Tri Tool Exterior LED Lighting Project

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About the Customer Advanced Technologies Program…

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), indirect/direct evaporative cooling, non-chemical water treatment systems, daylighting and a variety of other technologies.

For more program information, please visit:
https://www.smud.org/en/business/save-energy/rebates-incentives-financing/customer-advanced-technologies.htm

1 EXECUTIVE SUMMARY

The engineer reviewed the calculations one last time. Sure, LED lighting had made a lot of progress, but would the new fixtures be up to the task? To his knowledge, no one else in the area had yet tried using LED fixtures mounted at 50ft. for a parking lot application. What if they didn't work? Especially since the previous state-of-the-art lighting system had just failed. The engineer took a deep breath and ordered the new fixtures.

It is no secret that LED lighting systems have made tremendous progress during the past three years. Literally thousands of products are available for just about every application, and dozens of demonstration projects have been completed. So what makes this project noteworthy? Two things: (1) 50ft. mounting height (2) extending the use of a wireless control system designed primarily for interior applications to a parking lot application.

Tri Tool Inc. is no stranger to emerging technology research and has participated in several of SMUD's programs in the past. In fact, what generated the need for this project was the failure of an early generation light-emitting-plasma system. This report describes Tri Tool's three year journey starting with the original high pressure sodium lighting system and ending with the current system which includes high-output LED fixtures, motion sensors and a wireless control system. Like most demonstration projects, we encountered several obstacles and learned some valuable lessons along the way.

Figure 1: The new LED fixtures at Tri Tool Inc. were mounted at 50ft. above the ground, which at this time, was considered to be a challenging application for LED technology.

Summary of Results

Overall the final results of this project were favorable:

- Estimated energy savings: 76,773 kWh per year (80%)
- Project cost (without research grant): $32,951
- Estimated annual cost savings: $9,213
- Simple payback: 3.6 years

Acknowledgements

Several people contributed to the success of this project including:

- Joel Walton (Tri Tool Inc.)
- Walter Pazik (Global Energy Partners)
- Daniel Mort (ADM Associates)
- Connie Samla (SMUD)
- Leah Pertl (SMUD)

2 TECHNOLOGY DESCRIPTIONS

2.1 LIGHT EMITTING PLASMA

Originally this project involved replacing the existing high pressure sodium (HPS) fixtures with light emitting plasma (LEP) fixtures from Luxim Inc. The light emitting plasma system consists of the components listed below and are shown in Figure 2. These components are housed within a light fixture (a.k.a. luminaire). The luminaire also includes an optical assembly to distribute the light produced by the lamp.

- **Lamp:** consists of a very small quartz tube (3/4" long), which contains a mixture of rare earth halides - similar to conventional metal halide lamps. However, unlike conventional lamps, the plasma lamp does not contain electrodes (more on this later).
- **Emitter:** the plasma lamp is housed within an aluminum assembly specifically designed to concentrate radio frequency energy within the lamp.
- **Radio frequency (RF) driver:** connects to the emitter via a coax cable and produces the radio frequency energy needed to ignite and operate the plasma lamp.
- **AC/ DC power supply:** converts incoming line voltage to DC and supplies power to the radio frequency driver.

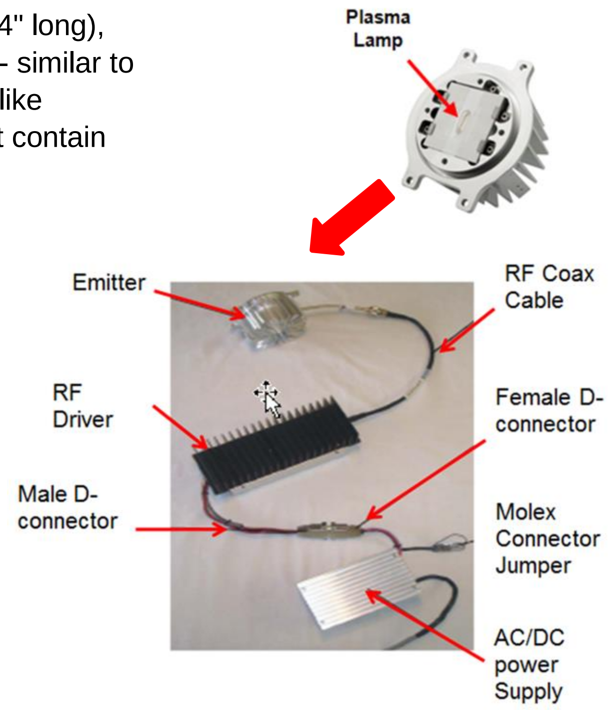

Figure 2: Light emitting plasma system

2.1.1 Potential Benefits

According to the manufacturer, light emitting plasma offers the following advantages over conventional high intensity discharge lamps:

- **Better reliability:** conventional metal halide lamps require electrodes within the arc tube (Figure 3). These electrodes are usually made of tungsten and require a mechanical seal - which can lead to premature lamp failure. As the tungsten degrades, it darkens the walls of the lamp and reduces the light output. Since LEP does not require the use of electrodes, the reliability and light output should be better than conventional metal halide lamps.

- **Rapid start:** 45 seconds to reach 80% of full brightness
- **High efficacy:** 82 lumens per Watt
- **Better optical control:** since the LEP lamp is only ¾" long, it is easier to direct the light where it is needed and provide even illumination levels. Better optical control is the key to energy savings in outdoor lighting applications.
- **Faster re-strike:** when the power is turned off to high intensity discharge lamps (e.g. metal halide) they require time to cool down before they can be reignited. This is called the re-strike period and can last up to fifteen minutes for some older lamp types. The re-strike period for LEP lamps is only about 2 minutes – much faster than conventional metal halide or high pressure sodium systems.

Figure 3: Conventional metal halide lamps require electrodes within the arc tube—a potential failure point. LEP does not require the use of electrodes.

- **Good color rendition:** the ability of light sources to render colors accurately is rated by a metric known as the Color Rendering Index (CRI). A CRI of 100 is considered to be ideal. LEP lamps are available with CRI values of 75 and 90.
- **Longer rated lamp life:** 30,000 hours @ 90 CRI and 50,000 hours @ 75 CRI. Note: unlike high intensity discharge lamps, the rated life for LEP lamps is not based upon predicted failures; it is when the lamps are expected to lose 30% of their output. This is known as L^{70} life and is the same method used for rating the life of LEDs.

2.1.2 Important Things to Consider

Like every other technology, there are some potential downsides to Light Emitting Plasma:

- **Weight:** LEP produces a lot of heat and requires extensive heat sinks, which adds a significant amount of weight to the light fixtures. For example, LUXIM's R400 Roadway Luminaire weighs 34 pounds – slightly more than comparable 400 Watt metal halide or high pressure sodium options. Care must be taken during retrofits to ensure the existing poles and mounting arms will be able to handle the added weight.
- **High Correlated Color Temperature (CCT):** The light produced by the LEP systems we tested was blue-greenish white in appearance (5700K) and was noticeably different from other light sources. Some users may find this objectionable.
- **Limited choice of manufacturers:** Since LEP technology is relatively new, only a few manufacturers offer fixtures with LEP lamps as an option.

- **Position sensitive:** Some LEP lamps are position sensitive and cannot be operated in a face up position. Care must be taken to select the proper LEP lamp for applications such as illuminating building façades.

- **Premature failures:** Although the rated life of LEP lamps is 50,000 hours, customers at all three of SMUD's test sites have experienced premature failures.

2.2 HIGH OUTPUT LED FIXTURES

Tri Tool selected Cree's high output EDGE LED fixtures (Figure 4), which have the following rated characteristics:

- 29,994 initial lumens (120 LEDs driven at 1,000 mA)
- 426 Watts
- Efficacy: 70.4 LPW
- CCT: 4000K
- CRI: 70 minimum
- Rated L70 life: 60,000 hours
- Five year warranty
- Dimmable 0-10V LED driver

Figure 4: Cree Edge™ LED fixtures

2.2.1 Potential Benefits

According to Cree, their EDGE HO LED fixtures offer several advantages over fixtures with conventional high intensity discharge lamps:

- **Longer lamp life:** Cree EDGE fixtures are rated to last 60,000 hours before losing 30% of the output. This compares favorably to high pressure sodium lamps which are typically rated for 24,000 hours (average failure).

- **Instant on:** no restrike or warm up period required

- **Better optical control:** Cree LEDs are specifically designed and manufactured to precisely direct the light where it is needed and provide even illumination levels. This helps eliminate wasted light and reduce light pollution.

- **Control friendly:** unlike most exterior HID systems, these LED fixtures are dimmable and are designed to work with controls that use the popular 0-10V protocol. This provides the opportunity for additional energy savings through the use of motion-sensor based dimming and other control strategies.

- **Customer satisfaction:** customers converting from HPS to LEDs (or other white light sources) often report increased satisfaction levels. This is likely due to improvements in color rendering and appearance.

2.2.2 Important Things to Consider

Although LED lighting fixtures may offer several benefits, there are some important things to keep in mind when considering using them in exterior lighting applications:

- **Lower efficacy at higher drive currents:** using LED fixtures at higher mounting heights (i.e. > 30ft.) usually requires operating the LEDs at higher drive currents. For example, the efficacy of the EDGE HO LED fixtures ranges from 70 LPW @ 1000 mA to 89 LPW @ 700 mA.

- **Weight:** since LEDs are electronic devices, they require heat sinks which add a significant amount of weight to the light fixtures. This is especially true for LEDs operated at higher drive currents. For example, the EDGE HO fixture with 120 LEDs weighs 45 lbs. while the 240 LED option weighs in at a hefty 80 lbs. Care must be taken during retrofits to ensure the existing poles and mounting arms will be able to handle the added weight.

- **Cost:** for applications that require higher illumination levels, LED fixtures often cost two to three times more than traditional HID options.

2.3 WIRELESS CONTROLS

In 2012, Tri Tool retrofitted all of their office spaces and some of their production areas with LED fixtures and Daintree Networks wireless controls. Daintree's system uses multiple control devices and the ZigBee wireless communication standard to form a wireless mesh network as shown in Figure 5 (next page). Since Daintree's control devices use low power signals to communicate, they are primarily designed for interior applications. Advanced lighting controls (such as Daintree) offer several capabilities including:

- **Task tuning:** allows the users to adjust the lighting levels according to their needs and avoid having unneeded, over-lit areas. Task Tuning typically saves 20-30%.

- **Energy tracking:** ability to track energy usage, costs and savings in real-time.

- **Web-based control:** ability to control lighting on-site or remotely from internet-based interfaces, such as smart phones or wireless computers. Users may create simple operating schedules or implement advanced control strategies such as motion-sensor based dimming.

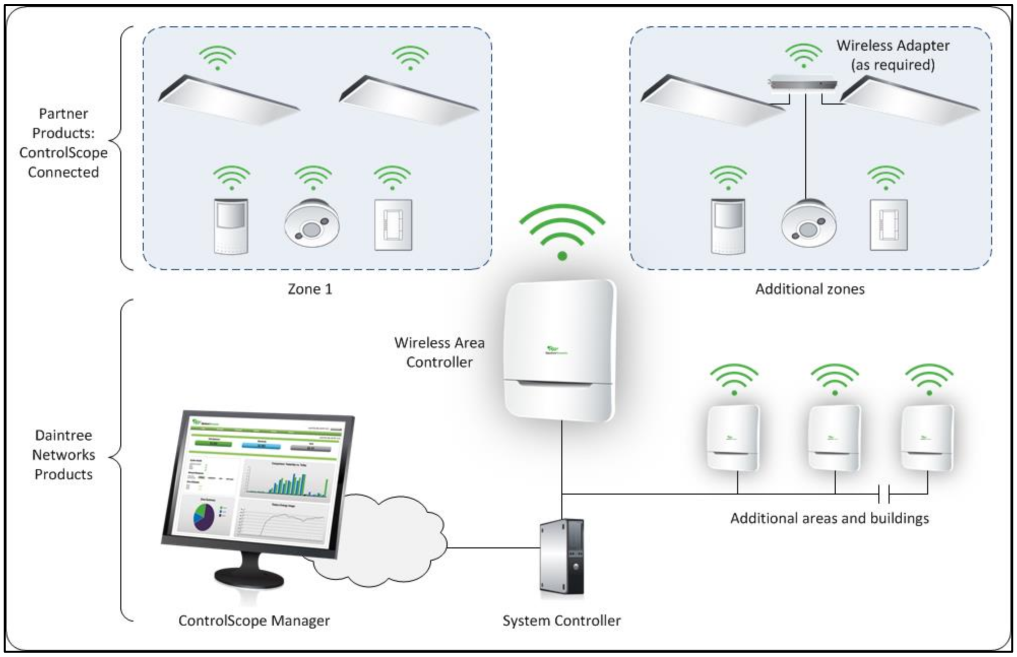

Figure 5: Daintree's wireless mesh network

Tri Tool controlled the LED fixtures through the use of Daintree Wireless Adapters (WA100s) and Wattstopper HB350W-L3 motion sensors. These components were field installed by Tri Tool's electricians.

3 PROJECT DESCRIPTIONS

3.1 BACKGROUND AND OBJECTIVES

The original purpose of this study was to evaluate the field performance and cost effectiveness of Luxim's light emitting plasma technology in a high mast, exterior lighting application. Objectives included gathering the necessary data to compare illumination levels, energy consumption and Tri Tool's perception of the LEP technology.

When this project began (early 2011), LED technology was not yet considered to be a viable option for applications with mounting heights of anything over 30 feet. However, due to excessive failures, Tri Tool chose to replace the light emitting plasma fixtures with high output LED fixtures in 2013 (Figure 6). Consequently, this study was expanded to include the performance of the original HPS system, the LEP system and the high output LED system.

Figure 6: when the LEP fixtures failed prematurely, they were replaced with high output LED fixtures

3.2 PROJECT LOCATION: TRI TOOL INC. RANCHO CORDOVA, CA

For over 40 years, Tri Tool Inc. has been the world's leading designer and manufacturer of precision portable machine tools for pipe beveling, tube squaring and severing, clamshells for in-line cutting, and flange facing equipment. Tri Tool also produces heavy-duty pipeline machinery, provides custom machinery design and manufacturing, on-site machining and welding services, and offers equipment rental options.

3.3 ORIGINAL LIGHTING SYSTEM

The original lighting system consisted of twenty-three, shoebox type fixtures with 1,000-Watt high pressure sodium lamps. The fixtures were mounted on 50 ft. poles and were controlled via a time clock set for dusk to dawn operation. Before Tri Tool moved into this facility, it was used as a secure government storage site. Consequently, the measured illumination levels in the parking lot were excessively high (Figure 7).

The measured illumination levels for the high pressure sodium lights were:

- Average: 15.98 fc
- Maximum: 23.8 fc
- Minimum: 7.65 fc
- Max/Min: 3.11
- Max/Ave: 1.49

Figure 7: the original illumination levels were excessively high!

The original HPS lighting system consumed an estimated 96,554 kWh per year. Although Tri Tool wanted to upgrade their lighting system, few viable options were available since their fixtures were mounted at 50ft. above the ground.

3.4 LIGHT EMITTING PLASMA SYSTEM

In October of 2011, Tri Tool decided to replace their existing system with Luxim's R400 Light Emitting Plasma (LEP) fixtures (Figure 8). At first the results were very positive. Even though the illumination levels were much lower than provided by the HPS lights, Tri Tool was very pleased with the improved color rendering and was looking forward to the predicted 75% energy savings. Unfortunately, the LEP fixtures failed prematurely and had to be replaced. The initial measured illumination levels were as follows:

- Average: 2.84 fc
- Maximum: 4.12 fc
- Minimum: 1.66 fc
- Max/Min: 2.48
- Max/Ave: 1.45

PRODUCT CODE	41-01	41-02
LAMP LUMENS	23,000	17,000
WATTS	280	280
LIFE HOURS	50,000	30,000
CRI	75	95
CCT	5700	5600

Figure 8: Ratings for Luxim's light emitting plasma fixtures

4 SUMMARY OF FINDINGS

4.1 ASSESSMENT OBJECTIVES

SMUD hired ADM to monitor the LED lighting system and calculate the annual energy savings compared to the original HPS system. Commissioning the lighting controls turned out to be a difficult, drawn-out process. Consequently, ADM monitored the parking lot lighting energy use for nearly one year.

4.2 METHODOLOGY

Lighting power consumption was measured at the breaker panel using an Enernet K20 multi-channel power logger. High accuracy split-core current transducers (CTs) were placed inside the electrical panel (Figure 9). The system was set to record energy use in 2-minute intervals and the logger would hold 27 days of data. Monitoring started after the LEDs and controls were installed. However, since the control strategies were changed several times to address problems, the monitoring period lasted nearly one year.

In order to separate the savings resulting from the controls, the monitoring data was organized into three categories:

1. HPS baseline period: the original high pressure sodium lights operating from dusk to dawn.
2. LED baseline: the new LED lights operating from dusk to dawn.
3. LED with controls: new LED lights with the wireless controls activated

Figure 9: Split-core transducers were placed in the electrical breaker panel to measure the lighting system energy consumption.

4.3 HIGH OUTPUT LED SYSTEM

In June of 2013, Tri Tool replaced all twenty-one light emitting plasma fixtures with high output LED fixtures (Figure 10). Each new fixture included pole mounted motion sensors and Daintree wireless controls. The parking lot lights operated approximately 4,600 hours per year or 52% of the time.

The Daintree system uses ZigBee wireless communications to control each light pole. Daintree's software incorporates an astrological time clock and feedback from the motion sensors to adjust the lighting level to reduce energy use. Initially Tri Tool's Facility Manager was very enthusiastic about the system and implemented some very sophisticated control strategies. Unfortunately, these initial strategies did not pan out, due to a bug in the software which caused lights to turn off when they should not be off. After several unsuccessful attempts to solve this problem, Tri Tool's Facility Manager implemented a much simpler, yet still effective, control strategy which is shown below in Figure 10.

Time period	Control Strategy
4:30 a.m. to 8:00 a.m.	On/off via photocell, set to 75% maximum
8:00 a.m. to 4:30 p.m.	Lights scheduled off
4:30 p.m. to 9:00 p.m.	On/off via photocell, set to 75% maximum
9:00 p.m. to 4:30 a.m.	Bi-level operation based upon motion sensors - High mode: 50% of maximum output - Low mode: 25% of maximum output

Figure 10: Tri Tool parking lot control strategies

4.4 ENERGY MONITORING RESULTS

ADM monitored the parking lot lighting from November 7, 2013 through October 13, 2014. Data was collected several times during the year to gather information following changes in the control strategies. The data was organized into three different categories:

1. Original high pressure sodium fixtures (1000W HPS)
2. LED fixtures controlled only by a time clock (LEDs Full ON)
3. LED fixtures with wireless controls activated (Controlled LEDs)

The tabulation of annual energy use for the three lighting situations is shown in Figure 11 and Fixture 12. The savings when comparing these situations are shown in Figure 13.

The savings for the new LED parking lot lights and controls versus the original HPS lighting is a very substantial 80%. Some of this savings is due to the fact that the original lights were much higher wattage than necessary (as evidenced by the extraordinarily high illumination levels). If Tri Tool had been able to use the motion sensor controls during the morning and evening hours, the savings could have been even higher.

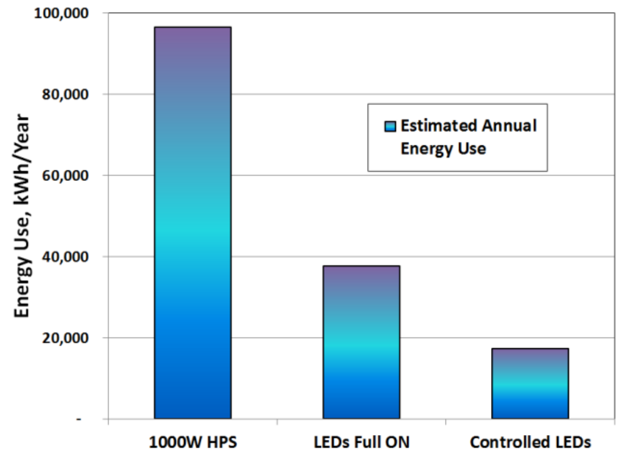

Figure 11: Annual energy consumption graph

System	Annual Energy Use (kWh)
1000W HPS	96,55
LEDs Full ON	37,77
Controlled LEDs	19,78

Figure 12: annual energy consumption

Comparison	Annual Energy Savings (kWh)	Percent Savings
LEDs with controls vs. 1000W HPS	76,773	80%
LEDs Full ON vs. 1000W HPS	58,810	61%
LEDs with controls vs. LEDs Full ON	17,963	48%

Figure 13: Lighting system comparison

4.5 LIGHTING LEVEL MEASUREMENTS

Light level measurements were made under several poles one night in November 2013. Approximately ten feet away from the pole the light levels ranged from 1.4 to 2.0 foot-candles when the lights were at 55%.

4.6 ECONOMICS

The cost of lighting systems using new technology is often expensive, sometimes simply because the economics of volume manufacturing has not kicked in. The cost of material and installation for this case study was $32,951. Using an average of $0.12/kWh the 76,773 kWh in annual energy savings translates to $9,213 per year. The customer's simple payback is 3.6 years.

5 CONCLUSIONS

Three years ago, SMUD began working with Tri Tool to assess the performance of Luxim's light emitting plasma (LEP) system. However, due to excessive product failures, Tri Tool replaced the LEP fixtures with high output LED fixtures and Daintree wireless controls. Ultimately the results of this study were mixed:

Benefits

- Energy savings of 80% (compared to the original HPS system)
- Annual cost savings of $9,213 per year
- Simple financial payback of 3.6 years
- Positive feedback from Tri Tool employees regarding the improved appearance and lighting quality

Challenges

- Premature failures of the light emitting plasma fixtures
- Difficulty commissioning the controls and software

Since this study began, LED products have improved dramatically. Customers can now have confidence using LED fixtures for parking lots with fixture mounting heights of 50ft. and perhaps even higher. However, more work may be needed in the area of lighting controls—especially using motion sensors at heights above 20 feet. SMUD wishes to once again thank the people at Tri Tool Inc. for their pioneering spirit.