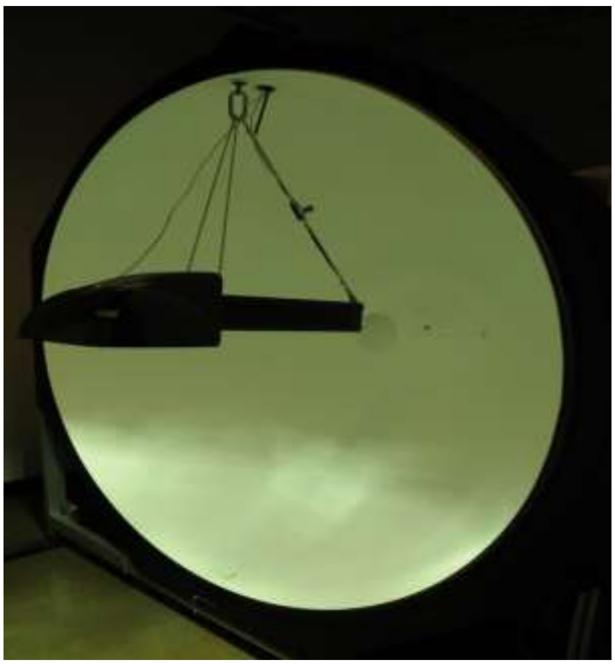
ELECTRODELESS HID EVALUATION PHASE 2 LAB

ET08SCE10702 Report



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Acknowledgements

Southern California Edison's Emerging Products (EP) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technologies Program under internal project number ET08SCE10702. EP project manager Neha Arora conducted this technology evaluation with assistance from Grant Davis at Technology Test Centers (TTCs) and overall guidance and management from Teren Abear and Paul Delaney. For more information on this project, contact Teren.Abear@sce.com.

EXECUTIVE SUMMARY

The goal of this project is to evaluate the feasibility of Electrodeless High Intensity Discharge (ELHID) technology as a light source for outdoor lighting applications that employ shoe-box style fixtures (e.g. parking lot lighting); and to potentially be a viable alternative to the High Intensity Discharge (HID) technology. During this evaluation, ELHID technology was also compared to Light Emitting Diode (LED) technology to understand the state of technology in comparison to other potential technologies available in market.

Commercial lighting accounts for 34.5% of all commercial electricity used in Southern California Edison (SCE) service territory. This lighting load is one of the major contributors to the peak electrical demand. To address this demand, new and upcoming lighting technologies are tested by SCE for possible inclusion in its incentive portfolio that can be offered to its customers.[i]

ELHID or commonly known as Plasma is a new lighting technology and is different from conventional lighting. This technology has no electrodes penetrating a glass envelope, and therefore no mechanical failure points within the bulb. Instead, radio frequency waves are concentrated on the gases in the glass envelope or bulb to generate an intense, bright white light source. This emerging technology has been showcased at various lighting events as a potential replacement for HID lighting that has higher power draw and longer re-strike time. This technology is being developed by various manufacturers.

To access these potential advantages of this technology, SCE tested this technology at its Technology Test Center laboratories. Baseline systems were tested per relevant industry standard methods. ELHID systems were tested per synthesized industry standard methods, since no specific test method existed for ELHID technology. Electrical, photometric, and thermal measurements were taken during each test.

The data collected during the lab testing of this technology revealed that the Plasma technology performed on par with the LED technology in terms of electrical power quality performance. The power demand of Plasma technology is higher than the LED technology (227 Watt (W) vs. 147W respectively); however, it has a considerable demand savings potential when compared to HID technology (e.g., 446W of HID vs. 227W of ELHID). The results are summarized in Table 1.

TABLE 1. SUMMARY OF POWER DRAW

LUMINAIRE TYPE	POWER (W)	LUMEN OUTPUT (LM)
LED luminaire,	147	11000
HID luminaire, 400W standard	446	29685
HID luminaire, 400W high performance	447	36150
ELHID luminaire 2,	227	16930
ELHID luminaire 1,	227	16770

When comparing the results of luminous performance for all three technologies it is evident that the light output of LEDs is the lowest and is corresponding to its lowest power demand. Similarly, ELHIDs use more energy than LEDs and correspondingly, provide more light output. It is also evident that the HIDs consume the most power and provide the highest light output.

While dimming the ELHID fixture a noticeable color shift occurs. The light goes from a greenish-white tint to a bluish-white tint rapidly. This is unlike the LED fixture which maintains its color fairly well.

The thermal test results show that the ELHID fixtures had temperatures comparative to the LED fixture and HID fixtures while operating. This is a significant improvement from the earlier versions of the ELHID fixtures that had high fixture temperatures during operation.

Cost analysis was performed in order to compare the ELHID luminaires with the HIDs and LEDs on the basis of Life Cycle Cost (LCC). The LCCs are calculated at the industry standard life rating of 15,000 hours for HIDs, 50,000 hours for ELHID and LEDs and 100,000 hours for LEDs. Existing standards support predicted longer life for LEDs but field data to support this is very limited. An energy rate of $0.15 per Kilowatt hour (kWh) was used for energy cost calculations.

Table 2 shows the calculated LCC comparisons at average rated hours of operation for these three technologies. The operating hours are assumed to be 12 hours per day for a typical night operation.

TABLE 2. LCC ANALYSIS OF ELHID, HID AND LED TECHNOLOGY

TECHNOLOGY	REPLACEMENT LCC AT 15,000 HOURS ($)	REPLACEMENT LCC AT 50,000 HOURS ($)	REPLACEMENT LCC AT 100,000 HOURS ($)
HID (Standard)	1753	3986	5987
LED	1279	1825	2315
ELHID	1440	2266	4161

The cost of luminaires is the largest impact on the LCC of the ELHID. Although the LCC analysis shows that the ELHID is a viable alternative to the HID technology, reducing the cost further may aid in increasing LCC savings of the ELHID and allow it to compete with LEDs.

As this technology continues to evolve, it is recommended that the Emerging Technology program continue to monitor the progress and continue to test future revisions of this product.

ABBREVIATIONS

CCT	Correlated Color Temperature
CRI	Color Rendering Index
ELHID	Electrodeless High Intensity Discharge
HID	High Intensity Discharge
LCC	Life Cycle Cost
LED	Light Emitting Diode
Lm	Lumen
RF	Radio frequency
SCE	Southern California Edison
SPD	Spectral Power Density
W	Watt

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INTRODUCTION

Commercial lighting accounts for 34.5% of all commercial electricity used in Southern California Edison (SCE) service territory. This lighting load is one of the major contributors to the peak electrical demand. To address this demand, new and upcoming lighting technologies are tested by SCE for possible inclusion into the incentive portfolio that can be offered to SCE customers.

Electrode-Less High Intensity Discharge (ELHID) or commonly known as Plasma is a new lighting technology that is different from conventional lighting. This technology has no electrodes penetrating a glass envelope, and therefore no mechanical failure points within the bulb. Instead, radio frequency waves are concentrated on the gases in the glass envelope or bulb in order to generate an intense, bright white light source. This emerging technology has been showcased at various lighting events as a potential replacement for induction lighting that has higher power draw and longer re-strike time. This technology is being developed by various manufacturers.

The technology will be tested for its performance in terms of lumen intensity, power consumption, color rendering index (CRI), correlated color temperature (CCT), and dimming capability at the Technology Test Centers (TTC) of SCE located in Irwindale, California.

BACKGROUND

SCE’s Emerging Products group first became aware of the ELHID technology and its demand and energy savings potential in 2008. At that time two U.S. companies were developing the technology for high intensity lighting applications. The ELHID technology of one of the manufacturer’s was tested in 2011 during phase 1; this project is the phase 2 testing of this technology as it has improved from its earlier versions.

Investigating manufacturer performance claims by way of documenting luminous flux and power usage, as well as other performance characteristics, helps overcome market barriers and provides a basis for more widespread acceptance of this emerging technology.

To access the potential advantages of this technology, SCE is testing this technology at its TTC laboratories. TTC consists of a suite of integrated demand-side management laboratories for studying the performance characteristics and energy savings of air conditioning, lighting, and refrigeration systems under replicable conditions. TTCs also have a dedicated area to test and evaluate every aspect of lighting systems using specialized equipment such as integrating sphere and state-of-the-art power logging equipment. See Appendix A – Technology Test Centers for more details on the TTCs.

ASSESSMENT OBJECTIVES

The objectives of this evaluation are to:

- Perform a laboratory technology assessment in order to evaluate the performance of ELHID lighting technology and its potential to replace High intensity Discharge (HID) technology for outdoor lighting applications that employ shoe-box style fixtures (e.g., parking lot lighting).
- Assess incremental demand savings over other mainstream HID lighting systems.
- Assess and compare the performance of ELHID technology to Light Emitting Diode (LED) technology.
- Measure and evaluate the photometric performance parameters for this technology such as, total light output in lumens, Correlated Color Temperature (CCT), and Color Rendering Index (CRI). Additionally, power demand, ambient temperature, and surface temperatures are also recorded.
- Measure and evaluate the change/shift in color temperature, power demand, and response time to change the intensity levels or dimming system.

TECHNOLOGY/PRODUCT EVALUATION

ELHID technology consists of two main components, a manufacturer's development kit and the fixture.

The development kit consists of an emitter or the light source, a small sealed glass envelope that contains a proprietary mixture of gases and a driver or the waveguide. The driver and emitter are connected by a radio frequency (RF) cable that transmits 440 megahertz (MHz) radio frequency power from the driver to the emitter. As the cable itself is an RF waveguide, it must be custom made to certain lengths that are integer multiples of the transmitted frequency. This is a design consideration for fixture manufacturers in order to minimize attenuation for maximum performance by using the shortest possible cable between the driver and emitter.

The light producing side of the emitter is an un-terminated RF waveguide that must be shielded. Per Federal Communications Commission (FCC) regulations (Title 47, Part 15, Section 15.109a),[ii] electrical and electronic devices must not produce emissions or 'noise' of significant intensity as to interfere with surrounding electronic devices. Inserting a Faraday screen between the source and fixture shields the emitter. However, this reduces the usable light output from the source.

This small glass envelope is strategically placed in a radio frequency waveguide and is bombarded with power at a predetermined frequency tuned to simulate the gases inside the glass envelope. The gases, when sufficiently excited and energized, produce a white light that is used for illumination in various applications via an appropriate fixture. The light source (e.g., the glass envelope) can be mounted in the fixture either vertically or horizontally depending on the application for which it is used. The light from the source is produced without the use of electrodes that penetrate the glass envelope; it eliminates the common point of failure seen in other technologies. Figure 1 shows the entire development kit.

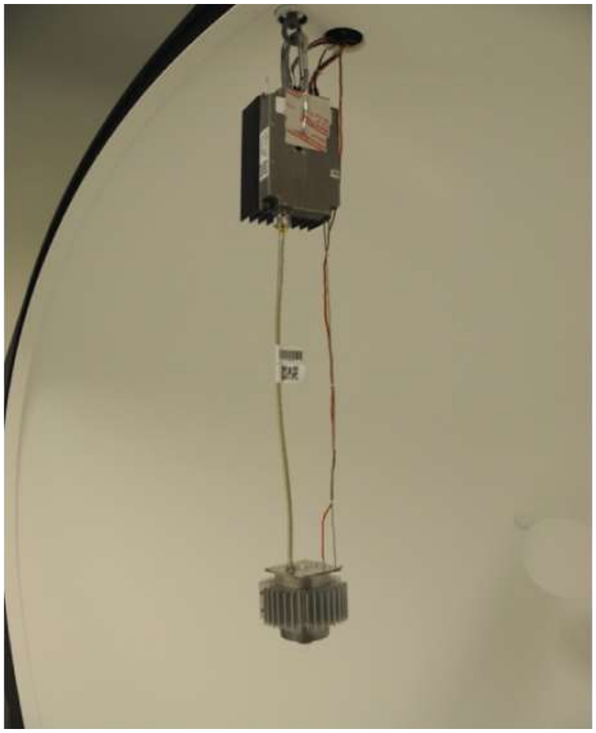

FIGURE 1. DEVELOPMENT KIT

The fixture in the ELHID technology is designed specifically for outdoor application based on the orientation of the light source and is instrumental in directing the light to the desired area with uniform intensity. The fixture used in this evaluation is shown in Figure 2.

FIGURE 2. ELHID LUMINAIRE UNDER TEST

This technology is designed to replace HIDs, metal halides, and LED fixtures for parking lot lighting applications. Major advantages of this technology over the incumbent technologies are: longer life span due to elimination of electrodes; higher density uniform lighting; and reduced power consumption in comparison to the metal halides and HIDs.

To access the potential advantages, SCE is testing this technology at its TTC laboratory. TTC consists of a suite of integrated demand-side management laboratories for studying the performance characteristics and energy savings of air conditioning, lighting, and refrigeration systems under replicable conditions. TTCs also have a dedicated area to test and evaluate every aspect of lighting systems using specialized equipment such as integrating sphere and state-of-the art power logging equipment. See Appendix A – Technology Test Centers for more details on the TTCs.

TECHNICAL APPROACH/TEST METHODOLOGY

Eight devices under test (DUTs), including five representative baseline systems and three representative ELHID systems, were chosen for the project. Baseline systems were tested per relevant industry standard methods. ELHID systems were tested per synthesized industry standard methods, since no specific test method existed for ELHID technology. Electrical, photometric, and thermal measurements were taken during each test. All testing was conducted at Southern California Edison's TTC in Irwindale, in the 2-Meter Sphere-Spectroradiometer Laboratory (2MSSL).

BASELINE SYSTEMS

The five representative baseline systems were comprised of two HID luminaire/lamp systems, two HID bare-lamp systems, and one LED luminaire system. The LED tested during this evaluation was recommended by the manufacturer as a viable replacement for the HID under test as shown in Table 3. The two HID bare-lamp systems used the same physical lamps and ballasts as the two HID luminaire/lamp systems. All baseline devices tested during this evaluation are listed in Table 3.

TABLE 3. BASELINE DEVICES TESTED

DEVICE NAME	SYSTEM TYPE	TECHNOLOGY	NOTES
HID luminaire, 400 Watt (W) standard performance	Luminaire/lamp	HID	Tested as a luminaire/lamp system with 400W/H75/ED28/PS/740 lamp
HID luminaire, 400W high performance	Luminaire/lamp	HID	Tested as a luminaire/lamp system with MS400/PS/BU-ONLY/BT28 lamp
HID lamp, 400W standard performance	Bare-Lamp	HID	Tested as a bare-lamp system with the same physical lamp and ballast as 400W standard performance luminaire/lamp system above
HID lamp, 400W high performance	Bare-Lamp	HID	Tested as a bare-lamp system with the same physical lamp and ballast as 400W high performance luminaire/lamp system above
LED luminaire	Luminaire	LED	Per manufacturers recommendation

Highlights and images for each representative baseline system follow. Manufacturer specification sheets are available in the Appendix B- DUT Spec Sheets.

HID LUMINAIRE, 400W STANDARD PERFORMANCE

Design highlights:

- Fully-enclosed parking/area shoebox-design with flat glass lens
- Textured aluminum reflector
- Fixed output magnetic ballast
- 400W pulse-start metal halide (PSMH) lamp
- Horizontal (base sideways) lamp orientation

FIGURE 3. MANUFACTURER IMAGE OF BASELINE "HID LUMINAIRE, 400W STANDARD PERFORMANCE"

HID Luminaire, 400W High Performance

Design highlights:

- Fully-enclosed parking/area shoebox-design with flat glass lens
- Polished multi-surface aluminum reflector
- Fixed output magnetic ballast
- 400W PSMH lamp
- Vertical (base up) lamp orientation

Figure 4. Manufacturer image of baseline "HID Luminaire, 400W High Performance"

HID Lamp, 400W Standard Performance

- Note: Same physical lamp and ballast as 400W standard performance luminaire/lamp system
- Fixed output magnetic ballast
- 400W PSMH lamp
- Horizontal (base sideways) lamp orientation

HID Lamp, 400W High Performance

- Note: Same physical lamp and ballast as 400W high performance luminaire/lamp system
- Fixed output magnetic ballast
- 400W PSMH lamp
- Vertical (base up) lamp orientation

LED LUMINAIRE

Design highlights:

- Convectively cooled parking/area design
- Individually lensed LED packages
- Dimmable electronic driver (0–10 Voltage Direct Current (VDC), current source)
- 152W LED light engine

FIGURE 5. MANUFACTURER IMAGE OF BASELINE "LED LUMINAIRE"

ELECTRODE-LESS HID SYSTEMS

The three representative ELHID systems were comprised of two luminaire systems and one development kit system, as shown in the Table 4. The two luminaire systems were the same make and model. All three ELHID systems used the same make and model of light engine and AC-to-DC power supply.

TABLE 4. BASELINE DEVICES TESTED

DEVICE NAME	SYSTEM TYPE	TECHNOLOGY
ELHID luminaire 1	Luminaire	ELHID
ELHID luminaire 2	Luminaire	ELHID
ELHID Development Kit	Development Kit	ELHID

Highlights and images for each representative ELHID system follow. Manufacturer specification sheets are available in the Appendix B- DUT Spec Sheets.

ELHID LUMINAIRES 1 AND 2

Design highlights:

- Fully-enclosed parking/area design with integral mounting arm and flat glass lens
- Polished multi-surface aluminum reflector
- Dimmable electronic transmitter/driver (0–10 V dc, current sink)
- 230W ELHID light engine
- Vertical (base up) lamp/capsule orientation

FIGURE 6. MANUFACTURER IMAGE OF "ELHID LUMINAIRES 1 AND 2" (NOTE: THE ARM MOUNT WAS AN INTEGRAL PART OF THE LUMINAIRE, CONTAINING THE AC-TO-DC POWER SUPPLY AND ELECTRONIC TRANSMITTER/DRIVER.)

ELHID DEVELOPMENT KIT

Design highlights:

- Luminaire manufacturer-oriented light engine without lens or RF mesh
- No reflector
- Dimmable electronic transmitter/driver (0–10 V dc, current sink)
- 230W ELHID light engine
- Vertical (base up) lamp/capsule orientation

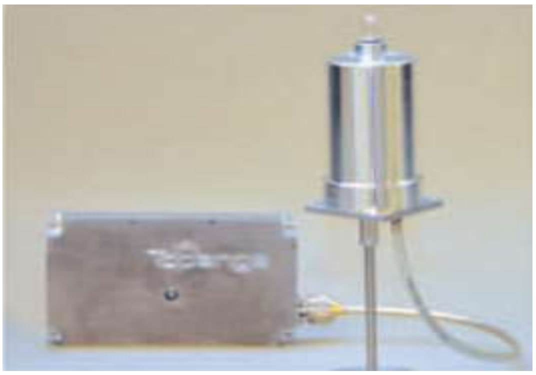

FIGURE 7. MANUFACTURER IMAGE OF ELHID DEVELOPMENT KIT (NOTE: AC-TO-DC POWER SUPPLY IS NOT SHOWN.)

TEST PLAN

DUT SELECTION

All five representative baseline systems were chosen with input from a local area lighting manufacturer to create a nominal point of reference in which to compare the representative ELHID systems. Characteristics for consideration included nominal power draw, luminous flux, and IES distribution classification. (Real-world baseline system characteristics may vary from those used for this project.) All three representative ELHID systems were provided by the respective light engine or luminaire manufacturer.

TEST CONFIGURATIONS

Baseline systems were tested per relevant industry standard methods. ELHID systems were tested per synthesized industry standard methods, since no specific test method existed for ELHID technology. Electrical, photometric, and thermal measurements were taken during each test. All testing was conducted at Southern California Edison's TTC in Irwindale, in the 2-Meter Sphere-Spectroradiometer Laboratory (2MSSL). See Figure 8.

FIGURE 8. TECHNOLOGY TEST CENTERS' 2-METER SPHERE-SPECTRORADIOMETER LABORATORY (2MSSL)

SEASONING

"HID luminaire, 400W standard performance" (including lamp), and "HID luminaire, 400W high performance" (including lamp) were seasoned for at least 100 hours per IES LM-54-99, "IESNA Guide to Lamp Seasoning," Section 2.2 "Discharge Lamps," in order to minimize time-related changes in photometric, colorimetric, and electrical characteristics. Additionally, "ELHID luminaire 1" was seasoned for 408 hours. However, "ELHID luminaire 2" was not seasoned, so it could be compared to "ELHID luminaire 1." Also, the "LED luminaire" was not seasoned because LED lighting typically is not seasoned prior to testing.

DUTs were connected to a Tenma 72-7675 AC power source at 277 Vrms and 60 hertz (Hz) during seasoning, as shown in Figure 9. DUTs were also mounted to a custom test stand for proper orientation during seasoning; see Figure 9 and Figure 10.

FIGURE 9. TENMA 72-7675 AC POWER SOURCE

FIGURE 10. DUTS MOUNTED TO CUSTOM TEST STAND

ELECTRICAL AND PHOTOMETRIC TEST STANDARD

"HID luminaire, 400W standard performance," "HID luminaire, 400W high performance," "HID lamp, 400W standard performance," and "HID lamp, 400W high performance" were tested per IES LM-51-00, "IESNA Approved Method for the Electrical and Photometric Measurements of High Intensity Discharge Lamps," Section 9.2 "Integrating Sphere" and Section 10.3 "Integrating Sphere Measurement," to measure electrical and photometric characteristics. Similarly, "LED Luminaire" was tested per IES LM-79-08, "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products," Section 9.1 "Integrating sphere with a Spectroradiometer," to measure electrical and photometric characteristics.

All three ELHID systems were tested per a synthesized version of IES LM-51-00 and IES LM-79-08. LM-79 applies to solid-state lighting (SSL) technology and uses absolute photometry where the luminaire and light engine are tested together as an integrated system. Conversely, LM-51 applies to HID technology and uses relative photometry (see IES LM-51-00 and IES LM-78-07), meaning the luminaire and lamp are tested separately. Since ELHID technology is a blend of HID and SSL technology, neither LM-79 nor LM-51 applied directly to the ELHID systems. However, ELHID technology is integrated in nature and requires absolute photometry, similar to SSL technology. Therefore, LM-79 was used as a starting point for the ELHID test method, with criteria from LM-51 used for determining the stability of the light output.

Dimmable DUTs were tested in 10% increments from 100%to minimum operating input power. The LED and ELHID fixtures tested during this evaluation were dimming fixtures whereas the HID fixture was non-dimming. Therefore, HID and ELHID are compared at full power only. LED and ELHID fixtures are compared at full power as well as dimming levels.

TEST SETUP

The following measurements were taken during each test.

Electrical

Electrical measurements were taken at the primary power input for luminaire tests. Electrical measurements were also taken at the lamp (secondary of ballast) for bare-lamp tests. For the development kit, electrical measurements were taken on the primary and secondary sides of the AC-to-DC power supply. For all dimmable systems, electrical measurements were also taken on the control signal path (negligible power levels). The details of each parameter recorded for electrical, photometric and thermal performance are provided in Table 5, Table 6, and Table 7.

TABLE 5. ELECTRICAL MEASUREMENTS RECORDED

MEASUREMENT	UNITS
Voltage	Vrms
Voltage Total Harmonic Distortion (THD)	%
Current	A rms
Current THD	%
Power	W
Power Factor	PF
Phase Angle	°
Frequency	Hz

Photometric

TABLE 6. PHOTOMETRIC MEASUREMENTS RECORDED

MEASUREMENT	UNITS
Radiant Flux	mW
Luminous Flux	Lm
Correlated Color Temperature	K
Color Rendering Index	Ra
Chromaticity	X
Chromaticity	Y

Thermal

TABLE 7. ELECTRICAL MEASUREMENTS RECORDED

MEASUREMENT	UNITS
Sphere interior air temperature	° F
Sphere exterior air temperature	° F
Housing surface temperature (only HID DUTs)	° F
Resonator surface temperature (only UHID DUTs)	° F
Transmitter heat sink surface temperature (only UHID DUTs)	° F
Luminaire surface temperature oblique image	° F

INSTRUMENTATION PLAN

ELECTRICAL

The power analyzer system was comprised of a Yokogawa WT1800 precision power analyzer, as shown in Figure 11. DUTs were powered by an Elgar CW1251P programmable AC power source, also shown Figure 12. Dimming control signals for current source systems were provided by a standard 0–10 VDC fluorescent slide dimmer. For current sink systems, dimming control signals were provided by an Agilent E3634A DC power source, shown in Figure 11.

FIGURE 11. YOKOGAWA WT1800 PRECISION POWER ANALYZER (BLUE SCREEN IN MIDDLE), ELGAR CW1251P (BOTTOM), AND AGILENT E3634A (TOP)

PHOTOMETRIC

The sphere-spectroradiometer system was comprised of a Labsphere LMS-760 light measurement sphere, LPS-100-0307 auxiliary lamp power supply, CDS 1100 spectrometer (280–850 nano meter (nm), and MtrX-SPEC spectral light measurement software, as shown in Figure 12.

FIGURE 12. SPHERE-SPECTRORADIOMETER SYSTEM

THERMAL

The thermal infrared (IR) camera used during testing was a Fluke TiR3 thermal imager. The data acquisition (DAQ)-thermocouple system was comprised of a National Instruments cDAQ-9172 8-slot USB chassis, 9211 4-ch thermocouple differential input module, and LabVIEW full-development system, as shown in Figure 13.

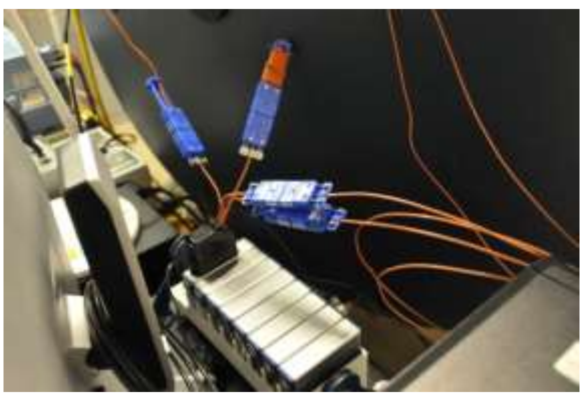

FIGURE 13. DAQ-THERMOCOUPLE SYSTEM

RESULTS

The results of this evaluation are divided into three sections: electrical; photometric and thermal. Analysis of each parameter measured during this evaluation is provided in their respective sections below.

ELECTRICAL

NON DIMMING

The HID luminaire tested during this evaluation was non-dimming; therefore ELHID and LED luminaire were compared to HID luminaire at full power only. The power and power factor comparison of the three technologies is shown in Table 8.

TABLE 8. POWER AND POWER FACTOR COMPARISON AT FULL POWER

LUMINAIRE TYPE	POWER (W)	POWER FACTOR
LED luminaire	147	0.97
HID luminaire, 400W standard	446	0.95
HID luminaire, 400W high performance	447	0.98
ELHID luminaire 2	227	0.93
ELHID luminaire 1	227	0.93

Table 8 shows that Plasma technology has a considerable demand savings potential when compared to traditional HIDs but the demand of Plasma technology compared to LEDs is higher at full power.

DIMMING

While dimming, only ELHID and LED technology was compared. The power factor of ELHID and LED luminaire during testing were very close and followed the same trajectory till 65% dimming level. The ELHID technology could not be dimmed further due to its design. LED technology was further dimmed to 11% of full power and its power factor dropped significantly at 40% of full power and continued to degrade with each consecutive lower dimming level. The reduction in power draw for ELHID technology was higher during dimming whereas the LEDs had a straight line depreciation in its power draw corresponding to the dimming levels. The electrical performance of ELHID and LEDs while dimming is shown in Figure 14.

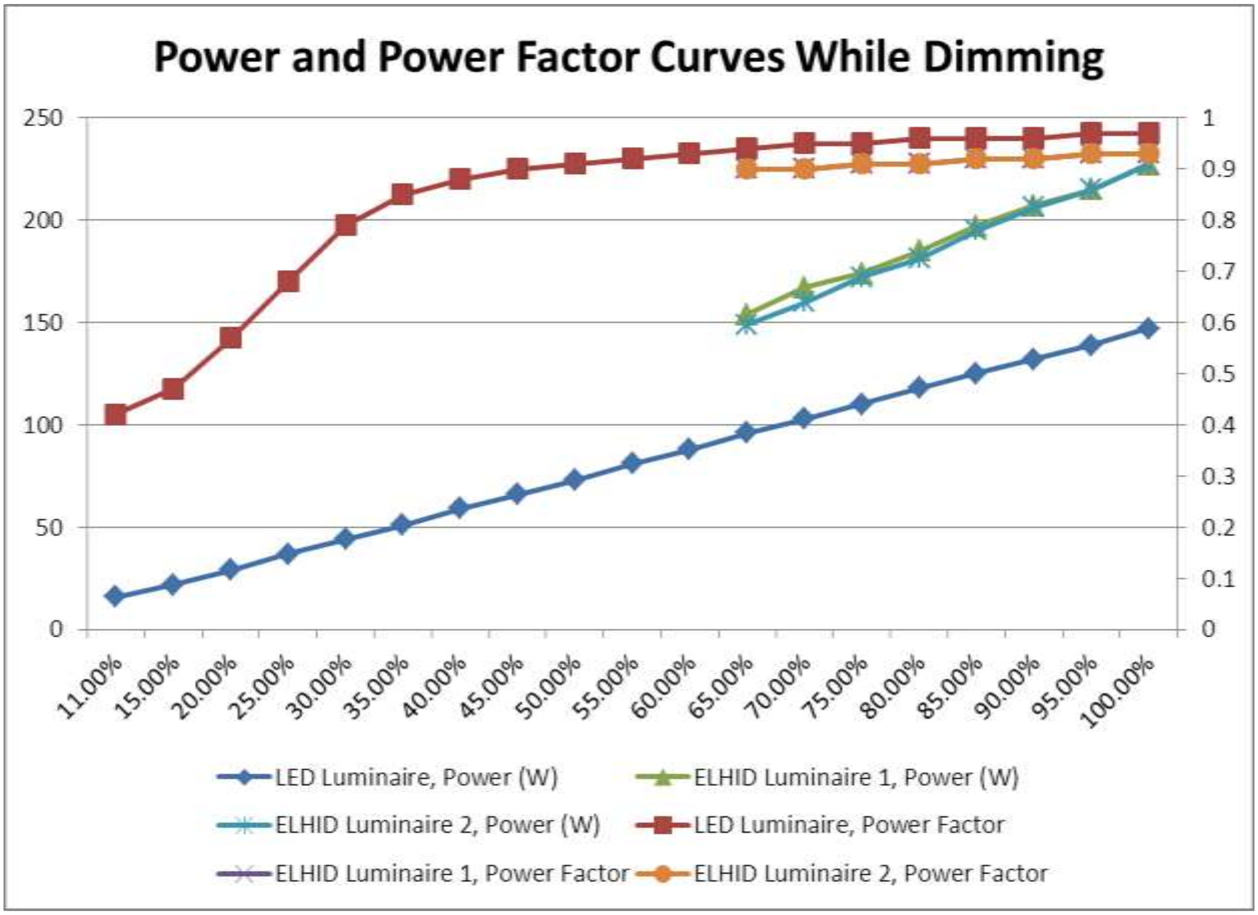

FIGURE 14. POWER AND POWER FACTOR ELHID AND LED TECHNOLOGY WHILE DIMMING

LIGHT SOURCE ELECTRICAL PERFORMANCE COMPARISON

The comparison of bare lamps for HID and ELHID technology is shown in Table 9.

TABLE 9. ELECTRICAL PERFORMANCE COMPARISON OF ELHID AND HID LIGHT SOURCE

LAMP TYPE	LAMP POWER (W)	LAMP POWER FACTOR
HID lamp, 400W standard	129.7	0.90
HID lamp, 400W high performance	133.0	0.92
ELHID development kit, dimming, 100% input power	23.3	N/A*

*Note: The ELHID development kit consists of a light source that contains a proprietary mixture of gases and a driver or the waveguide. The waveguide is typically custom-made to certain lengths that are integer multiples of the transmitted frequency to minimize attenuation for maximum performance. The ELHID light source cannot be isolated from the waveguide. Therefore, the technology does not yield itself to collect power factor of just the light source.

Table 9 above shows that the power demand of an ELHID development kit (light source) is fairly low compared to the bare-lamp of an HID. LED light source could not be compared because the LED's fixtures are manufactured such that the light source cannot be isolated from the fixture for testing.

PHOTOMETRIC

NON DIMMING

To draw photometric comparison among three technologies, CCT, CRI, Luminous Flux, Radiant flux were measured and recorded. The results for CRI, CCT and Luminous Flux are shown in Table 10.

TABLE 10. PHOTOMETRIC PERFORMANCE COMPARISON OF ELHID, HID AND LED FIXTURE/LAMP

FIXTURE/LAMP	CCT	CRI (RA)*	CRI (R9)*	LUMINOUS FLUX (LM)	EFFICIENCY (LM/W)
ELHID, Luminaire 1	4816	69	-90	16770	73.99
ELHID, Luminaire 2	4789	69	-89	16930	74.61
HID, 400W Standard Luminaire	4310	62	-129	29685	66.52
HID, 400W, High Performance Luminaire	3778	61	-138	36150	80.96
LED Luminaire	3937	64	-33	11260	76.70

*Note: The first eight samples of a light source are relatively low saturated colors and are evenly distributed over the complete range of hues. These eight samples are employed to calculate the general color rendering index Ra. The last six samples provide supplementary information about the color rendering properties of the light source; the first four for high saturation, and the last two as representatives of well-known objects and are used to calculate R9-R15. The specification for measuring CRI is given in CIE publication 13.3-1995.

The spectral power density of each fixture was recorded in the lab to see the color distribution properties of each technology. The results of these tests are shown in Figure 15. From the graph shown in Figure 15, it is clear ELHID has a relatively smooth Spectral Power Density (SPD), similar to LED, while traditional metal halide HID has a very "peaky" SPD.

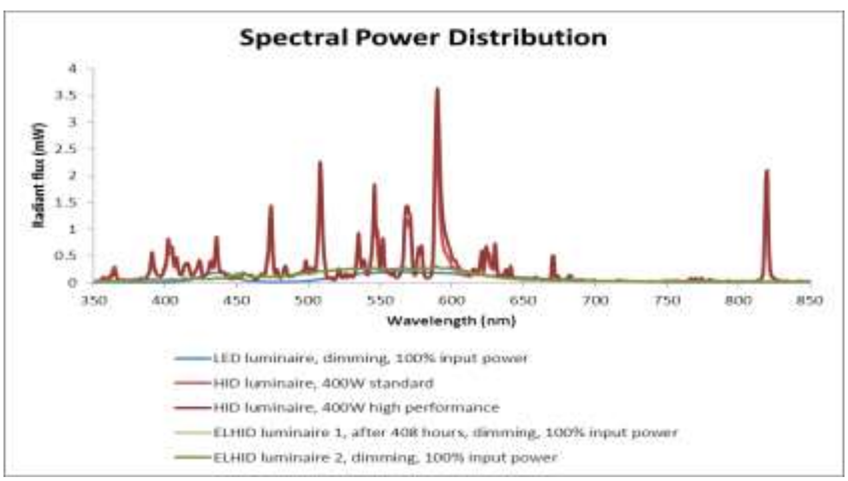

FIGURE 15. SPECTRAL POWER DENSITY DISTRIBUTION OF ELHID, HID AND LED AT FULL POWER

The smooth SPD or the continuous spectra of ELHID and LED fixtures indicate that the these light sources produce less distortion of the object colors whereas, the HID with its peaky SPD highlights certain colors more than others on an object illuminated by HID light source.

The chromaticity performance of the three technologies was also measured during this evaluation and is shown in Figure 16. The graph shows that the ELHID fixture provides a slightly greenish-white light compared to HID and LEDs. The HIDs light color is closest to the white area that lies between red and green area of the chromaticity diagram and the light output of LEDs is somewhere between the HID and ELHID light output levels.

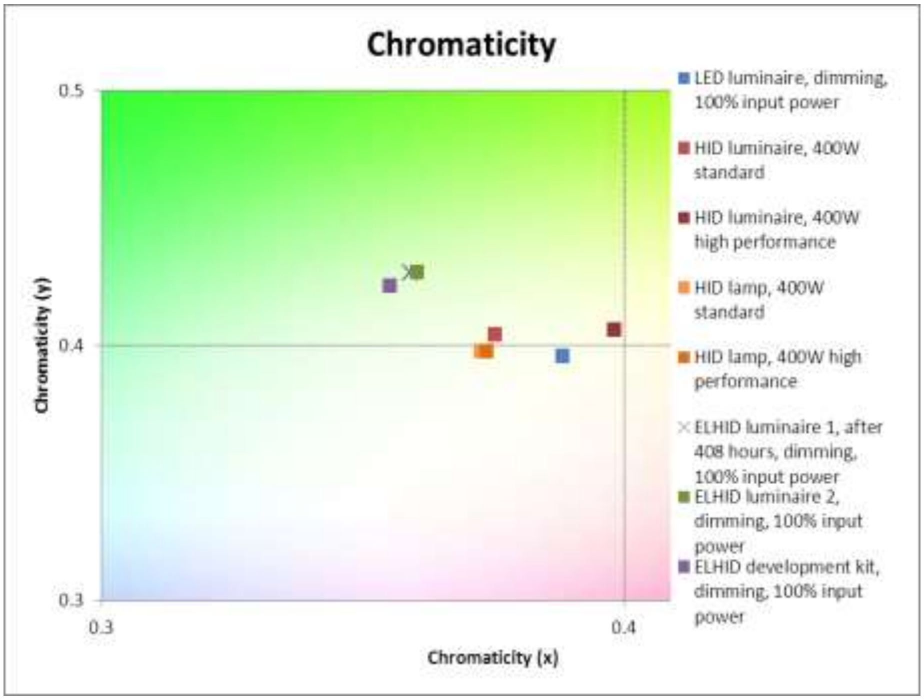

FIGURE 16. CHROMATICITY DIAGRAM REPRESENTING ELHID, HID, AND LED LUMINAIRE PERFORMANCE AT FULL POWER DURING LAB TESTS

The graph in Figure 16 indicates that of the three technologies. HID has the most white light and ELHID has a slightly greenish-white tint, at full power; although the greenish-white tint may not appear so distinct outside the testing sphere or when installed on a tall light pole.

DIMMING

Dimming ELHID is compared to LED technology only because the HID fixture tested during this evaluation was not capable of dimming. It is important to note that while dimming ELHID loses its efficacy and relative light output faster than LEDs, LEDs maintain the system efficacy fairly well and reduction in light output is proportional to the decrease in power supplied to the luminaire. Figure 17 shows the performance of an ELHID and LED while dimming.

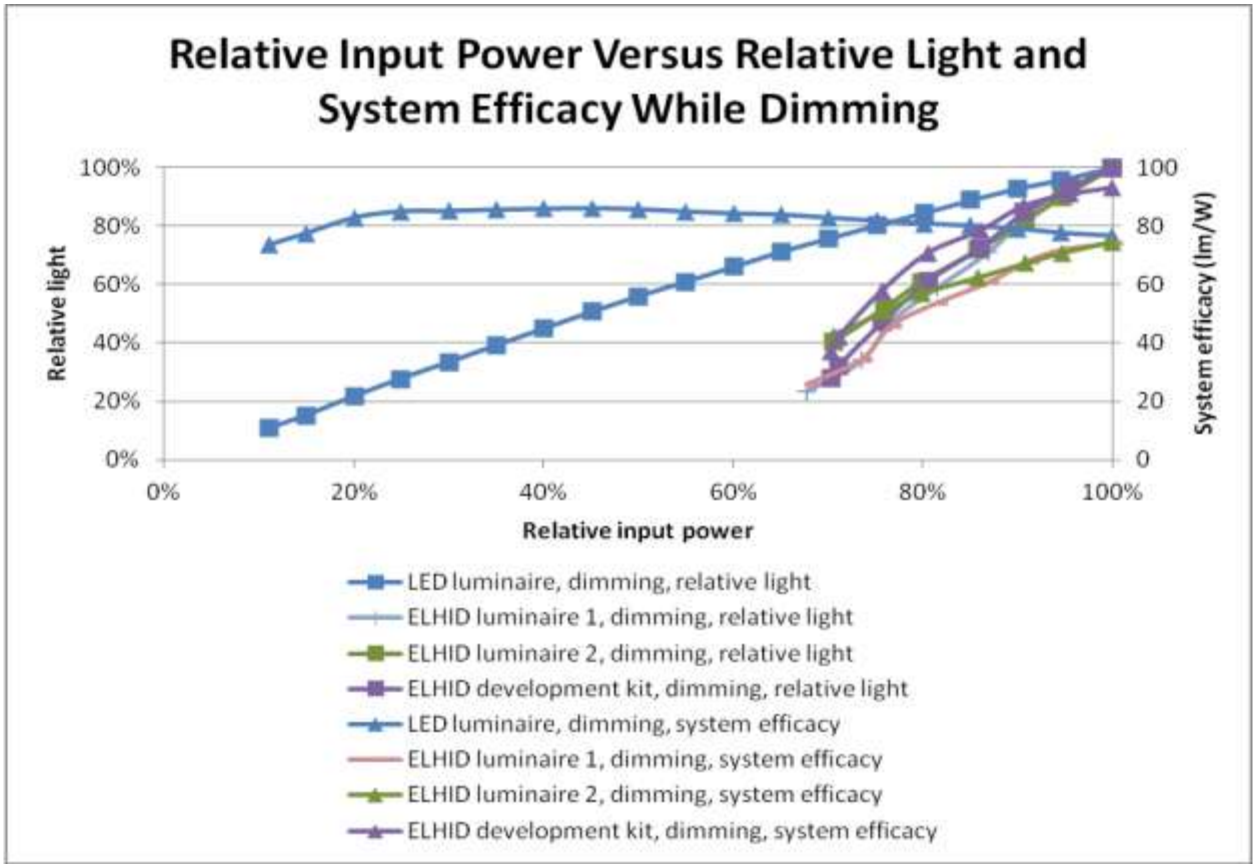

FIGURE 17. PERFORMANCE OF ELHID AND LED TECHNOLOGY WHILE DIMMING

The graph in Figure 17 clearly shows that the relative light output of an ELHID is fairly smooth up to 80% of input power level. After that the decline in light output and system efficacy is relatively fast and the lowest dimming level that can be achieved using this technology is 65%.

While dimming, the SPD of ELHID and LED fixture was recorded to see the color distribution properties of both technologies. The results of these tests are shown in Figure 18.

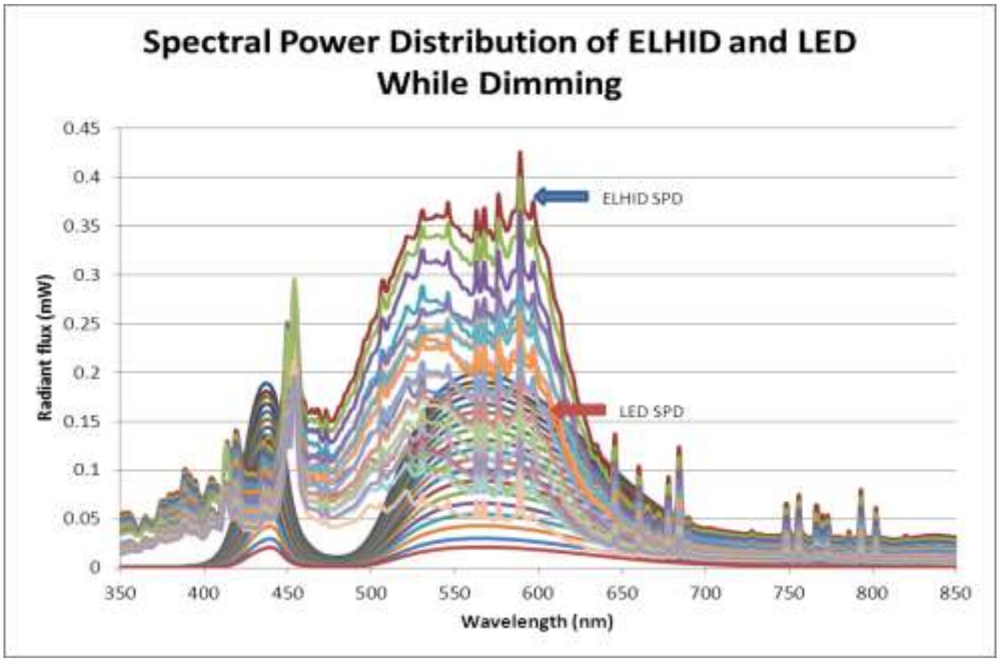

FIGURE 18. SPECTRAL POWER DENSITY OF ELHID AND LED WHILE DIMMING

From the graphs in Figure 18, it is observed that ELHID SPD has a larger color shift than LED technology. On observing closely, the color shift in ELHID technology can be noticed although it is more apparent in the chromaticity diagram.

The chromaticity performance of the ELHID and LED is shown in Figure 19. While dimming, the ELHID luminaire rapidly shifts its output light color from greenish-white to bluish-white whereas LED luminaire maintains its color fairly well.

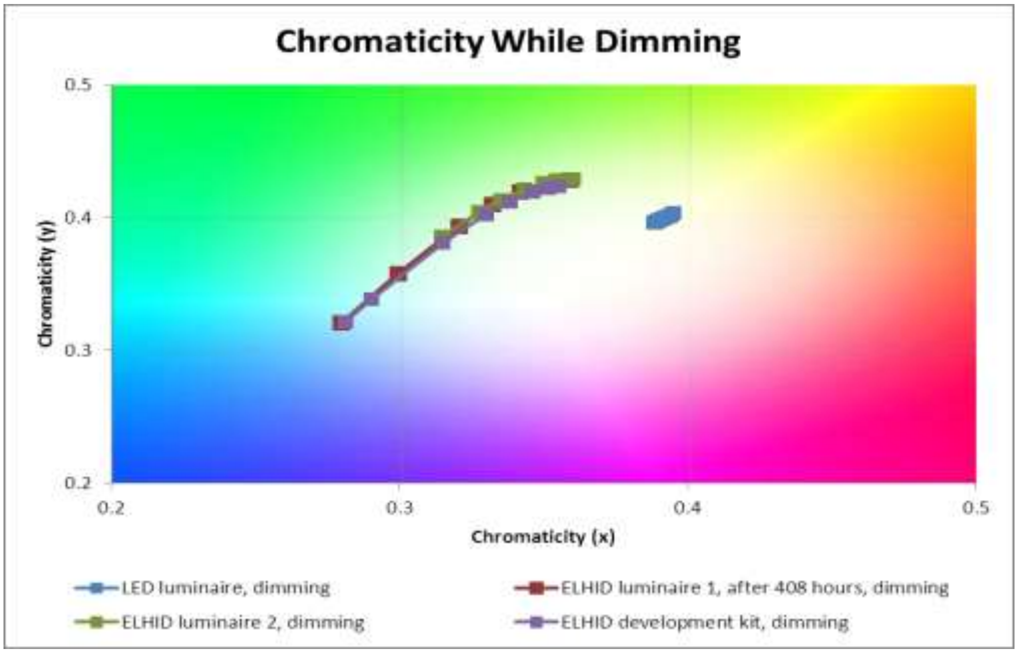

FIGURE 19. CHROMATICITY DIAGRAM REPRESENTING ELHID, HID AND LED LUMINAIRE PERFORMANCE DURING DIMMING

THERMAL

The thermal images of each fixture tested at the laboratory were taken using an IR camera. This exercise helps understand the operating temperatures of the fixture and provides an indication to the field performance of the fixtures. Figure 20 through Figure 25 shows the thermal performance of the LED, HID (standard and high performance), ELHID (Fixture 1 and 2) as well as the development kit of ELHID fixture (e.g., the light source).

Please note that the temperature scale of each figure is different, so "red" in one image means a different temperature than "red" in another image. IR thermography is not for measuring absolute temperatures. Rather, it shows temperature gradients/relative temperatures across the surface of an object.

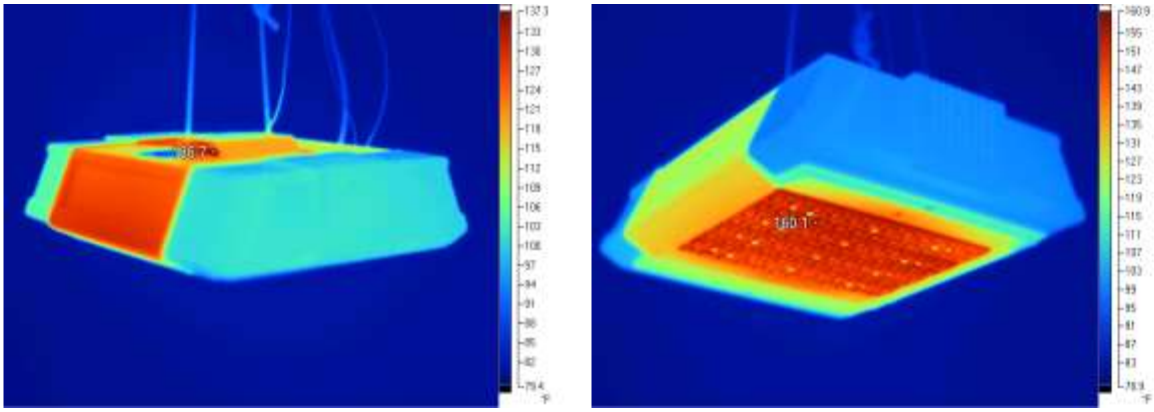

FIGURE 20. IR THERMAL IMAGE OF LED LUMINAIRE UNDER TEST

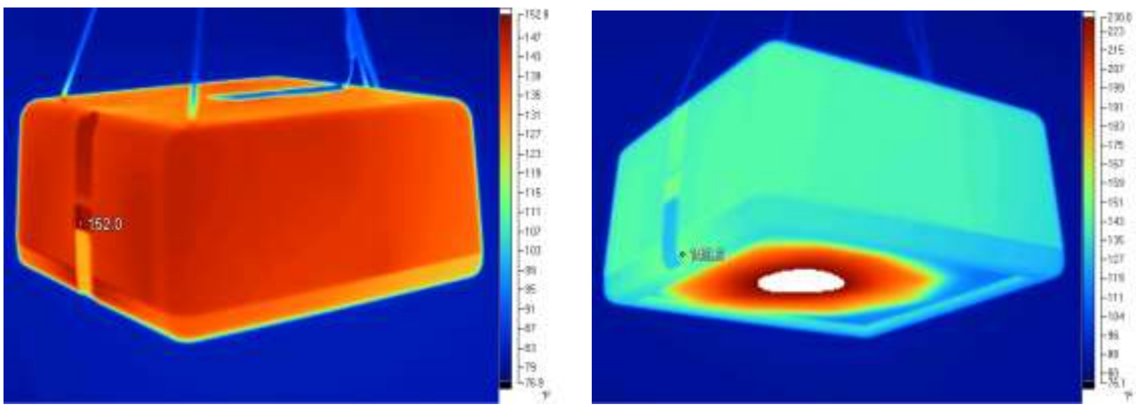

FIGURE 21. IR THERMAL IMAGE OF STANDARD HID LUMINAIRE UNDER TEST

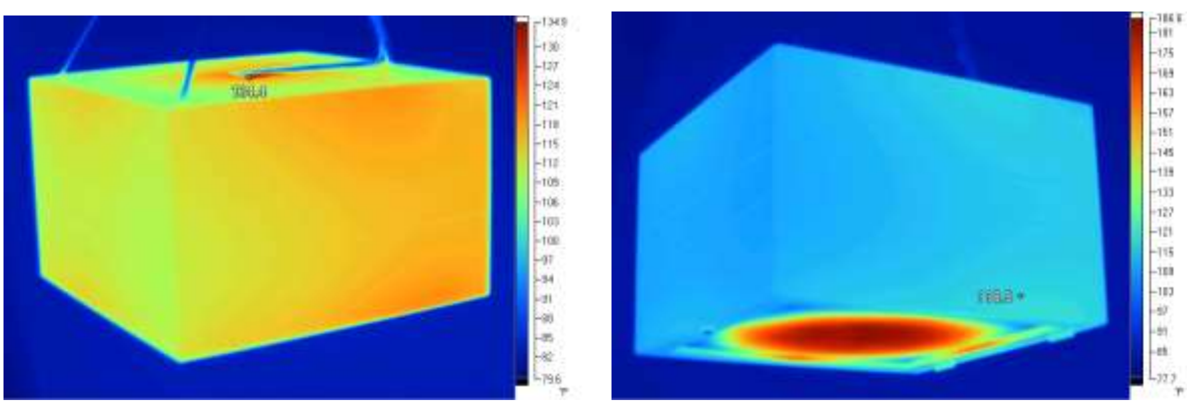

FIGURE 22. IR THERMAL IMAGE OF HIGH PERFORMANCE HID LUMINAIRE UNDER TEST

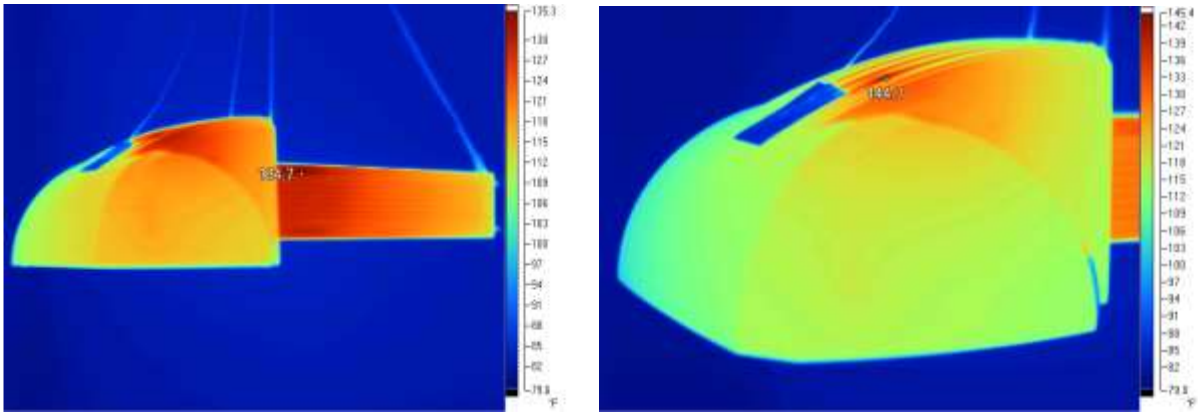

FIGURE 23. IR THERMAL IMAGE OF ELHID LUMINAIRE 1 UNDER TEST

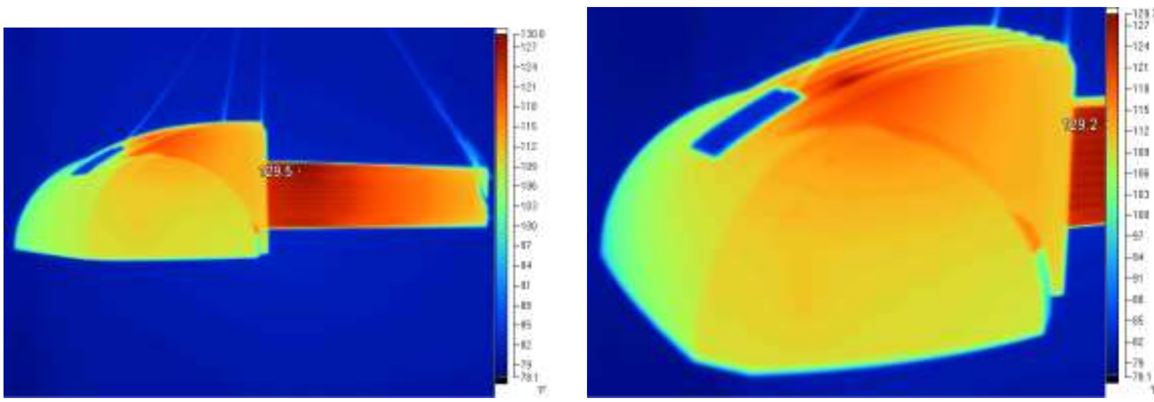

FIGURE 24. IR THERMAL IMAGE OF ELHID LUMINAIRE 2 UNDER TEST

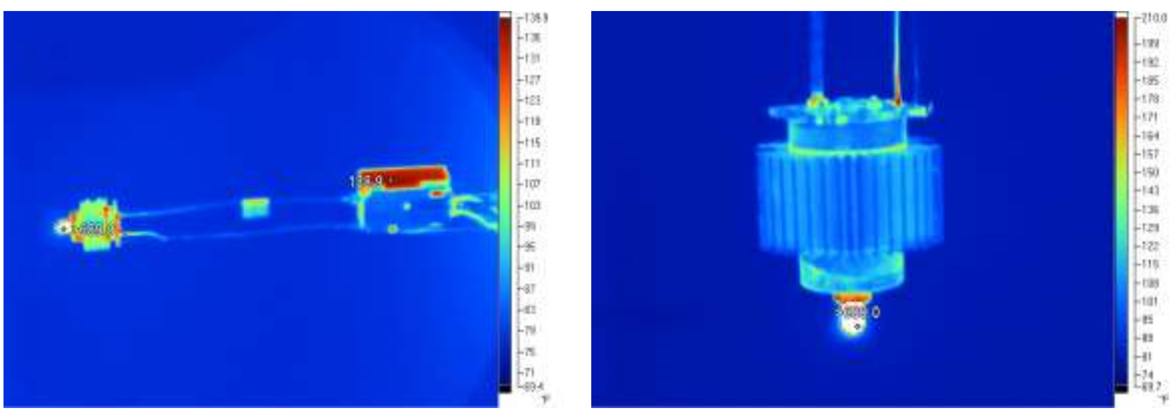

FIGURE 25. IR THERMAL IMAGE OF DEVELOPMENT KIT UNDER TEST

As seen in Figure 19 through Figure 25, temperature readings of the fixture surface and light source were measured and recorded. These readings enable the understanding of operating temperatures of these fixtures. In the previous testing of ELHID fixtures, the surface temperatures were extremely high and could potentially be deemed unsafe for use in the field. The ELHID fixture tested during this evaluation showed improvement in this area and the temperature of ELHID luminaires operating at full power was much lower and was comparative to that of LED luminaire and HID luminaires. This is a significant improvement for the ELHID technology.

COST ANALYSIS

METHODOLOGY

Due to the extended rated life of the LEDs in comparison with HPS, the entire cost needs to be normalized in order to obtain a direct comparison. The Lifecycle Cost (LCC) calculation is calculated using Equation 1.

EQUATION 1. LIFE CYCLE COST (LCC)

$$LCC = Capital\ Cost + \begin{pmatrix} Present\ worth \\ of\ Maintenance \end{pmatrix} + \begin{pmatrix} Present\ worth \\ of\ Energy \end{pmatrix} - \begin{pmatrix} Present\ worth \\ of\ Salvage\ Value \end{pmatrix}$$

Where:

Capital Cost = the cost of the equipment and installation

The present worth values for Maintenance, Energy and Salvage Value are calculated using Equation 2, Equation 3, and Equation 4.

EQUATION 2. PRESENT WORTH OF MAINTENANCE

$$((Present\ Worth)\,(of\ Maintenance)) = (((M_{P}Y) \times [(1-(1+NDR)]^{(-Y)})/NDR)$$

Where:

MpY = Yearly maintenance costs
NDR = Net Discount Rate: Expected inflation subtracted from a nominal investment rate, (for the calculations a default value of 5% is used).

Y = Number of years of equipment operation

EQUATION 3. PRESENT WORTH OF ENERGY

$$((Present\ Worth)\,(of\ Energy)) = (((E_{P}Y) \times [(1-(1+NDR)]^{(-Y)})/NDR)$$

Where:

EpY = Yearly energy costs
NDR = Net Discount Rate: Expected inflation subtracted from a nominal investment rate, (for the calculations a default value of 5% is used).

Y = Number of years of equipment operation

EQUATION 4. PRESENT WORTH OF SALVAGE VALUE

$$\begin{pmatrix} Present\ Worth \\ of\ Salvage\ Value \end{pmatrix} = (SV) \times (1 + NDR)^{-Y}$$

Where:

SV = Salvage Value Final Year: Total worth of equipment at its end of life (for the calculations a value of $5 is used for all luminaires).
NDR = Net Discount Rate: Expected inflation subtracted from a nominal investment rate, (for the calculations a default value of 5% is used).

Y = Number of years of equipment operation

COST ANALYSIS RESULTS

The calculations aim to compare the ELHID luminaires with the HIDs and LEDs on the basis of LCC. The LCCs are calculated at the industry standard life rating of 15,000 hours for HIDs; 50,000 hours for ELHID and LEDs and 100,000 hours for LEDs. Existing standards support predicted longer life for LEDs but field data to support this is very limited. An energy rate of $0.15 per kilowatt hour (kWh) was used for energy cost calculations.

Table 11 shows the calculated LCC comparisons at average rated hours of operation for these three technologies. The operating hours are assumed to be 12 hours per day for a typical night operation.

TABLE 11. LCC ANALYSIS OF ELHID, HID, AND LED TECHNOLOGY

TECHNOLOGY	REPLACEMENT LCC AT 15,000 HOURS ($)	REPLACEMENT LCC AT 50,000 HOURS ($)	REPLACEMENT LCC AT 100,000 HOURS ($)
HID (Standard)	1753	3986	5987
LED	1279	1825	2315
ELHID	1440	2266	4161

The LCC comparison at 50,000 hours of operation is equivalent to 11.4 years assuming the typical average of all-night operation at 12 hours per day. This value reflects the common industry standard with regard to LED luminaire life. The calculation includes approximately three replacements of the HID luminaire and no replacement for ELHID luminaire.

The LCC comparison at 100,000 hours of operation is equivalent to 22.8 years assuming the typical average of all-night operation is 12 hours per day. This value reflects the manufacturer-rated life times under ideal conditions that range around 100,000 hours depending on luminaire size. This calculation assumes approximately six HID luminaire replacements and one ELHID replacement.

Based on the analysis, it is clear that the cost of ELHID luminaires is the largest impact on the LCC. Although the LCC analysis shows that ELHID is a viable alternative to the HID technology, reducing the cost further will aid in increasing the LCC savings of ELHID and allow it to compete with the LED market.

CONCLUSIONS

The primary objective of this project is to determine the feasibility of replacing an HID shoe-box style parking lot luminaire with an ELHID luminaires. Additionally, the performance of ELHID technology in comparison to the LED technology while dimming was also a point of interest.

There are many factors to consider when replacing parking lot lighting. The data from this laboratory technology assessment indicates that the ELHID fixtures show significant reduction in demand in comparison to the HID technology. In comparison to the LED technology, the ELHID had a higher demand and the illuminance levels were corresponding to the power draw (e.g., ELHID had higher power draw and correspondingly provided higher illumination compared to the LED luminaire.)

Additionally, the chromaticity diagram shows that the ELHID luminaire had a green tint to its light output and that color shifted from greenish to bluish during dimming.

The first cost of the ELHID is lower compared to the HID but is higher when compared to LEDs. The LCC analysis shows that ELHID technology is always an economical alternative to the HID technology. Lowering the cost of ELHID fixtures further can help this technology compete with the LED market.

The depreciation of HID technology is well-established with a minimum rated life of 15,000 hours. ELHID technology also depreciates but varies depending on its environment, even though the manufacturers claim 50,000 hours of useful life for this technology. The short duration of this laboratory assessment did not lend itself to reveal any significant depreciation as it was tested in a laboratory setting under normal operation conditions. Moreover, all factors needed to determine fixture life could not be accounted for due to the nature and duration of testing.

Thermal performance of the ELHID technology showed vast improvements from the earlier versions of fixtures available for this technology and is now at par with both HIDs and LEDs. This shows that the ELHID is making improvements to its design and fabrication; however, it still has room for improvement in maintaining constant color output while dimming and providing a whiter light output at full-power.

RECOMMENDATIONS

The laboratory testing provides insight into the current state of the market of ELHID technology. Laboratory testing reveals that ELHID technology is a viable replacement for HIDs for applications where output light color is at full-power and dimming is not a consideration.

Currently, there is no test standard available to test ELHID technology and it is a crossover between the HID and the LED. At this point it is difficult to make decisions with limited tools and metrics. Further involvement and interaction with not only the industry, but standards organizations will help to push forward standards initiatives. The mutual benefit is a better understanding of the technology and its advancements.

As this technology continues to evolve, it is recommended that the Emerging Technology program continue to monitor the progress and remain involved in testing future revisions of this product.

APPENDIX A – TECHNOLOGY TEST CENTERS

LOCATION

All laboratory tests, referenced in this report, were conducted at SCE's Technology Test Centers (TTC) in Irwindale, California.

TECHNOLOGY TEST CENTERS

The mission of the TTC is to spread awareness of viable integrated demand-side management solutions to a wide range of SCE customers and energy efficiency (EE) programs. Through impartial laboratory testing and analysis of technologies, the portfolio of EE measure offerings can be expanded with quantified energy savings and alleviation of concerns about performance uncertainties. Testing in a laboratory setting allows for the performance of detailed and replicable tests that are realistic, impartial, and not influenced by unwanted variables while in a controlled environment.

The TTC includes the Refrigeration and Thermal Test Centers, and the Lighting Technology Test Center (LTTC).

REFRIGERATION AND THERMAL TEST CENTER

Controlled environment testing is conducted at the TTC's Refrigeration and Thermal Test Center (RTTC). This state-of-the-art research and testing facility examines refrigeration, air conditioning, cold storage, and other thermal-based technologies in support of SCE's EE programs, customers, and industry partners. The lab features walk-in controlled-environment chambers with impressive refrigeration and heating capacity, numerous types of test equipment and tools, and the ability to perform in-house calibration of many related instruments.

LIGHTING TECHNOLOGY TEST CENTER

Integrating sphere testing is conducted at the TTC's LTTC. In partnership with the California Lighting Technology Center (CLTC) in Davis, California, LTTC's mission is to foster the application of EE lighting and day-lighting technologies, in cooperation with the lighting industry, lighting professionals, and the design-engineering community. Unique lighting and day-lighting test equipment, EE lighting displays, and flexible black-out test areas enable the evaluation and demonstration of various lighting technologies and applications.

APPENDIX B- DUT SPEC SHEETS

ELHID 1 AND 2

ELHID Luminaire 1 and 2 Spec Sheet.pdf

ELHID DEVELOPMENT KIT

ELHID Development Kit Spec Sheet.pdf

HID STANDARD PERFORMANCE FIXTURE

HID Luminaire, Standard Performanc

HID HIGH PERFORMANCE FIXTURE

HID Luminaire, High Performance Spec Sh

LED FIXTURE

LED Luminaire Spec Sheet.pdf

CALCULATIONS

Comparison.xlsx

LifeCycleCost - Complete.xls

REFERENCES

[i] California Commercial End-Use Survey, March 2006, Prepared for: California Energy Commission, Prepared by: Itron, Inc.

[ii] FCC Title 47, Part 15, Section 15.109(a), 2009. The field strength of radiated emissions from unintentional radiators at a distance of 3 meters shall not exceed (200 μV/m) at (440 MHz) frequency of emission. http://www.gpo.gov/fdsys/pkg/CFR-2009-title47-vol1/pdf/CFR-2009-title47-vol1-part15.pdf