimmed DEG 325400 lamp, until a lower wattage product is identified for a group replacement. They plan to use occupancy sensors to further reduce energy use. The lamps have a 100,000 hour rated life and come with a 10 year warranty. The lamps might be eligible for a rebate from Tacoma Power if they were replaced as part of a pre-approved project, with an approved wattage reduction. The University has one electrical meter used to meter all their exterior lighting, with an electrical rate of $0.035/kWh.

EIKO

EIKO shows two case studies on their web site using low wattage (30W or 45W) post-top replacement lamps to retrofit 150W to 175W HID lamps on two different university campuses. No lighting metrics were provided.

In one case study, 175W MH lamps were replaced with LitespanLED Post-Top replacement lamps in decorative acorn luminaires.[11] The LED replacement lamps have a rated life of 60,000 hours. Based on a 12 hour per day operational schedule (4380 hours of use per year), and a $156,000 capital cost, the project payback is calculated to be 3.5 years. The case study does not indicate whether 30W or 45W lamps were used for replacement, and the economic details provided in the case study do not allow this to be accurately estimated.

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[8] Kitsap Peninsula Business Journal. 2014. *Let there be (new) light: 'Market is finding us'*. Accessed online at: http://kpbj.com/feature_articles/2014-02-06/let_there_be_new_light_market_is_finding_us

[9] DEG-325400. http://www.differentialenergy.com/#!deg-325400-hi-bay/cbsw

[10] The CCT of LED lamps they purchased and used is unknown.

[11] EIKO. *Case Study: The University of Tulsa, Tulsa, OK.* http://www.eiko-ltd.com/contentfiles/file/press%20release/University%20of%20Tulsa%20Case%20Study.pdf

In the second case study, 150W HPS lamps were replaced with LitespanLED Post-Top replacement lamps in decorative acorn luminaires.[12] The LED replacement lamps have a rated life of 60,000 hours. Based on a 12 hour per day operational schedule (4380 hours of use per year), and a $135,900 capital cost, the project payback is calculated to be 2.2 years. The case study does not indicate whether 30W or 45W lamps were used for replacement, however the economic details seem to indicate that 30W replacement lamps were selected.

Evluma

Evluma (an LED manufacturer) has published a case study in Crystal Falls, MI where 100W HPS lamps in security fixtures and 250W MH lamps in decorative acorn fixtures were replaced on a one-for-one basis with 50W Beacon LED lamps.[13] The city wished to cut its streetlight energy use by 50% if it could absorb the capital cost of the LED upgrades as part of a larger municipal upgrade which included ARRA grants and incentives from WPPI Energy.

In 2010, Crystal Falls initially evaluated both 50W Beacon LED lamps and 40W EcoSpot LED lamps in the security fixtures but preferred the illumination provided by the 50W lamp. Perceived brightness was used to compare the LED lamps to the incumbent HPS. The stakeholders from Crystal Falls also preferred the appearance of "white" light compared to HPS. Energy use was monitored to compare performance to the technical specifications given by Evluma, but lighting measurements were not performed.

Crystal Falls elected not to spot-replace failing HPS lamps, instead they removed large groups of fixtures at one time and rewired them in their maintenance shop to bypass the ballast as they installed the LED lamps. They also fabricated a new mounting bracket for the socket so that the lamp would be recessed further into the luminaire to further diffuse the light from the LED lamp. As of 2011, Crystal Falls started purchasing the Short 50W Beacon LED lamp instead (which is 7.7" long rather than 10.2" long) and the mounting plate does not have to be recessed as much.

More recently, Crystal Falls replaced 250W MH lamps in decorative acorn fixtures with the short 50W Beacon LED lamp. The light output from the 50W LED lamp is lower than the light output from the 250W MH lamp, but Crystal Falls likes the white light appearance and felt that the environment was over lit by the MH lamps. Evluma published 3 additional case studies using their lamps but these are not included because they do not indicate if these lamps are mogul base (their products are available in either medium or mogul base).

LEDtronics

LEDtronics has published two case studies.

At the Santa Monica Pier in Santa Monica, CA, mogul base 50W and 70W MH and HPS lamps were replaced with 20W cylindrical LED replacement lamps in pendant-style post top fixtures located in the outdoor rest area.[14,15] Other fixtures and lamps were also replaced during this project, which was funded by a $668,000 Energy Efficiency and Conservation Block Grant (EECBG) from the US DOE. The authors claim that the benefits of the relamping project include longer relamping intervals, and a 30% energy savings for the entire project. The authors also claim "better" lighting for the rest area, increase in safety and "lower" light pollution; although there is no data presented allowing for comparisons.

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[12] EIKO. *Case Study: Virginia Commonwealth University – Snead Hall.* http://www.eiko-ltd.com/contentfiles/file/press%20release/VCU%20-%20Snead%20Hall%20Case%20Study.pdf

[13] Evluma. *Clearlight Case Study: City of Crystal Falls, MI*. http://evluma.com/case_studies_cityofcrystalfalls.html

[14] LEDTronics. July 2013. *LEDtronics LED Lighting Reduces Energy More Than 30% at 97 Year-Old Landmark*. Accessed online at: http://www.ledtronics.com/Media/PressReleases.aspx?pressID=241

[15] LEDs Magazine. September 2013. *Iconic Santa Monica Pier gets LED facelift.* Accessed online at: http://www.smgov.net/uploadedFiles/Departments/OSE/Categories/Energy/LEDs_magazine_sept_2013.pdf

Another case study published by LEDtronics provides details regarding a parking garage installation where mogul base 150W HPS lamps were replaced with 41W LED lamps in a casino in Indio, CA. The clients feel that the replacements help them "save time, money, conserve energy and provide a bright, safe environment for our guests" and a "cleaner and brighter look".[16] By reducing their power demand from 180W to 41W, this installation qualified for an energy rebate and was able to achieve a 2.5 year payback.

Light Efficient Design

Light Efficient Design (LED LLC) has several case studies on its web site where LED replacement lamps are used to retrofit HID luminaires. Several of the case studies involve medium base lamp replacements, however there is one case study involving 400W HID mogul base lamps.

A furniture store replaced 400W lamps with 100W LED-8026 lamps in their showrooms and warehouse.[17] The management indicates that choosing furniture fabric colors is important so it is likely that the HID lamps that were previously installed in the showrooms were MH lamps. Along with a 75% reduction in power, the client prefers the color rendering and color appearance of the LED lamps. Previously they had to move furniture closer to the windows to match colors. The client also indicates that they are replacing lamps and ballasts less frequently so their maintenance costs have decreased.

Lunera

Lunera (an LED manufacturer) has published 3 case studies showing payback periods using their mogul base LED "Susan" lamp.[18] None of the case studies mentioned above included quantitative or qualitative lighting information (before or after). The Susan lamps claim to replace 175W, 250W or 400W metal halide (MH) lamps. The Susan 400 replaces a 400W MH lamp, the Susan 250 replaces a 250W MH lamp and the Susan 175 replaces a 175W MH lamps. In all 3 wattage categories, a "Pro" and "Junior" option of the Susan lamp is available. According to their literature, the "Pro" version provides equivalent mean "delivered lumens" as the MH lamp it replaces, while the "Junior" version is suggested for applications where lower light levels are preferred. Both lamp options claim to have longer lives than MH lamps and have 10-40% less energy use and significantly lower "lifetime costs" than MH.

Case Study 1: In a 100,000 square foot (SF) manufacturing facility in Wilmington, DE, operating 24/7, 400W MH lamps were replaced with Susan 400 Junior lamps (presumably on a one-for one basis). This case study claimed a 0.92 year payback based on a $0.10/kWh energy rate and a $38,000 capital cost.

Case Study 2: Susan 175 Pro lamps replaced 175W MH lamps in the produce area of a local grocery store in Alameda CA, operating 16/7, (presumably also on a one-for one basis). This case study claimed a 0.94 year payback period based on a $0.16/kWh energy rate and a $6,300 capital cost.

Case Study 3: 400W MH lamps were replaced with Susan 400 Pro lamps in a university gymnasium in Detroit MI. Operating 18/7, with a $0.12/kWh rate, the case study claimed a 1.5 year payback period for a capital cost of $14,900.
Lunera recently obtained five million dollars in new debt financing to help fund new "plug and play" (screw-in only) replacement lamps called BallastLED.[19] These lamps will operate on existing CFL and MH ballasts. The BallastLED lamps will have a driver integrated into the replacement lamp, rather than an external driver. Two disadvantages for these replacement lamp systems are mentioned in the article: (1) lower system efficiency because the existing ballasts are less efficient and (2) shorter rated lives and potentially higher failure rates for the existing ballasts than the LED replacement lamps. Lunera thinks that the simplicity of the "plug and play" replacements will overcome these other factors.

[16] Indian Gaming. September 2013. *LED Lights Help Fantasy Springs Resort Casino Save Energy and Receive Rebate*. Accessed online at: http://www.indiangaming.com/istore/Sep13_CaseStudy.pdf
[17] Light Efficient Design. *Light Efficient Design's Energy-Saving Solution Transforms Big Sandy Superstores*. http://www.led-llc.com/content/docs/Success_Stories/Big%20Sandy%20Furniture.pdf
[18] Lunera. 2014. *Introducing the Susan Lamp.* http://www.lunera.com/wp-content/uploads/2014/04/Introducing-the-Susan-Lamp_small.pdf
[19] Illumination in Focus. 2014. *Lunera Lighting gains funding, launches LED lamps for CFL and MH sockets.* Accessed online at: http://www.ledsmagazine.com/content/leds/en/articles/iif/2014/04/lunera-lighting-gains-funding-launches-led-lamps-for-cfl-and-mh-sockets.html

Neptun Light

Neptun Light has published a single case study on its web site showing 40W LED lamps used to replace 150W (nominal wattage, 190W for the system) and 175W MH lamps (205W for the system) in decorative acorn luminaires in Newtown, CT.20 The LED replacement lamps have a 70,000 hour rated life. The case study claims that the city will save $12,000 annually in energy costs and $180,000 in energy costs over the rated life of the lamps. An additional $16,000 will also be saved due to reduced maintenance and material costs over the rated life of the lamps. No lighting metrics were provided.

Wall-packs, BPA maintenance station

BPA recently compared the performance of mogul base 55W LED replacement lamps in existing wall-pack luminaires to the performance of the original 150W HPS lamp, as well as to new 50W integral LED wall-pack luminaires.[21]

Compared to the original 150W HPS lamp installation, the LED lamps produced less light directly in front of the fixture.[22] The LED lamp in the incumbent luminaire also produced less light compared to the integral LED fixtures.[23] The LED lamps were not as well received as the integral LED fixtures. Compared to the integral LED fixtures, the LED replacement lamps were more expensive, had a higher power demand, took twice as long to install, were perceived to be more glary and the light levels were noticeably lower and "less pleasing". In addition, the integral LED luminaires were perceived to produce a "much whiter" light appearance, and the luminaires themselves were more attractive than the incumbent wall-packs. Some of the wall-packs had medium sockets, so the longer installation time was caused by converting the mogul replacement kit to fit into a medium socket.

This information, along with Phase 1 test results, suggests that:

- Wall-packs might not be a good application for mogul LED replacement lamps.
- A high performance specification might be valuable, to limit inappropriate installations of mogul LED lamps that do not perform well.

[20] Neptun Light. *Municipal Lighting Retrofit, Newtown, CT.* Accessed online at: http://www.neptunlight.com/blobs/1/18f697a8ddac5a5518da02e5e00c91c1/Neptun%20LED%20Retrofit%20Case%20Study%20-%20Newtown,%20CT.pdf

[21] A Word document summarizing case study was provided by Levin Nock representing BPA on February 11, 2014, based on a site visit by Mira Vowles of BPA.

[22] Number of fixtures was not equal, nor is spacing between fixtures given in report. The original 150W fixture produced 14 FC in front of the fixture on average (using 2 fixtures), while one wall-pack using an LED lamp produced only 3 FC.

[23] Number of fixtures was also not equal in this comparison, and spacing between fixtures is unknown (1 LED lamp retrofit compared to 8 integrated LED fixtures). 3 FC was measured in front of the LED lamp and 26 FC was measured in front of the integrated LED fixture.

Appendix: Task 4 Survey Details

Q2: Please specify your affiliation.

245 respondents answered this question. Those that indicated they were manufacturers or manufacturer's reps continued with the survey. Their answers were recorded, but are not included in this report. In total, 191 non-manufacturer respondents are included in this report, as shown in Figure 11 and Table 11. Nineteen of the "Other" responses were assigned to existing categories.

Figure 11: Specifier survey details regarding affiliation

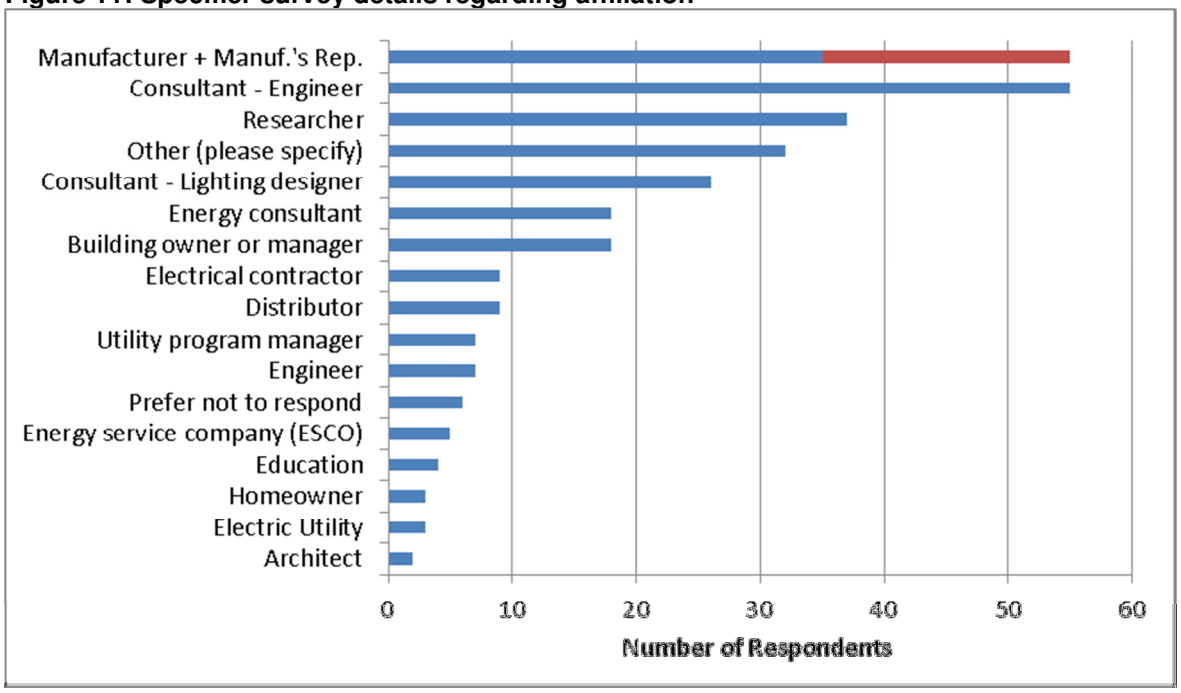


Table 11: Details for the remaining "Other" response with regard to respondent affiliation

Other (please specify)	
• Association publication • Biologist • Consultant • Consultant to advanced lighting manufacturers and manufacturer's representative • Consumer • Contractor • Contractor, Design Build for Federal Govt. • DIY'r • Electrical Inspector (Internal AHJ) for Large Entertainment Facility • Former retail antique lighting repair center. Uses e39d in retail lighting applications • Government agency responsible for promoting energy efficiency • Government officer • Just a guy who appreciates good lighting. • Just an interested party. • Library Technician.	• Lighting designer • Machine vision company. • Maintenance • Maintenance Electrician • Manufacturer • Member of community with serious accumulated knowledge of lighting and dark sky • Municipal roadway lighting manager • Neighbor to a proposed soccer stadium • NPO • Ohs consultant • Policy advisor • Sales • Student • Unemployed • User • Volunteer, dealing with technical stuff

Appendix: Task 5 Photos and Test Details

Table 12 shows the LRC identification numbers for each of the received and tested mogul base LED replacement lamps, and lamp-luminaire combinations. The first six digits in Product ID represent the luminaire ID; the second six digits represent the lamp ID. Combination codes: AL – area light, CL – cobrahead luminaire (roadway), HB – high bay luminaire, WP – wallpack luminaire, YL – yard light.

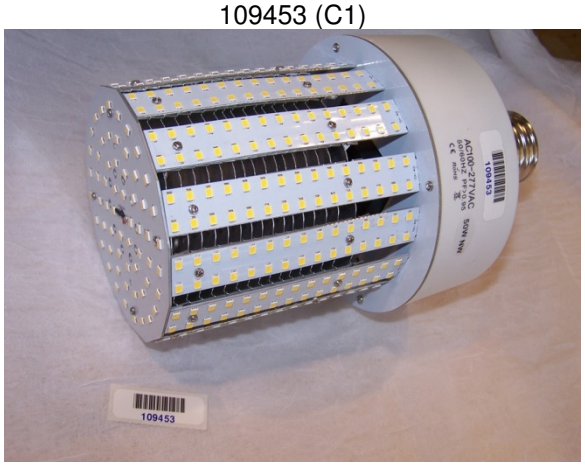
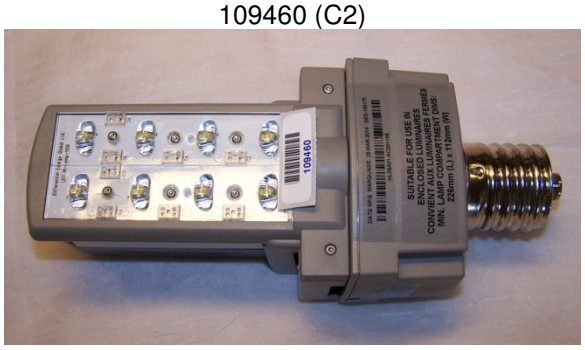
The Lamp Model column indicates if the magnetic ballast was bypassed or not during luminaire testing, following manufacturer instructions.

Table 12: LRC identification numbers and codes for lamps and luminaires measured in Phase 1.

Manufacturer	Lamp Model Bypass / No Bypass	LRC Lamp ID	LRC Luminaire ID	LRC Product ID	Code
Differential Energy Global	DEG-150175 Type III Bypass	109461	Area Light 109465	109465_109461	AL1
Differential Energy Global	DEG-070120 Bypass	109466	Area Light 109465	109465_109466	AL2
Light Efficient Design	LED-8024M42 Bypass	109468	Area Light 109465	109465_109468	AL3
Premium	G80-S30 30W Bypass	109472	Area Light 109465	109465_109472	AL4
Bbier	BB-HJD-053 No Bypass	109453	Cobrahead 109467	109467_109453	C1
Differential Energy Global	DEG-150175 Type II Bypass	109460	Cobrahead 109467	109467_109460	C2
Premium	G90-C40C Bypass	109473	Cobrahead 109467	109467_109473	C3
Differential Energy Global	DEG-325400 Bypass	109459	High Bay 109464	109464_109459	HB1
Light Efficient Design	LED-8030M42 Bypass	109463	High Bay 109464	109464_109463	HB2
Lunera Lighting	SN-VP-E39-400W-4000-G1 No Bypass	109471	High Bay 109464	109464_109471	HB3
Bbier	BB-HJD-003 No Bypass	109451	Wall Pack 109470	109470_109451	WP1
Bbier	BB-HJD-005 No Bypass	109452	Wall Pack 109470	109470_109452	WP2
Living LED	E39-27W LED Bypass	109455	Wall Pack 109470	109470_109455	WP3
Light Efficient Design	LED-8001M42 Bypass	109462	Wall Pack 109470	109470_109462	WP4
Bbier	BB-HJD-054 No Bypass	109454	Yard Light 109469	109469_109454	YL1
New Sunshine	NSGL-35W-590SMD No Bypass	109456	Yard Light 109469	109469_109456	YL2
LEDTRONICS	LED30MH-30X2W-XPW-001 Bypass	109457	Yard Light 109469	109469_109457	YL3
Evluma	CLEARLIGHT-BEA-50-4K-6-V-MO-S Bypass	109458	Yard Light 109469	109469_109458	YL4

Table 13 shows close-up photographs of each lamp and Table 14 shows photographs of each lamp-luminaire combination tested in this phase.

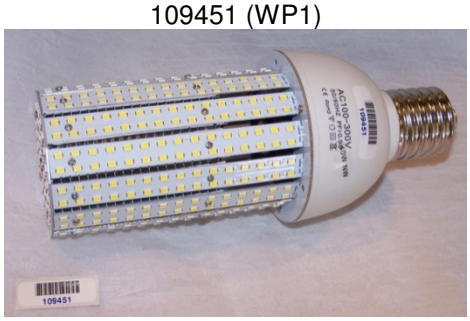
Table 13: Photographs of lamps tested in Phase 1 (2.5 pages total)

109461 (AL1) 	109466 (AL2) 
109468 (AL3) 	109472 (AL4) 
109453 (C1) 	109460 (C2) 
109473 (C3) 	109459 (HB1) 

109463 (HB2)

109471 (HB3)

109451 (WP1)

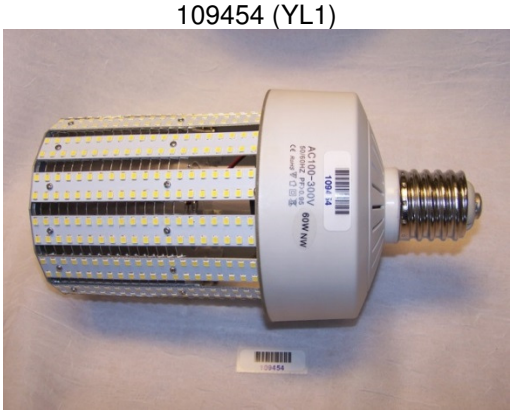


109452 (WP2)

109455 (WP3)

109462 (WP4)

109454 (YL1)



109456 (YL2)

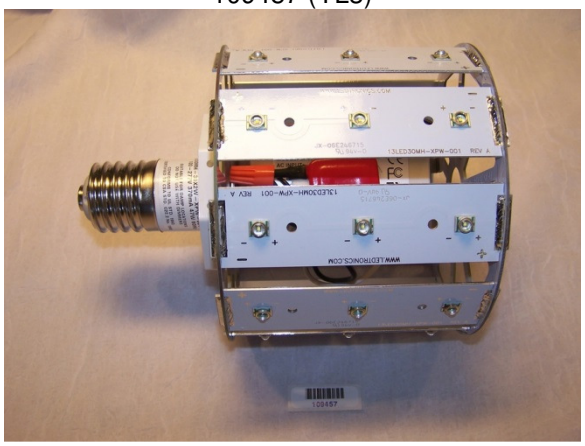
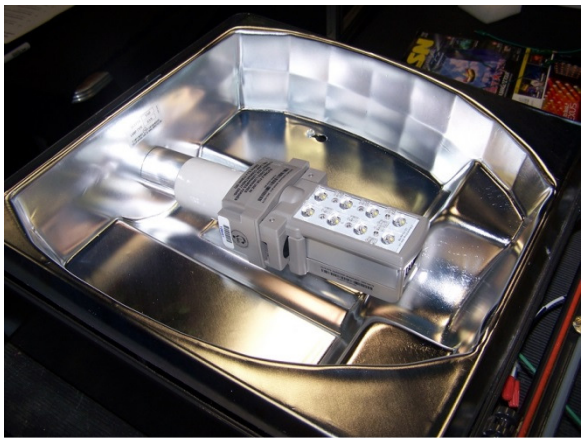
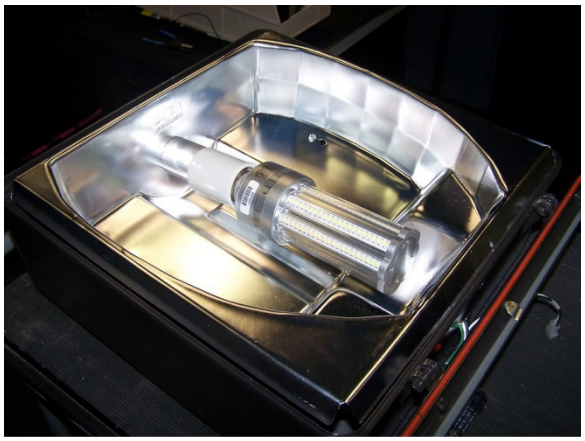
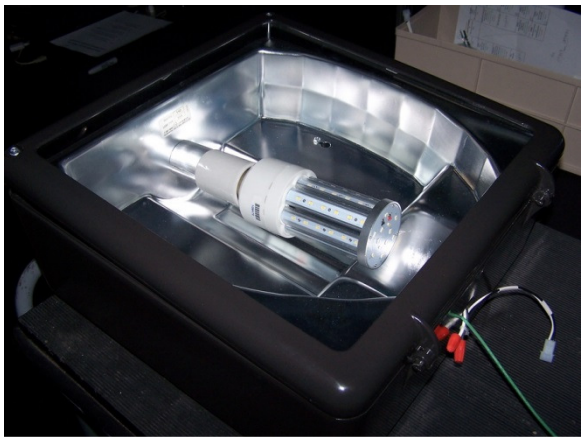
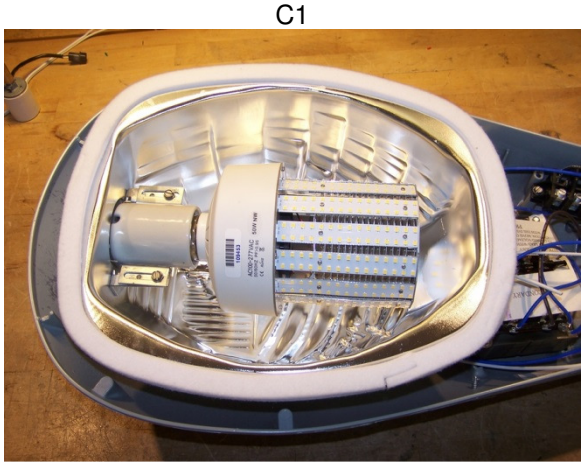
109457 (YL3)	109458 (YL4)
	

Table14: Photographs of lamp-luminaire combinations tested in Phase 1 (next 3 pages)

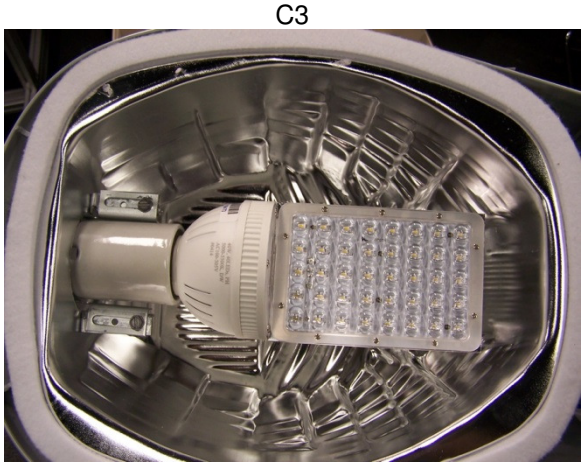
AL1	AL2
	
AL3	**AL4**
	

C1



C2

C3



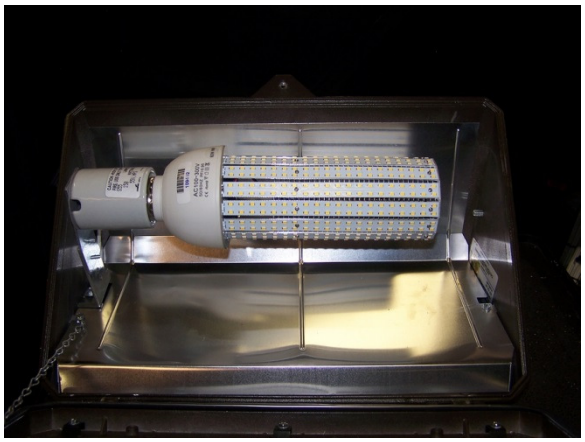
HB1

HB2

HB3

WP1

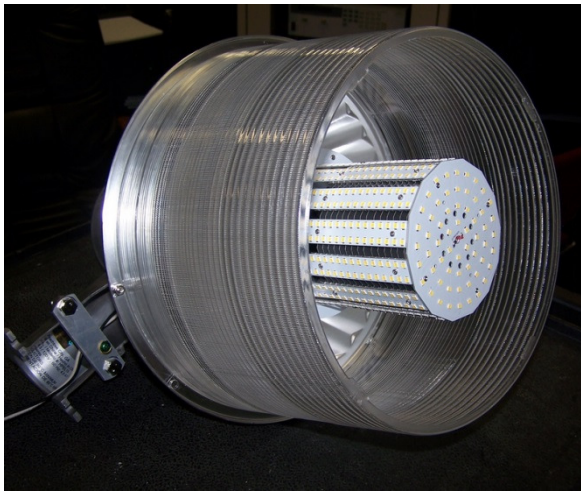
WP2



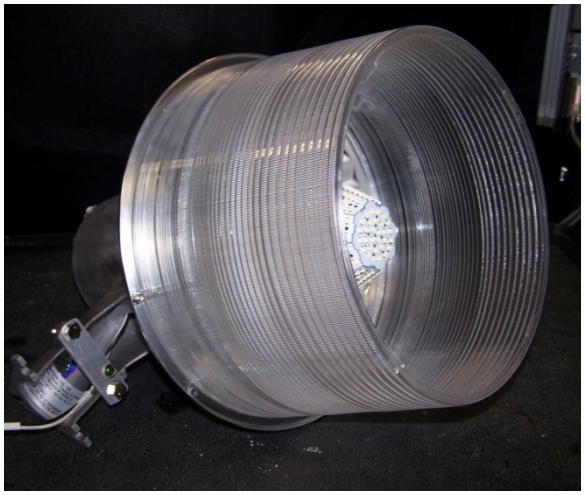
WP3

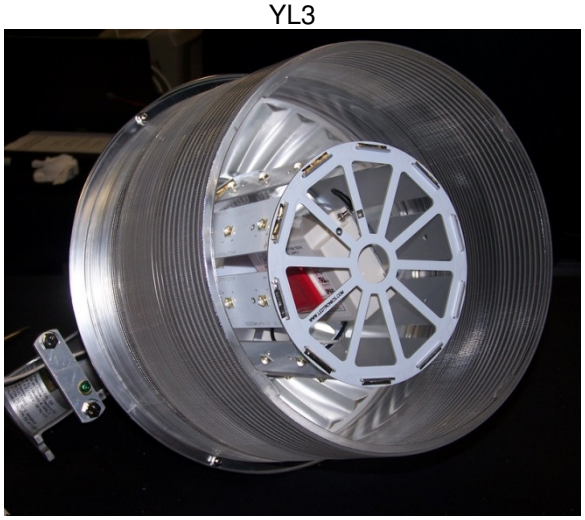
WP4

YL1



YL2



YL3	YL4
	

Test Methods

DLC requires 7 electrical and photometric metrics for retrofit kits. LRC used the test methods given in the Illuminating Engineering Society's (IES) approved method, LM-79-08[24], to conduct its electrical and photometric testing. Six of the seven metrics can be reported as a result of electrical and photometric testing using an integrating sphere: PF, THD, light output (lumens), luminaire efficacy (lm/W), CCT, and CRI. All of the mogul base LED lamps and lamp-luminaires combinations were tested at 120 V however, most of the lamps could operate at a line voltage up to 277V and the luminaires typically could be ordered with multi-tap ballasts. LRC can operate products at a range of line voltages up to 277V and elected to test the luminaires at 120 V to facilitate comparisons with other LED photometric evaluations.[25,26]

An instrument malfunction affected the THD measurements being taken in the sphere while the other photometric and electrical measurements were being taken. Therefore THD was measured after the photometric measurements were completed for 15 lamp-luminaire combinations using a bench-top setup. Power and THD were continuously monitored at the same time and a final THD was measured for each product when the power was stable within the LM-79 allowable tolerance.

LRC used a 2-meter integrating sphere to test the bare mogul base LED lamps and the lamp-luminaire combinations. Custom software was developed by the LRC to operate the products in the integrating sphere, monitor the lamps during testing and ensure that the testing tolerances allowed in LM-79 are monitored. When the bare lamps were tested in the integrating sphere, line voltage (120 V) was applied to the mogul socket directly to operate the lamps. When the mogul base LED lamps were operated in the applicable luminaire, the ballast was either bypassed according to the LED lamp manufacturer instructions, or the lamp was operated on the existing magnetic ballast if no instructions were provided by the LED lamp manufacturer or otherwise. Table 12 above indicates which lamp was tested with the magnetic ballast (no bypass) or without (bypass).

To determine the zonal lumens, LRC pilot tested the luminous intensity distribution (spatial distribution) of some of the luminaires and mogul base LED lamp combinations, using a moving-mirror goniophotometer. This instrument was used to determine the zonal lumens for the yard light and high bay luminaire combinations. An IES file was created from the goniometric results and the zonal lumens were

[24] Illuminating Engineering Society. 2008. *Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products,* LM-79-08. New York: Illuminating Engineering Society.
[25] http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRStreetlights.pdf
[26] http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_StreetlightsLocal.pdf

determined by evaluating the IES file in photometric evaluation software (Photometric Toolbox 32, Lighting Analysts, Inc.)

DLC Electrical and Photometric Technical Requirements for Retrofit Kits

For retrofit kit categories/products, DLC requires that the retrofit kit is tested inside a preapproved luminaire. Electrical and photometric testing has to be conducted per the LM-79 test method and an LM-79 report has to be submitted with the product application. In addition, a photometric (i.e., IES) file has to be submitted as well, presumably to determine if the product is compliant with the zonal lumens requirements.

Tables 15 and 16 show the minimum criteria and tolerances for DLC QPL retrofit kits. LRC used these values and tolerances to determine if the 18 tested products met the applicable criteria for retrofit kits.

Table 15: DLC criteria and tolerances for outdoor and high bay retrofit kits.

Metric	Minimum Required Value	Tolerance
Power Factor (PF)	≥ 0.9	-3%
THD	≤ 20%	5%
Light Output	Depends on category (300 – 10,000 lumens)	-10%
Luminaire Efficacy	Depends on category (60 – 85 lm/W)	-3%
CCT	≤5700K	Defined by ANSI C78.377-2011 For the Nominal 5700 K CCT category, the target CCT and tolerance is 5667 K +/- 355 K
CRI	Depends on category (65-80)	-2 CRI
Zonal Lumens	Depends on category	See Table 16

Table 16: DLC zonal lumens criteria and tolerances for outdoor and high bay retrofit kits.

Application	Zone/Spacing Criteria	Nominal Requirement	Tolerance	Requirement with Tolerance
25) Retrofit Kits for Outdoor Pole/Arm-Mounted Area and Roadway Luminaires	0-90°	100%	-1%	≥99%
	80-90°	≤10%	3%	≤13%
28) Retrofit Kits for Outdoor Wall-Mounted Area Luminaires	0-90°	100%	-3%	≥97%
	80-90°	≤10%	3%	≤13%
34) Retrofit Kits for High-Bay Luminaires for Commercial and Industrial Buildings	20-50°	≥30%	-10%	≥20%

Bare Lamp Results

Table 17 and Figures 12 – 15 show the test results for the bare mogul base LED lamps tested in the integrating sphere. Two of the 18 mogul base LED lamps would not stabilize within the tolerances allowed in LM-79 and their results cannot be reported accurately. One of the mogul base LED lamps requires a ballast and would not operate without one. Repeated testing of this lamp without a magnetic ballast resulted in the lamp failing, and the lamp could not be tested in the moving-mirror goniophotometer.

Table 17: Measured electrical and photometric results for mogul base LED lamps operated in open air.

Lamp ID	Comb. Code	Temp. sphere (℃)	Voltage (V)	Light Output (lm)	Power (W)	Lamp Efficacy (lm/W)	Power Factor	CCT (K)	CRI
109451	WP1	25.8	120.03	4601.0	37.9	121.5	99.0%	4199	84
109452	WP2	25.3	119.95	6684.5	57.2	116.8	98.7%	4239	84
109453	C1	24.9	120.01	5588.1	47.7	117.2	98.7%	4289	84
109454	YL1	25.1	119.95	6737.4	56.3	119.6	98.5%	4185	83
109455	WP3	24.6	120.04	2904.9	26.7	108.9	98.6%	5046	85
109456	YL2	24.8	120.02	3648.2	36.2	100.8	99.3%	4113	83
109457	YL3	24.6	120.01	3021.7	37.2	81.2	97.6%	6210	73
109458	YL4	25.2	119.98	3830.3	49.8	77.0	89.1%	3918	66
109459	HB1	25.4	119.75	12325.1	156.2	78.9	98.3%	4571	76
109460	C2	25.1	119.95	4464.5	54.1	82.6	98.1%	4301	74
109461	AL1	25.2	119.95	4706.0	54.8	85.9	98.0%	4329	74
109463	HB2	No data (lamp would not stabilize within tolerances allowed in LM-79-08)							
109462	WP4	24.7	120.03	2388.3	32.1	74.4	93.7%	4236	86
109466	AL2	24.6	120.05	2135.4	29.1	73.3	97.8%	4504	76
109468	AL3	No data (lamp would not stabilize within tolerances allowed in LM-79-08)							
109471	HB3	Lamp would not operate without magnetic ballast							
109472	AL4	24.3	120.05	2483.0	28.8	86.3	95.2%	5972	85
109473	C3	25.3	119.99	3431.9	39.3	87.3	97.8%	5821	86

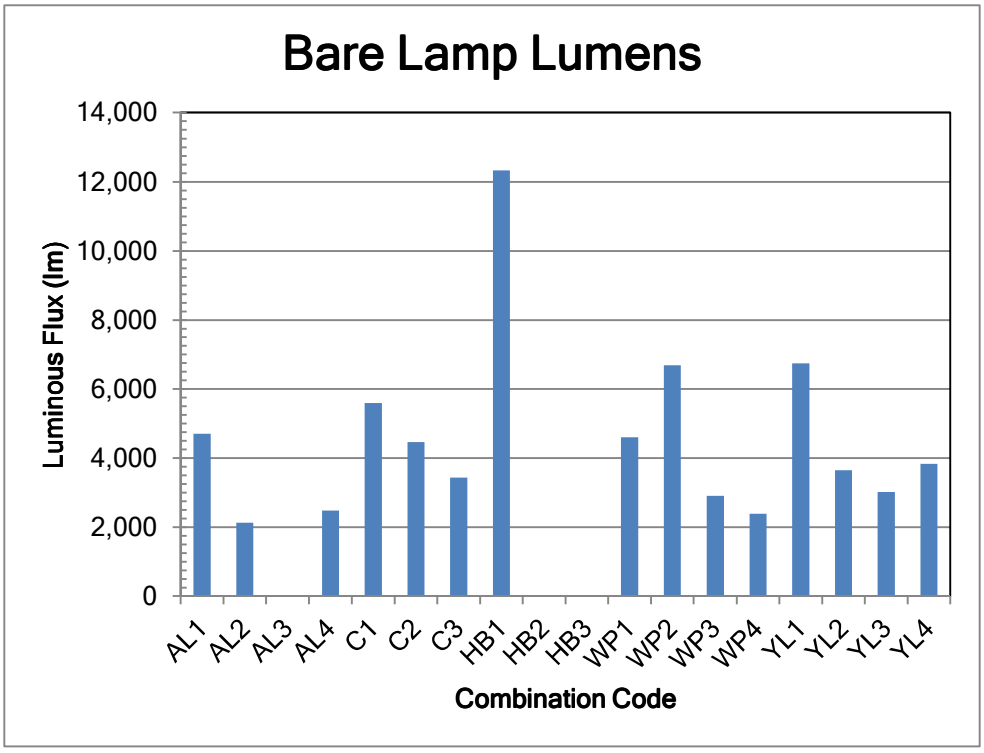


Figure 12: Measured lumens for lamps operated in open air.

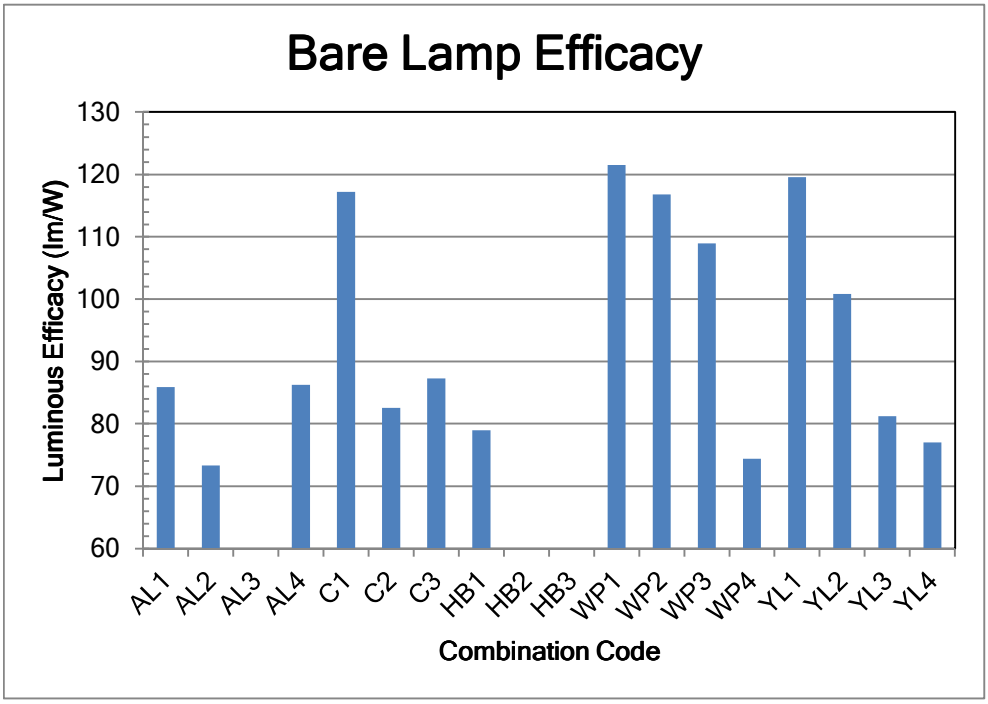


Figure 13: Measured lamp efficacy for lamps operated in open air.

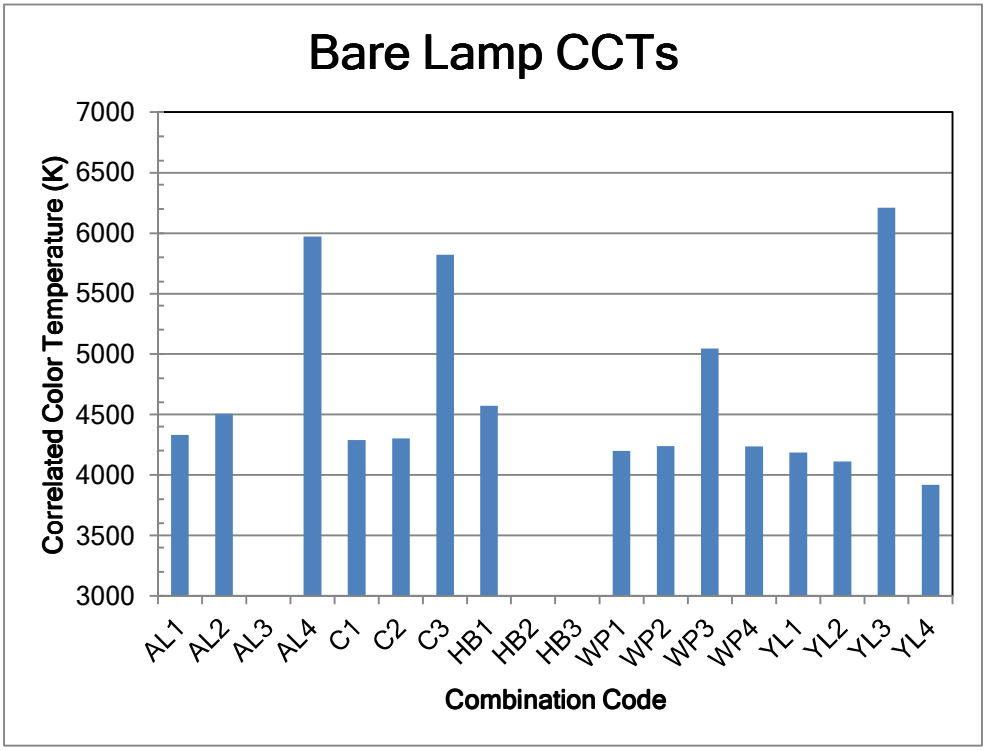


Figure 14: Measured lamp CCT for lamps operated in open air.

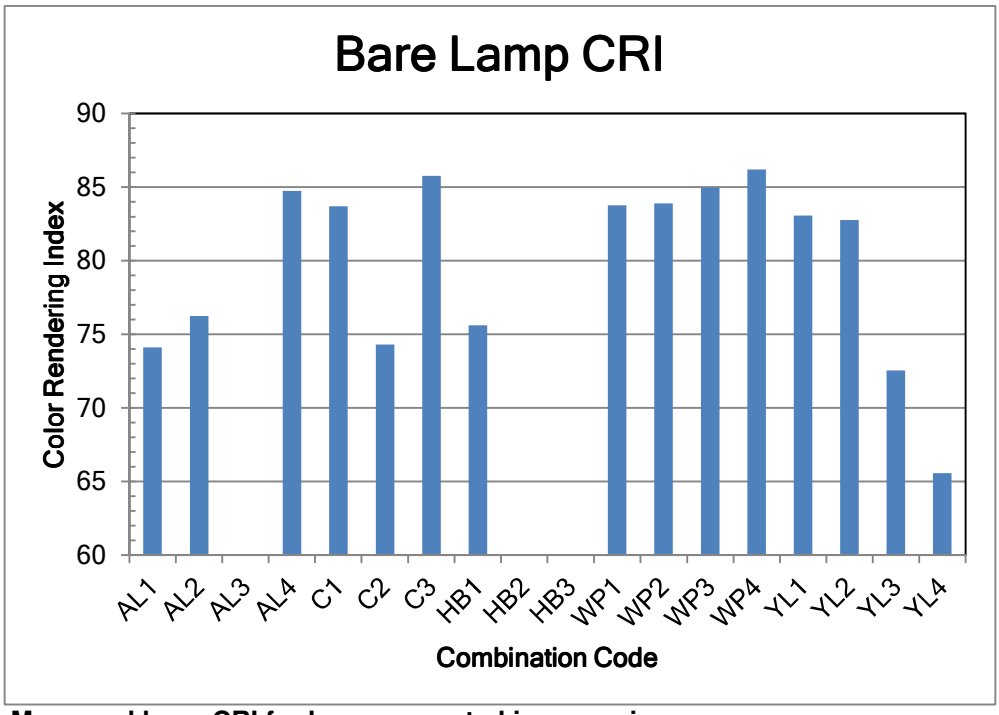


Figure 15: Measured lamp CRI for lamps operated in open air.

Luminaire Results

Table 18 below and Figures 8-10 above show the integrating sphere results for the tested luminaire-lamp combinations. The first six digits in Product ID represent the luminaire ID; second six digits represent the lamp ID. 16 of the 18 luminaire-lamp combinations were able to be measured and provided stable, accurate results[27]. Two of the luminaire-lamp combinations would not stabilize to the tolerances allowed in LM-79-08 and measurements for these products cannot be accurately determined. Light output and CRI (shown in Table 18) for the 16 luminaire-lamp combinations exceeded (e.g. passed) the minimum applicable (or comparable) DLC performance criteria, as shown in Table 20.

Table 18: Measured electrical and photometric results for mogul base LED lamps operated in preapproved luminaires.

Code	Product ID	Temp. sphere (°C)	Voltage (V)	Power (W)	Power Factor (%)	THD (%)	Light Output (lm)	CCT (K)	CRI	Luminaire Efficacy (lm/W)
HB1	109464_109459	25.2	119.85	154.9	98.2	16.9	11412	4517	76	73.7
HB2	109464_109463	No data (lamp would not stabilize within tolerances allowed in LM-79-08)								
HB3	109464_109471	25.1	119.83	359.4	92.0	No data	20791	4003	75	57.8
AL1	109465_109461	24.8	119.95	53.4	98.1	12.5	4075	4379	74	76.4
AL2	109465_109466	24.7	120.10	28.9	97.8	14.0	1811	4633	76	62.7
AL3	109465_109468	25.5	120.04	42.4	93.8	12.1	2904	3923	81	68.5
AL4	109465_109472	25.8	120.06	28.4	94.0	19.4	1629	6081	84	57.4
C1	109467_109453	No data (lamp would not stabilize within tolerances allowed in LM-79-08)								
C2	109467_109460	24.6	119.95	49.1	98.5	11.1	3566	4398	75	72.7
C3	109467_109473	24.8	120.06	38.5	97.0	12.7	3056	5984	86	79.5
YL1	109469_109454	24.4	119.91	58.5	98.9	14.4	6027	4184	83	103.1
YL2	109469_109456	24.6	120.02	38.2	99.5	8.8	3387	4110	83	88.7
YL3	109469_109457	24.4	119.96	36.4	97.6	15.7	2560	6271	73	70.3
YL4	109469_109458	24.7	120.00	41.0	87.9	40.3	3122	3915	66	76.1
WP1	109470_109451	24.4	119.91	65.7	17.9	3.0	2053	4303	83	31.2
WP2	109470_109452	25.1	119.84	84.9	23.0	2.4	2918	4358	83	34.4
WP3	109470_109455	24.2	120.11	26.3	98.5	13.3	1315	5212	84	49.9
WP4	109470_109462	24.3	120.07	31.9	93.6	12.0	1715	4364	86	53.7

[27] The Lunera lamp-luminaire combination (HB3) ceased to be operational after we tried to operate the lamp without a ballast to determine the lamp characteristics. Zonal lumen density and THD measurements could not be conducted on this product.

Table 19 shows the luminaire efficiencies for the tested lamp-luminaire combinations. As indicated previously, three of the LED lamps did not produce bare lamp data, so luminaire efficiencies are only available for 15 of the 18 products tested. The results show that the luminaire efficiency can vary greatly depending on the lamp used. Of particular importance, one of the half-cylindrical mogul base LED lamps tested in the wall pack (WP4) had 60% higher luminaire efficiency than the other three lamps tested in this luminaire (photographic comparisons are shown in Table 14).

Table 19: Measured luminaire efficiencies.
Luminaire efficiencies are only available for products that had measurable bare lamp data.

Code	Product ID	Luminaire Efficiency
HB1	109464_109459	93%
HB2	109464_109463	-
HB3	109464_109471	-
AL1	109465_109461	87%
AL2	109465_109466	85%
AL3	109465_109468	-
AL4	109465_109472	66%
C1	109467_109453	-
C2	109467_109460	80%
C3	109467_109473	89%
YL1	109469_109454	89%
YL2	109469_109456	93%
YL3	109469_109457	85%
YL4	109469_109458	81%
WP1	109470_109451	45%
WP2	109470_109452	44%
WP3	109470_109455	45%
WP4	109470_109462	72%

Results Relative to DLC Criteria

Table 20 indicates the measured Phase 1 luminaire performance relative to the applicable DLC performance requirements for retrofit kits for each luminaire type. Fourteen of the measured mogul base LED lamp-luminaire combinations are comparable to applicable QPL retrofit categories (high bay, area lights, roadway, and wall pack luminaires); the other 4 mogul base LED lamp-luminaire combinations are yard lights, which is not an approved QPL category. Only 4 of the 14 (28%) lamp-luminaire combinations passed all of the applicable DLC performance criteria that were tested, primarily because the remaining 10 products did not meet the minimum luminaire efficacy requirement (including all of the wall pack and high bay luminaire combinations). One of the 14 combinations did not meet the required CCT criteria and two of the 14 combinations did not meet the PF performance criteria (both tested with the magnetic ballast).

Table 20: LED mogul base lamp performance relative to applicable DLC retrofit kit performance criteria.

Lamp-luminaire combinations that pass the DLC QPL requirements for retrofit kits are shaded in green. The yard light metrics are shown in italics and not shaded in green, as described in the text, because there is no yard light category in the DLC QPL. *The pass rating given in the Zonal Lumens column for the high bay combination is based on pilot data.

Code	Product ID	Pass DLC PF Criteria?	Pass DLC THD Criteria?	Pass DLC Light Output Criteria?	Pass DLC Efficacy Criteria?	Pass DLC CCT Criteria?	Pass DLC CRI Criteria?	Pass DLC Zonal Lumens Criteria?
HB1	109464_109459	PASS	PASS	PASS	FAIL	PASS	PASS	PASS*
HB2	109464_109463	No data (luminaire would not stabilize within tolerances allowed in LM-79-08)						
HB3	109464_109471	PASS	Lamp not operational	PASS	FAIL	PASS	PASS	Lamp not operational
AL1	109465_109461	PASS	PASS	PASS	PASS	PASS	PASS	not tested
AL2	109465_109466	PASS	PASS	PASS	FAIL	PASS	PASS	not tested
AL3	109465_109468	PASS	PASS	PASS	PASS	PASS	PASS	not tested
AL4	109465_109472	PASS	PASS	PASS	FAIL	FAIL	PASS	not tested
C1	109467_109453	No data (luminaire would not stabilize within tolerances allowed in LM-79-08)						
C2	109467_109460	PASS	PASS	PASS	PASS	PASS	PASS	not tested
C3	109467_109473	PASS	PASS	PASS	PASS	PASS	PASS	not tested
YL1	*109469_109454*	*PASS*	*PASS*	*PASS*	*PASS*	*PASS*	*PASS*	*N/A*
YL2	*109469_109456*	*PASS*	*PASS*	*PASS*	*PASS*	*PASS*	*PASS*	*N/A*
YL3	*109469_109457*	*PASS*	*PASS*	*PASS*	*PASS*	*FAIL*	*PASS*	*N/A*
YL4	*109469_109458*	*PASS*	*FAIL*	*PASS*	*PASS*	*PASS*	*PASS*	*Lamp flickered and would not stabilize*
WP1	109470_109451	FAIL	PASS	PASS	FAIL	PASS	PASS	not tested
WP2	109470_109452	FAIL	PASS	PASS	FAIL	PASS	PASS	not tested
WP3	109470_109455	PASS	PASS	PASS	FAIL	PASS	PASS	not tested
WP4	109470_109462	PASS	PASS	PASS	FAIL	PASS	PASS	not tested

The yard light is not a covered category given in the DLC QPL. However, we can compare the measured results to DLC criteria for similar applications. Two of the 4 mogul base LED lamps tested in the yard light would have passed the retrofit kit criteria for outdoor arm-mounted area and roadway luminaires for all but the zonal lumens criteria. Since the yard light has a prismatic refractor, it is more similar to a decorative luminaire in that it produces both uplight and downlight. Applying the zonal lumens criteria for decorative outdoor luminaires to this category may be more applicable, since these luminaires do not focus all the light downward by design. To avoid glare, it may also be important to apply a limit on the zonal lumens in the 80-90° zone (the "glare" zone) as is done for the area light and roadway retrofit kit luminaires. If the yard lights were covered by a DLC QPL category and the zonal lumen requirements were applied as follows (≥62% light output: 0-90° and ≤13% light output: 80-90°), two of the 4 yard light combinations tested could meet applicable minimum DLC criteria for retrofit kits.