A Comprehensive Store Retrofit to LED lighting in Common Lighting Applications

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Photo Credit: CREE, Inc.

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ABBREVIATIONS AND ACRONYMS

CALiPER	Commercially Available LED Product Evaluation and Reporting Program
CCT	Correlated color temperature
CFL	Compact Fluorescent lamp
CRI	Color rendering index
DLC	DesignLights Consortium
DOE	US Department of Energy
IES	Illuminating Engineering Society
IRR	Internal Rate of Return
LED	Light emitting diode
LEDA	LED Accelerator Program
LPW	Lumens of light output per watt of electric input, the unit of lighting efficacy
MR	Multifaceted reflector
NPV	Net Present Value
OBF	On-Bill Financing
PAR	Parabolic aluminized reflector
PF	Power factor
ROI	Return on investment
THD	Total Harmonic Distortion

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EXECUTIVE SUMMARY

Commercial lighting consumes 349 TWh per year (DOE 2012a) in the US, roughly equal to the annual energy output of 115 500 MW coal power plants.[1] While LEDs are used in only 1% of commercial lighting fixtures, they continue to gain market penetration in niche lighting applications, and have begun to make significant progress in replacing incumbent technologies in common lighting applications such as directional lighting and downlighting applications (DOE 2013a).

Linear fluorescent lighting represents 72% of energy use in the commercial lighting sector and 80% of all commercial light fixtures, and therefore represents an enormous opportunity for potential LED savings. As of 2012, LED replacements for linear fluorescents are just beginning to gain traction: only 1% of LED energy savings in 2012 were from linear fluorescents replacements (DOE 2013b). As LED chip-level efficacies continue to improve and LED costs continue to decrease, there has been a dramatic increase in the number of LED replacement fixtures for traditional linear fluorescent applications.

With these recent advances, suitable LED replacements for all common lighting applications are now commercially available. For the first time it may be possible for commercial buildings to conduct a comprehensive, cost-effective LED retrofit that addresses every common lighting application.

The goal of this project was to evaluate the economic and technical viability of a comprehensive LED retrofit for all major fixture applications within a Fry's Electronics store in Northern California. This includes general service fluorescent lighting, general service incandescent lighting, downlighting, and directional lighting applications.[2] Due to the lack of existing field assessment of LED retrofits for fluorescent lighting, the project specifically focused on three different fluorescent lighting applications, including 2x4 recessed troffers, 1x4 strip fixtures and wraps, and 1x4 suspended box louvers.

Under PG&E's LED Accelerator program (LEDA), Fry's retrofitted 720 fixtures of various types for six different lighting applications throughout the entire store to LED fixtures.[3] This study evaluated all six lighting applications over a total of eight separate study areas. These products were evaluated based on power and energy usage measurements, lighting performance characteristics, qualitative host satisfaction, and economic factors. In addition, the project sought to understand the customer's internal product selection processes and their decision to complete a comprehensive store retrofit and scale it across multiple retail locations.

[1] Assumes a 70% capacity factor and 7% transmission and distribution losses (Koomey et al 2010).

[2] As part of this retrofit, Fry's installed 163 LED linear tube lamps with internal drivers. These products were not included in this study because this product category is ineligible for PG&E incentives at this time.

[3] This excludes metal halide high bay fixtures, which were not considered due to a recent retrofit in 2010.

PROJECT RESULTS

The project confirmed that completing a store-wide, comprehensive LED retrofit is not only feasible, but cost-effective as well. Overall, the project achieved a 58% reduction in energy use for LEDA eligible products, and 47% on a store-wide basis. Fry's was very satisfied with the energy savings, projected maintenance savings, and lighting quality provided by the LED products that were installed. For products that were eligible for a LEDA incentive, Fry's achieved a simple project payback (SPP) of 5.8 years and an ROI of 17.3% without an incentive, not including installation costs. With the LEDA incentive, the qualifying products achieved a 4.1 year SPP and 24.2% ROI, not including installation costs. Accounting for both the LEDA incentive and maintenance savings, the project achieved a 3.3 year SPP, and 30.5% ROI.

LEDA qualified equipment accounted for 50% of the overall project cost.[4] The remaining equipment did not receive an incentive, but is still projected to achieve substantial energy and maintenance savings. Storewide, including installation costs of maintenance savings, the project achieved a 5.0 year SPP and 19.8% ROI without an incentive, and 4.4 year SPP and 22.8% ROI with the LEDA incentive. Payback periods can be significantly reduced by incorporating retrofits into regularly scheduled maintenance, which reduces installation costs. For LEDA qualified equipment, the investment generated a Net Present Value (NPV) of $94,944 and $177,693 when accounting for installation costs and maintenance savings over the estimated 12 year average product lifetime of the LED retrofit. Storewide, the investment generated a Net Present Value (NPV) of $225,518 when accounting for installation costs and maintenance savings.

Update after 6000 hour lamp testing for CREE CS14 fixtures:
Laboratory testing of two CS14 fixtures showed performance to be very stable. Lamps were tested initially at 2200 hours and again after 6000 hours of operation. In that time, lumen output decreased by less than 2.9% and 3.6%, respectively. CCT decreased by 10 and 4 Kelvin (imperceptibly warmer), respectively, while CRI varied by 0.2. In terms of color shift, the fixtures had a $\Delta u'v'$ of 0.0003 and 0.0002, respectively. This is well within the bounds of ENERGY STAR's 6000 hour Color Maintenance requirements which require a change of chromaticity ($\Delta u'v'$) of less than 0.007.[5]

SUMMARY OF FINDINGS:

1) Utility incentive programs can continue to address LED market barriers by providing appropriate incentives and services, such as rigorous product qualification standards.

2) Due to the long lifetime of LED retrofits, consumers and utility programs should consider lifecycle costs and benefits rather than simply first cost and simple payback in evaluating LED retrofit projects and options.

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[4] 88% of non-qualifying equipment was composed of LED Linear tubes, which are not currently eligible for LEDA incentive, and high wattage downlights, which do not have an appropriate product category within LEDA.

[5] ENERGY STAR Program Requirements for SSLs Version 1.4
http://www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf?2fe9-86db

3) On-Bill Financing can reduce the high initial project cost of LED retrofits and encourage adoption of comprehensive retrofits.

4) LED linear tubes, which have significant savings potential, merit further study to address product quality and safety concerns.

5) Utility programs can expand early commercialization of LED incentive programs to encourage a comprehensive retrofit approach.

6) Utility programs can integrate advanced lighting controls within existing LED incentive programs to achieve deeper energy savings and improved facility asset management through operational efficiency.

Finding#1: Utility incentive programs can continue to address LED market barriers by providing appropriate incentives and services, such as rigorous product qualification standards.

LED lamps and fixtures remain in the early commercialization stage and require utility program intervention to address market barriers including high initial product costs as well as variability in product quality. The high initial product cost remains the most significant barrier to widespread LED replacement lamps and fixtures. Without aggressive utility incentives, these projects may not meet corporate payback requirements, which in this case was two years (not including installation costs).[6] Product quality also continues to be a concern; although Fry's was very satisfied with the fixtures they ultimately selected, they went through a multi-year fixture selection process in which many test fixtures performed poorly during mockups.

Utility incentive programs can continue to address these market barriers by providing incentives to reduce initial cost, coupled with rigorous product qualification standards. In this pilot case, over 75% of the fixtures that Fry's selected qualified for LEDA incentives that reduced the project cost and made the retrofit possible,[7] demonstrating the influence incentive programs can have in product selection. We recommend utility programs continue to couple incentives and rigorous product qualification standards to accelerate the adoption of high quality products in the market. The long lifetime of LED products means that retrofits will occur far less frequently than before, increasing the importance of selecting high quality products and ensuring customer satisfaction.

[6] While the store retrofit did not meet the two year payback requirement on its own, it did achieve a two year payback, including the LEDA incentive, when bundled with a concurrent retrofit of Fry's corporate office. The office retrofit was primarily composed of recessed 2x4 fixtures with linear fluorescent lamps.

[7] This does not account for LED Linear Tubes, which are not eligible for PG&E incentives at this time.

Finding#2: Due to the long lifetime of LED retrofits, consumers and utility programs should consider lifecycle costs and benefits rather than simply first cost and simple payback in evaluating LED retrofit projects and options.

High initial product cost can also be addressed through reframing those costs as lifetime financial benefits. The long lifetime of LED fixtures means energy and maintenance savings are much longer than previous efficiency retrofits. While simple payback may be useful for retrofits with an expected lifetime of 4-6 years, it does not adequately account for the fact that the LED product is actually generating savings for operational costs for many years over its useful life. In the case of the Fry's comprehensive LED retrofit, because the LED measure lifetime is so long, the focus on short payback periods obscure the fact that the investment has an ROI of 24.2% and NPV of $94,944 for equipment only, and an ROI of 30.5% and NPV of $177,693 when including installation costs and projected maintenance savings.[8]

Finding #3: On-bill financing can reduce high initial project costs of LED retrofits and encourage adoption of comprehensive lighting retrofits.

The primary barrier to widespread LED adoption is the high initial cost (DOE 2013a). To reduce or eliminate upfront project costs, we recommend utility programs continue to integrate non-incentive services such as On-Bill Financing (OBF) into LED incentive programs. OBF complements existing incentives to address the primary market barrier to LED adoption by further reducing upfront capital costs, allowing customers to pay for the retrofit through their energy bill, based on energy savings achieved. OBF encourages a comprehensive approach to building retrofits by encouraging customers to bundle retrofits and address fixtures that may not have been cost-effective on their own. If Fry's had utilized PG&E's OBF for its comprehensive store retrofit, the LEDA eligible portion of the project would have reduced upfront capital costs by 60%. This would change the project economics from $100,000 upfront to $40,000 up front, or $40,000 phased over 3 years, while the remaining $60,000 would be paid through energy savings from the store utility bill. Accounting for maintenance savings and utilizing OBF, the project requires less than $6,000 up front and achieves an NPV of $177,693 (including maintenance savings), while the OBF loan is repaid through energy and maintenance savings. While this does not address structural issues such as separated capital expense and operations and maintenance (O&M) budgets or the need to float a loan while waiting for incentive and OBF loan processing, it highlights the potential of OBF to reduce capital costs.

Finding #4: LED Linear Tubes, which have significant savings potential, merit evaluation to determine whether these products should be considered for future program incentives.

While LED linear tubes have had product quality concerns in the past, their quality is rapidly improving. Roughly 12% of the Fry's LED retrofit budget was used for the purchase of LED linear tubes. As LED linear tubes continue to improve in quality and efficacy, it is likely that

[8] ROI and NPV values for LEDA eligible equipment only. NPV calculations assume a 7% discount rate and inflation rate of 3%.

their use will continue to grow. The Design Lighting Consortium now has a category of LED linear tubes on their national recognized Qualified Product List, and many products have been listed in the past six months. Linear tubes with external drivers which replace the existing fluorescent ballasts and do not use existing lamp sockets have fewer electrical and safety concerns. We recommend conducting further evaluation to determine whether these products have sufficiently addressed prior quality and safety concerns and should be considered for future program incentives.

Finding #5: Utility programs can expand LED commercialization incentive programs and encourage a comprehensive retrofit approach.

The comprehensive retrofit approach reduces costs by achieving economies of scale on equipment and installation costs, allowing companies to complete retrofits that may not otherwise be cost effective. Utilities can expand early commercialization to non-retail commercial buildings, where comprehensive retrofits may also be cost effective, particularly for facilities with high hours of operation or large quantities of recessed fixtures with three and four linear fluorescent lamps.

Finding #6: Utility programs can integrate lighting controls within existing LED incentive programs to achieve deeper savings and improved facility asset management through operational efficiency.

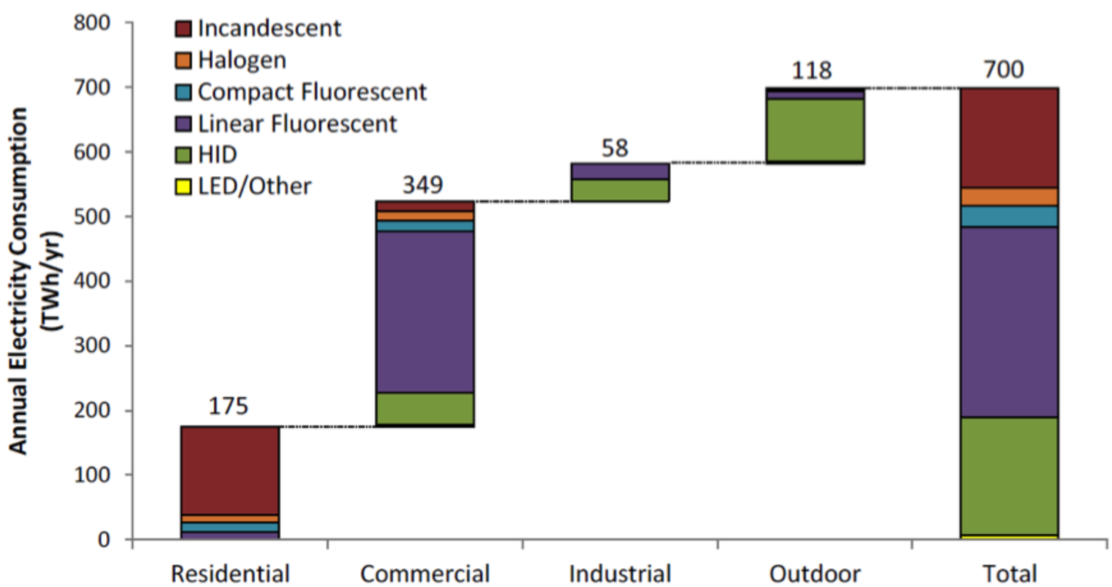
Advanced controls allow facilities to realize additional benefits that extend beyond a simple retrofit. Advanced controls play an important role in not only saving energy, but also by providing data inputs to intelligently operate and control facility assets. They also provide opportunities to achieve additional financial benefits by participating in utility Automated Demand Response (ADR) programs and grid ancillary services. A recent study estimated the global advanced lighting controls market will grow to over $5 billion by 2020, and is driven by increased demand for both task tuning, via dimmable ballasts and drivers, and occupancy information via occupancy sensors (Navigant 2013). The long lifetime of LED products means that lighting LED retrofits likely represent the last major retrofit opportunity for much of the lighting market,[9] so once a business has completed a comprehensive LED retrofit, it is unlikely that they will conduct another major lighting retrofit for at least ten years. During this time, we expect advanced lighting controls to achieve widespread market adoption and play a major role in facility asset management. We recommend that utility programs bundle future advanced controls installations with comprehensive retrofits, which will give customers greater control of their facility assets and participate in future demand management programs.

[9] CREE, a major LED manufacturer, recently extended its warranty for certain products to 100,000 hours, which is over 16 years, even with Fry's high hours of operation

INTRODUCTION

Commercial lighting consumes 349 TWh per year (DOE 2012a) and represents 50% of all lighting energy use, roughly equal to the power output of 115 500 MW coal power plants.[10] In California, commercial lighting uses roughly 19 TWh per year (CEC 2006). The commercial lighting sector is dominated by linear fluorescent lamps, which accounts for 72% of lighting energy consumption, followed by High Intensity Discharge (HID) sources (14%), compact fluorescents (5%), incandescents (4%), and halogen (4%) (DOE 2012a). LED sources offer significant benefits over existing light sources, due to their high efficacy, long operating life, minimal heat loss, dimmability and controllability, and durability (DOE 2013a). However, LEDs currently account for less than 1% of total energy consumption.

FIGURE 1. ANNUAL ELECTRICITY CONSUMPTION OF LIGHTING IN US



Source: DOE 2012a. US Lighting Market Characterization.

Despite the benefits of LEDs, their high initial cost remains a significant barrier to widespread adoption. Many commercial businesses require a minimum of a two year (or less) simple payback (time at which energy savings recuperate initial cost) on energy efficiency upgrades (Energy Solutions 2012). LED fixture costs remain a major barrier to large scale adoption. LED retrofits can be more cost-effective if the energy and maintenance savings over their longer operating lifetime are taken into account in financial calculations.

[10] Assumes a 70% capacity factor and 7% transmission and distribution losses for each coal power plant(Koomey et al 2010).

As LED efficacy and overall product quality (lifetime, reliability, distribution, and color rendering) continues to improve, LEDs have made significant gains in replacing low-efficacy sources such as incandescent, halogen, and HID lamps. This trend is expected to continue as LEDs increase in efficacy and decrease in price.[11] To date, most commercial LED retrofits have been limited to A-lamps, exterior lighting and directional lighting such as PAR and MR16 replacement lamps, as shown in Figure 2 (DOE 2013b). Even with commercial retrofit activity to date, the following table illustrates how far LEDs still have to go – for almost all applications LEDs represent no more than 1-2% of the installed stock.

TABLE 1. US PREVALENCE OF LED SOURCES IN SELECT LIGHTING APPLICATIONS[12]

TABLE 2.1 U.S. PREVALENCE OF LED SOURCES IN SELECT LIGHTING APPLICATIONS [20, 1]

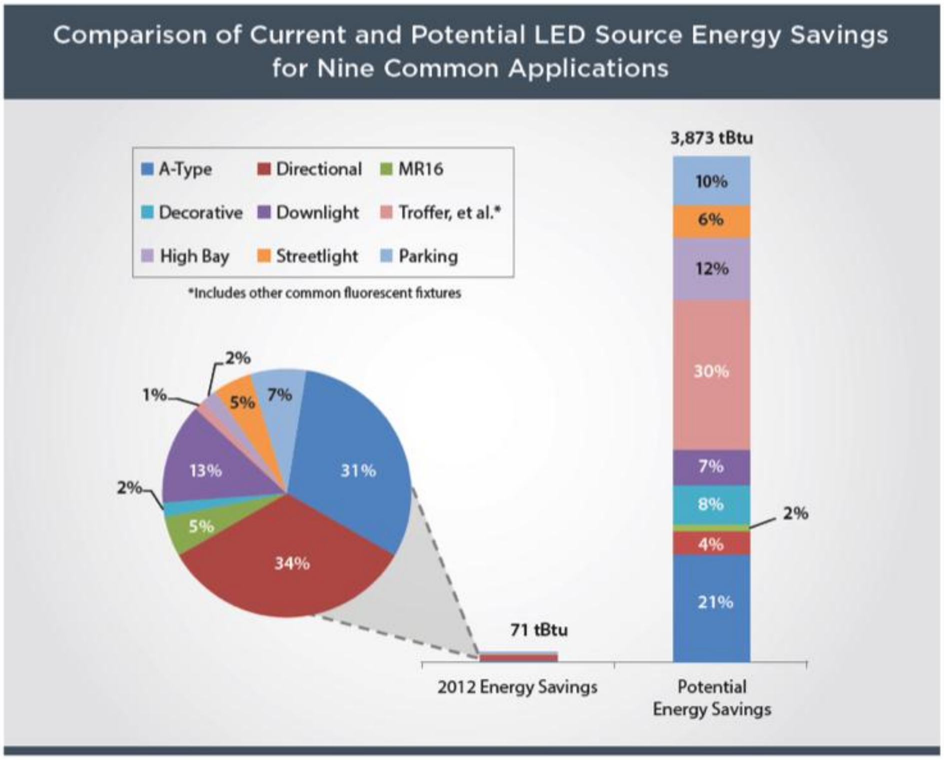
Application	Estimated LED Penetration of Installed Stock (%)[1]	
	2010	2012
A-Type	–	<1
Directional	<1	5
MR16	3	10
Decorative	–	<1
Downlight	<1	<1
Troffer	–	–
High-Bay	–	<1
Parking[2]	<1	1
Streetlight[2]	1	2

Notes:
1. Values less than 0.1% are considered negligible.
2. These estimates have been updated using data from the 2010 U.S. Lighting Market Characterization report.

[11] The US Department of Energy (DOE) estimates that LED efficacy will improve by 20-25% and prices will decrease by 50% from 2013 to 2015, for warm white LED packages with CCT 2580-3710 K and CRI>80) (DOE 2013c).

[12] DOE 2013c. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2013_web.pdf

FIGURE 2. COMPARISON OF CURRENT AND POTENTIAL LED SOURCE ENERGY SAVINGS FOR NINE COMMON APPLICATIONS



Source: DOE 2013a. Adoption of Light Emitting Diodes in Common Lighting Applications.

Due to the high efficacy of linear fluorescent lamps, there have only recently been suitable LED replacements for traditionally linear fluorescent applications, such as general purpose commercial lighting (DOE 2013a).[13] Although fluorescent fixtures represent 80% of commercial fixtures and 72% of energy use (DOE 2012a), they account for only 1% of 2012 LED energy savings (DOE 2013b). However, DOE estimates that LED replacements for linear fluorescent lamps accounts for 30% of potential energy savings.

In March 2013, The US Department of Energy's (DOE) Commercially Available LED Product Evaluation and Reporting (CALiPER) program released a report on LED retrofits in recessed troffers. The report described testing conducted on dedicated LED troffers, LED retrofit kits, and LED linear replacement tubes. The study found that dedicated LED replacements for 1x4 and 2x4 luminaries, such as LED troffers, are ready to compete with recessed fixtures using linear fluorescent lamps.[14] The DOE estimates that LED efficacy will improve by 20-25% and prices will decrease by 50% from 2013 to 2015 (DOE 2013c).

[13] Based on the DesignLights Consortium (DLC) Qualified Products List (QPL), the first DLC qualified 2x4 troffers were available in 2011, while four foot linear replacement lamps were first qualified in 2012.

[14] Although there are many LED fixtures that provide better or equivalent lighting performance to a linear fluorescent fixture, one third of LED troffers studied exhibited flicker when using 0-10V dimming (DOE 2013). Therefore, maintaining high product quality standards remains an essential component of LED programs. In addition to dedicated troffers, the study tested LED retrofit kits and LED replacement tubes, and found that many of these products continue to have quality concerns.

LEDs Available for all Common Lighting Applications

With the advent of high quality LED products for linear fluorescent applications, there are now suitable LED fixtures for all common and retail lighting applications. A typical retail store has a mixture of incandescent, halogen, HID, compact fluorescent and fluorescent sources (DOE 2012a). To date, the majority of LED retrofits targeted non-fluorescent sources, which represents only a small portion of total lighting energy use. With a growing number of high-quality troffer, wrap, and strip fixtures available on the market, it is increasingly feasible to complete a comprehensive LED retrofit across all common lighting applications within commercial stores. A full-scale LED store retrofit has a number of significant system-wide benefits, including improved lighting performance due to fewer outages, better controllability (via 0-10V dimming), reduced energy and maintenance costs, and reduced cooling loads.

Fry's Electronics Comprehensive LED Retrofit Pilot

Fry's Electronics, Inc. is a major national consumer electronics retailer, with 34 locations nationwide, half of which are in California. In 2011, in collaboration with PG&E's Emerging Technologies program and the LED Accelerator program (LEDA),[15] Fry's Electronics began assessing the potential of a complete store retrofit for all major lighting applications, excluding high bay fixtures.[16] Fry's completed a full store retrofit in their flagship San Jose store, which adjoins their corporate headquarters. This retrofit was conducted in parallel with a comprehensive retrofit of the office headquarters to LED fixtures. Although this retrofit was not included in the scope of this report, it provides an example of comprehensive retrofit in an office environment. [17] Like most commercial lighting applications, the headquarters facility uses primarily fluorescent lighting, but also includes a variety of MR16 lamps, PAR lamps, and incandescents in recessed cans.

Fry's primary goals for the comprehensive store LED retrofit were to reduce energy and maintenance costs and maintain, or improve upon, existing light quality. If the pilot is successful and meets Fry's lighting and economic requirements, Fry's plans to expand the retrofit to additional stores within PG&E territory.[18] For the San Jose store, the lighting applications for LED retrofit include:

- General Service Lighting: Linear Fluorescent
  - 2x4 recessed troffers with prismatic lens with linear fluorescent lamps
  - 2x4 surface mounted fixtures
  - 1x4 suspended box louver fixtures with fluorescent lamps
  - 1x4 wrap fixtures
  - 1x4 hooded industrial strip fixtures
  - 1x4 strip fixtures[19]

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[15] PG&E's third party LEDA program, administered by Energy Solutions, provides large multi-site commercial businesses with calculated incentives for installing cutting edge LED products in large numbers. The program also offers customized technical support, including lighting audits, product demonstration and selection, and product specification assistance. For more information, see http://ledaccelerator.com/. In March 2013, The LEDA program was recognized as an "Exemplary Program" in the Market Transformation category.

[16] This includes 4 foot LED replacement tubes, which are not incentivized by LEDA at this time.

[17] Similar to other commercial applications, the Fry's office retrofit was composed of a

[18] In 2013, Fry's is completing major LED retrofits in 4 additional stores within PG&E territory.

[19] The majority of 1x4 strip fixtures were replaced with 4 foot LED replacement lamps with internal drivers. This product category is not eligible for the LEDA program at this time and therefore was not included in this study.

- General Service Lighting: Incandescent
    - 60W incandescent candelabra lamps with standard screw base fixtures

- Downlighting: High Intensity Discharge
    - 100W metal halide replacement in a cylinder pendent fixture
    - 175W metal halide replacement in a recessed can fixture

- Directional Lighting: Parabolic Aluminized Reflector (PAR)
    - 50W halogen PAR 20 lamps

To date, there have been very few field demonstration assessments of LED replacements for linear fluorescent lighting, and none that we are aware of for a comprehensive store retrofit across numerous fixture types. [20]

[20] To date, 20 of the 28 DOE GATEWAY demonstrations have been on exterior HID lighting, 6 of the other 8 studies have focused on directional lighting in museums or hotels. In March 2013, DOE published an evaluation study of dedicated LED troffers, LED retrofit kits, and LED linear tubes. However this study was completed in a mockup environment and not completed as an actual retrofit in a commercial space.

ASSESSMENT OBJECTIVES

SCALED FIELD PLACEMENT: DEFINITION AND INTENT

A scaled field placement is focused on evaluating product performance in multiple sites or applications for potential broader market adoption. Scaled field placements allow stakeholders with adoption influence, in this case a major consumer electronics retailer, to experience the benefits of an energy efficiency or demand response measure. This Emerging Technology project is categorized as a "Scaled Field Placement" due to its focus on a comprehensive store retrofit for all major applications within a single Fry's store and the potential to subsequently scale this retrofit to additional store locations.[21] A second component of the study was to understand how a large retailer such as Fry's evaluates energy efficiency opportunities, makes lighting fixture selections, and scales them across its many locations.

This Fry's Scaled Field Placement will help utilities and efficiency organizations better understand how to assist end-use customers in commercial and industrial lighting retrofits. This will hopefully lead to broader, large-scale adoption of LED lighting, both by Fry's and throughout the commercial sector. A scaled field placement intends to reduce adoption barriers such as information and search costs, performance uncertainties, as well as better understanding of organizational practices. For further information on Scaled Field Placements, see Appendix B.

The study assessed the feasibility of a comprehensive store LED retrofit, from both a product quality and financial payback standpoint, with a specific focus on LED retrofits for linear fluorescent lighting, and to identify opportunities to accelerate adoption of high quality LED products in retail and commercial lighting applications. To achieve these goals, the evaluation focuses on four key assessment objectives.

OBJECTIVE #1: EVALUATE ENERGY USE AND POWER QUALITY CHARACTERISTICS

Evaluate energy use and power characteristics, such as power draw, power factor, and total harmonic distortion across each lighting system, where possible. The lighting system is defined as the total number of fixtures in a specific end use application, and may include measurements from multiple individual electrical circuits. Energy savings are thus calculated on a per fixture basis, for each end use and aggregated at the store level. See "Product Results" section for study results.

OBJECTIVE #2: EVALUATE LIGHTING SYSTEM PERFORMANCE AND QUALITY

Evaluate lighting system performance using photometric measurements and comparative photographs. In addition to comparing the base and measure case, this study also uses lighting modeling to create an accurate comparison between a new base case fixture and the retrofit without having to conduct a complete re-lamping of the base case. See "Product Results" section for study results.

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[21] Fry's plans to retrofit four additional stores within PG&E territory in 2013.

OBJECTIVE #3: CUSTOMER SATISFACTION AND DECISION MAKING SURVEY

Develop a detailed understanding the customer decision making process and how utility programs can address adoption barriers through the implementation of a customer satisfaction and decision making survey. The survey focuses on four core areas:

- Understanding how Fry's evaluates and selects lighting products for use, with a specific focus on their experience with the various fixtures.
- Evaluating the role of utility incentive programs and identifying areas in which utility programs could address existing barriers to adoption.
- Identifying challenges in scaling technology to a large number of stores.
- Evaluating store employee satisfaction with the lighting retrofit.

For additional detail on the customer satisfaction and decision making survey, please see Appendix A. For survey results, please see section titled "Customer Satisfaction and Decision Making Survey Results".

OBJECTIVE #4: ASSESS THE ENERGY SAVINGS AND ECONOMIC IMPACTS OF A COMPREHENSIVE RETROFIT

Perform a financial analysis to quantify project costs, energy savings, maintenance savings, and other financial metrics such as simple payback and return on investment (ROI). These metrics are calculated both at a fixture and store-wide level to identify the cost effectiveness of both individual measures and a comprehensive store retrofit. For project results, see the "Evaluation" section of this report.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

This assessment was conducted at a Fry's store in the San Jose Area. Through discussions with Fry's, this site was selected due to its representative lighting stock and proximity to Fry's corporate headquarters, which is located in an adjoining building. The Fry's store selected for this study was equipped with a variety of recessed fixtures, fluorescent strip fixtures, A-lamps, PAR lamps, and metal halide downlights, which represents the range of fixture types present in most Fry's locations. The San Jose store retrofitted most major end-use lighting applications throughout the store, including PAR lamps, recessed 2x4 fixtures, downlights, 1x4 strip fixtures, and A lamps. These applications include general service illumination and accent lighting for product illumination.

Field measurements were completed by Energy Solutions staff with assistance from Fry's staff, T Marshall Electric, and Chargon Electric. Photometric lab testing was conducted by the California Lighting Technology Center at the University of California, Davis.[22]

Due to the similarities between Fry's locations, there is potential to scale this demonstration to a number of stores in the future. In addition, many of these LED fixtures, such as the CREE CS14, only recently became available on the market. Although Fry's has an Energy Management System, the lighting controls do not include any advanced control mechanisms such as dimming or scheduling, so the lights remain at full power during store operating and stocking hours.

TEST PLAN

To conduct an effective Emerging Technology study, the evaluation team prepared and planned for the primary steps of the study, which aimed to evaluate lighting system performance, energy use, power quality and energy savings potential, as well as to assess customer acceptance and product selection process.

In order to evaluate lighting system power characteristics and energy savings potential, circuit–level electric power measurements were planned for areas with each base case and retrofit technology. Preliminary site visits were carried out to identify study locations and determine where electrical measurements would be taken for each fixture type.

For the lighting performance testing, photometric measurements were planned under the base case and retrofit lighting systems. Measurements included grids of illuminance measurement points to quantify overall light levels, as well as color temperature measurements. Often it is desirable to re-commission the existing lighting system at a study location (re-lamp and re-ballast fluorescents for example) in order to characterize the "as-

[22] Energy Solutions has conducted a number of Emerging Technology assessments for a variety of clients, including utilities, efficiency organizations, and international organizations such as the United Nations. For more information about Energy Solutions' qualifications, visit www.energy-solution.com.

designed" or "as-built" system. However, due to the large-scale nature of the lighting retrofit, it was not feasible to re-lamp and re-ballast each area in order to create a fair comparison between the base and retrofit case. In place of a re-lamp and re-ballast, study areas were modeled using lighting modeling software, where feasible, to create an equivalent comparison between the base case and the retrofit case.[23]. An additional component of lighting performance testing was before and after photographs to compare qualitative appearance of the lighting under base case and retrofit systems.

Another aspect of test planning related to lighting performance was the assessment of product lifetime and lumen maintenance for the fluorescent replacement fixtures. The CREE CS14 was first commercially released in 2012, and was first listed on the Design Lights Consortium Product List in October 2012. Due to the lack of existing product testing for commercially installed CS14 fixtures, laboratory photometric testing was also completed for the CS14 fixture to measure lumen output and lumen maintenance at 2,000 and 6,000 hours of operation.

In order to understand the product selection process for retail lighting, a product selection survey was developed and administered to Fry's employees in charge of facility energy management. While the results reflect the criteria of only one organization, the survey is intended to provide insight into the energy efficiency decision making processes of large organizations, identify opportunities for utilities to address market adoption barriers, and provide feedback on the overall satisfaction of this particular set of products.

METHODOLOGY

On October 26, 2012, Energy Solutions staff visited the Fry's site and took power measurements, photometric measurements, and photographic documentation for the existing base case fixtures. The team returned on March 22, March 28, and April 26, 2013 to replicate these measurements on the retrofit LED fixtures.

POWER MEASUREMENTS

Power measurements were completed for six of eight fixture types studied. For three of the eight study locations (Checkout Register Area fluorescents, Checkout Register Area Chandelier incandescents, and Audio Room PAR lamps) circuits serving the study fixtures were identified and measured at the electrical service panel. For one of the study locations (Auto Install Garage fluorescents), fixture power was measured at the junction boxes in the location. In two of the locations (Break Room and Restroom), fixture power was measured at the wall switch. On-site measurements were conducted for both the base case and the retrofit case using a PowerSight PS-3000. During the March 22, 2013 visit to take retrofit measurements, it was found that the PS-3000 could not measure current for electrical loads smaller than 0.5 amps, which were found on LED fixtures in the Restroom and Break Room. These loads were measured on follow-up site visit, using a Fluke FLU-434 power analyzer with i400s current clamps.[24] All electrical work was completed by a certified electrician. The

[23] Four of the six lighting environments were modeled using lighting modeling software. The remaining two environments were not modeled due to significant ambient light intrusion from store high bay fixtures which made an accurate comparison impossible without modeling much of the entire store, which was beyond the scope of modeling exercise.

[24] Further information on the PS-3000 and FLU-434 instruments are detailed in the 'Instrumentation Plan' section.

lighting systems monitored had a static configuration, with no dimming or other system controls enabled. The Fry's store operates on an Energy Management System (EMS) which controls lighting operations. Hours of operation estimates account for all open store hours, stocking, and maintenance. Due to the consistent nature of the site's operating hours, instantaneous measurements were taken in lieu of long term power logging measurements without any significant loss to data quality.

Measurements were taken at line voltage (120V or 277V) either at the electrical panel, junction box, or at the wall switch. Voltage was measured by attaching the voltage probes to the hot and neutral line. Current was measured using a current transformer. Power factor and total harmonic distortion (THD) were also calculated by the PS-3000 and by the FLU-434.

Checkout Register Area and Checkout Chandeliers

The Checkout Register Area is composed of 1x4 box louvers with linear fluorescent lamps, operating at 277V, as well as chandeliers fixtures with candelabra lamps operating under a decorative flame-shaped cover. These fixtures operate are 277V and 120V, respectively. All measurements for the register area were taken at the electrical service panel. The linear fluorescents were on three circuits and the chandeliers were on three circuits. The original lighting audit listed the chandelier fixture as a 60W incandescent candelabra lamp. However, high levels of THD on the chandelier circuits during the October 26, 2012 audit suggested that the chandeliers were composed of a mixture between incandescent and CFLs. Upon further investigation, the base case was found to be composed of roughly 25% 60W incandescents and 75% 19W CFLs.

Break Room

The Break Room is composed of nine 2x4 recessed fixtures operating at 277V. These fixtures are controlled by two separate wall switches in a checkered configuration. The staff was not able to locate a devoted circuit at the electrical panel, so measurements were taken at the wall switch.

Auto Install Garage

The Auto Install Garage is composed of ceiling mounted 1x4 strip fixtures operating at 277V. The staff was not able to locate a devoted circuit at the electrical panel, so measurements were taken at the junction box upstream of all fixtures.

Restroom

The Restroom is composed of five ceiling mounted 1x4 wrap fixtures operating at 277V. Energy Solutions staff were not able to locate a devoted circuit at the electrical panel, so measurements were taken at the switch. Fixtures are controlled by one main switch.

Audio Room

The Audio Room is composed of (29) 50W PAR 20 lamps operating at 120V.[25] Two of these lamps were burned out during base case measurements. The PAR lamps are operated on three dedicated circuits and recessed 2x4 fixtures are located on a separate circuit.

[25] The Audio Room also includes recessed 2x4 fixtures, which are typically switched off and therefore not included as part of the Audio Room study. These fixtures are located on a separate circuit from the PAR lamps.

Customer Service Area

The Customer Service area is composed of metal halide fixtures operating at 277V. Staff were not able to locate a devoted circuit at the electrical panel or any other location to take power measurements, therefore no measurements were taken in this area. Measurements are estimated using standard fixture wattages from manufacturer cut sheets.

Computer Sales Area

The Computer Sales area is composed of metal halide fixtures operating at 277V. Staff were not able to locate a devoted circuit at the electrical panel or any other location to take power measurements, therefore no measurements were taken in this area. Measurements are estimated using standard fixture wattages from manufacturer cut sheets.

PHOTOMETRIC MEASUREMENTS

Illuminance and correlated color temperature (CCT) measurements were taken for both the base and retrofit case. With the exception of the Audio Room, all measurements were taken horizontally at the same height, with the light meter facing the ceiling. Illumination measurements were taken in all seven areas evaluated in the lighting study. Location and distribution of the measurements of each area are detailed by area in the section below.

Checkout Register Area

Measurements at the checkout counters were taken at each checkout kiosk in the middle of each counter where customers place merchandise. Although this location did have a significant number of lamp burnouts, measurement locations were selected to minimize these effects on lighting measurements. Counters were separated by cash registers and plastic displays which hold fliers and other printed materials. Each measurement was taken in the center of the open counter to minimize light interference from the adjacent registers which block some incoming light. Measurements were taken approximately five feet apart, at a height of 39 inches (3 feet, 3 inches), the height of the counter.

Break Room

Measurements taken in the break room were taken on a 2' x 4' grid, matching the drop ceiling tile grid. Measurements were taken in the center of each ceiling tile or fixture. Measurements were spaced to capture the widest range of illuminance values by being positioned directly underneath light fixtures and in between fixtures. Measurements were taken at a height of 30 inches, the height of the tables.

Auto Install Garage

Measurements were spaced approximately 10' x 4' apart in order to capture a range of light levels from the relative position to the light fixtures, including directly underneath fixtures, in between the two fixtures, and on either end of the room. Measurements were positioned this way to capture light levels in each of the three car bays, where stereo installation took place. Measurements in the Auto Install Garage were taken at both a height of zero and 30 inches, the latter per Illuminating Engineering Society of North America (IESNA) recommendations recommended in The Lighting Handbook (IESNA 2011). This study uses measurements taken at 30 inches for the purpose of evaluation. While the Auto Install Garage typically has the car door bays open during operation, measurements were taken with the bay doors closed to eliminate daylight intrusion.

Restroom

A grid of 2x3 measurements was used due to the small size of the space, with measurements spaced approximately 3' x 3' apart. One row of measurements was taken on the countertop, and one taken in the center of the room parallel to the counter. Measurements were taken in this manner to evaluate the range of light values across the space by positioning one measurement row directly underneath the light fixture and the other row in between the two light fixtures. Measurements were taken at counter height, 36 inches above the floor.

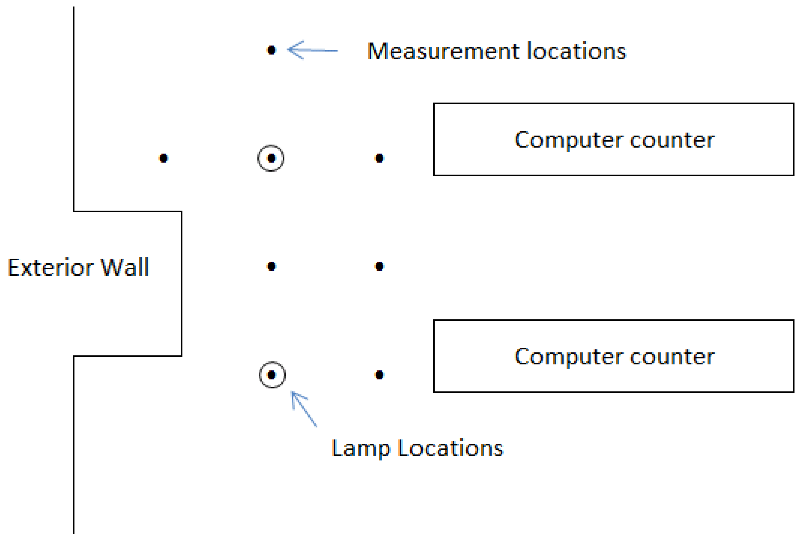
Audio Room

The audio room was the only area in the study that used a vertical grid for illuminance measurements. The directional light sources illuminated a vertical display of speakers set against a wall, providing a vertical, two dimensional plane for analysis. Measurements were made against the wall display of speakers at a variety of heights and distances across the display. Measurements were evenly spaced a foot apart along both the horizontal and vertical axes, starting at a height of two feet. Measurements were spaced this way to capture the distribution and maximum possible range of light levels by positioning measurements directly underneath fixtures and between fixture installation points. In addition, a row of measurements was taken at the floor (height of zero feet) to capture the lowest possible illuminance values.

Computer Sales Area

Due to the irregular layout of the computer sales area, measurements did not conform to a regularly shaped grid. Measurements were taken in the configuration show in Figure 3 below, spaced five feet apart in both directions. This specific configuration was used to evaluate the range of light levels for measurements in relation to their position to the fixtures. This included measurements positioned directly underneath fixtures, spaced in between fixtures and at a fixed distance from the fixture. Measurements were taken at a height of three feet, the height of the counters.

FIGURE 3. COMPUTER SALES MEASUREMENT DIAGRAM



Customer Service Area

A 3x3 measurement grid was used in the customer service area to assess the counters and the walkway in between. Measurements were spaced approximately four feet apart in both directions. This grid captured a range of light values across the customer service counters ranging from directly underneath light fixtures to in between two fixtures. Measurements were taken at a height of 43 inches, the height of the counter.

The height of the measurements per area is summarized in Table 2 below.

TABLE 2. MEASUREMENT HEIGHT BY AREA

Room	Measurement Height	Reason for Measurement Height
Checkout Register Area & Checkout Chandeliers	39 inches	Counter height
Break room	30 inches	Table height
Auto Install Garage	30 inches from floor	IESNA recommendation
Restroom	36 inches	Counter height
Audio Room	Varies	Vertical grid against wall
Customer Service Area	43 inches	Counter height
Computer Sales Area	30 inches	Counter height

Table 3, below, shows the color gradient used to represent light levels visually in the illuminance tables in this report. The highest relative values have the darkest red coloration and the lowest values have the lightest. The colors do not correspond to absolute values, but rather relative percentages of the maximum illuminance found within each comparison group of measurements (before and after). For example, the highest and lowest recorded base case measurements in the Auto Install Garage, were 49.6 and 27.8 footcandles respectively, and were both recorded under the base case lighting. The retrofit LED measurements in the Auto Install Garage were concentrated in the middle of this range. The color gradient provides a visual depiction of the lighting distribution of each system, where tables with relatively consistent coloring indicate more even illumination levels and a lower contrast ratio. Tables with redder and whiter cells indicate a more uneven distribution, resulting in hotspots and under-lit areas, respectively.

TABLE 3. SAMPLE COLOR GRADIENT OF ILLUMINANCE MEASUREMENTS

Sample color gradient										
100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%

CORRELATED COLOR TEMPERATURE

Correlated Color Temperature (CCT) measurements were taken in all study areas before and after the LED retrofit. In all cases, the measurements were taken with the meter directly facing the light fixture to minimize obstruction or interference from other light fixtures. In some areas, such as the Checkout Register Area and Computer Sales Area, there was unavoidable light intrusion from external sources such as daylight from the store entrance and the high bay HID fixtures.

PHOTOGRAPHS

Photographs were taken of the base case and retrofit to provide a qualitative comparison of the visual impact resulting from the change in the lighting system. For each pair of photographs, a Canon 40D DSLR used identical camera settings (shutter speed, f-stop, and ISO). The photographs were used to visually characterize lighting distribution across the space, and determine the lighting distribution patterns and the presence of over-lit and under-lit areas.

LIGHTING SIMULATION

For this project, an accurate field comparison between the base case lamp configuration at its design performance and the LED retrofit could not be completed without re-lamping existing fixtures. At the time of the retrofit, many fixtures were burned out or near the end of their useful life. The high degree of lamp lumen depreciation and burnouts negatively impacted the base case measurements. However, given the broad scale of the project retrofit, re-lamping the base case fixtures to create a representative base case was too expensive and not considered feasible. In place of a re-lamp, lighting simulation software was used to develop and compare a representative base case with the LED retrofit. This comparison provides a simulation of base case fixtures performance for expected output.

Lighting simulations for this report were completed using AGi32, a software program published by Lighting Analysts, Inc. With this program, the user creates a three-dimensional model space and integrates light fixture data to create accurate simulations of how light sources perform within the space. Additionally, the software includes tools to evaluate and compare illuminance values. To construct the simulations, measurements of physical dimensions were taken in each retrofit area of the Fry's store. These areas were then recreated within the software. The modeled environments represent discrete areas of the store featuring a range of LED retrofit technologies to evaluate. The specific areas chosen each had well defined walls and boundaries, which minimizes intrusion from external light sources. Each room was built in a separate modeling file to maintain isolation and to speed up the rendering process. Simulations were completed for the following five areas within Fry's.

- Break room
- Auto Install Garage
- Restroom
- Audio Room
- Customer Service Area

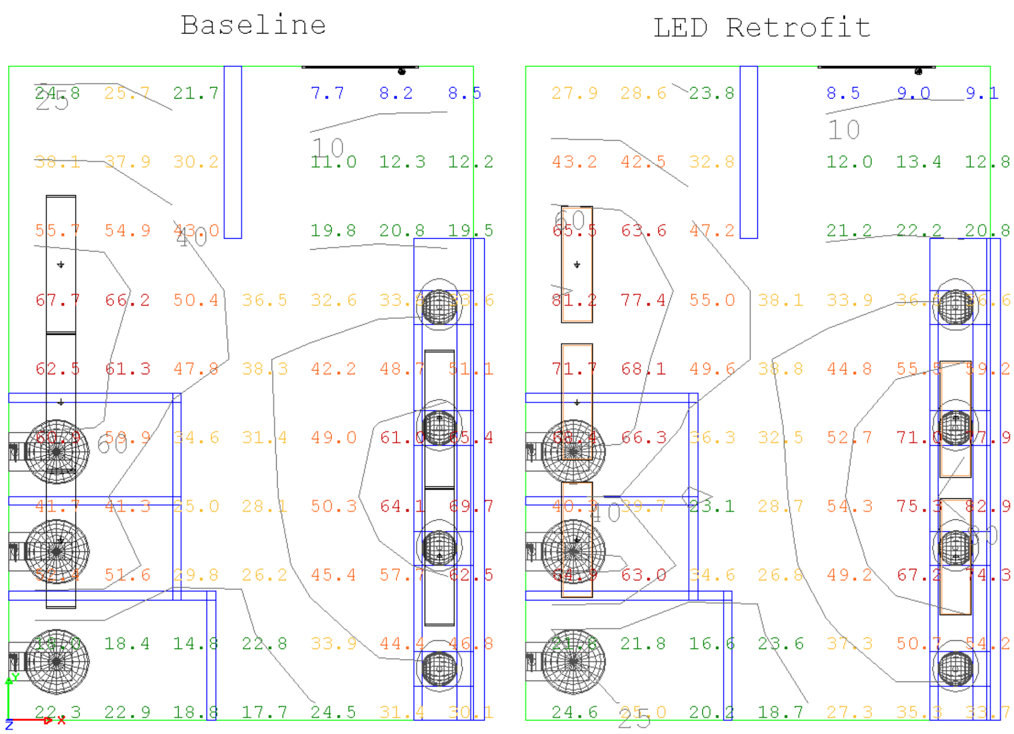
Lighting simulations could not be completed for the Checkout Register Area and Checkout Chandeliers or the Computer Sales Area due to the open floor plan and substantial light intrusion from other light fixtures, including the high bay metal halide fixtures located throughout the store. The open floor plan made a 3D model impractical without building a comprehensive model of the entire store to fully capture this lighting intrusion, which was beyond the scope of this study.

For each area simulated in AGi32, an illuminance map was created from the lighting model that highlights several pieces of information about the space:

- Objects and light fixtures within the space, such as tables, toilets, and internal walls are depicted in blue and black outlines.
- Illuminance values simulating measurement points are represented by color-coded numbers ranging from darkest (blue) to brightest (red).
- Illuminance isolines are represented by solid grey lines. Along each isoline, the illuminance matches the value of the line's label. These lines depict how light is distributed across the space at different levels of illumination.

For more details on lighting simulation design, please see Appendix C.

FIGURE 4. EXAMPLE OF AGI32 MODEL OVERHEAD VIEW WITH ISOLINES



An additional feature of AGi32 is the ability to create three-dimensional rendered images of the model. These renderings provide a visual, rather than data-based representation of how the retrofit will perform. An example of a rendering is shown below.

FIGURE 5. EXAMPLE OF AGI32 MODEL RENDERING

ENERGY SAVINGS AND ECONOMIC IMPACTS ASSESSMENT

An in depth energy and cost savings analysis was conducted for each product individually and for the entire project. Store lights were assumed to operate 5,895 hours per year (about 115 hours per week), based on feedback from Fry's Corporate Energy Manager. Energy costs were determined using the most current PG&E E19 rate schedule, which is approximately $0.14/kWh.[26] Avoided maintenance costs are based on the savings from the number of times the existing lamp, fixture, and ballast would each need to be replaced (which includes the cost of existing lamp/fixture/ballast and labor to install) during the lifetime of the corresponding LED product. It is assumed that the labor to install the existing products is half the labor cost of the corresponding LED product to install. While this is highly dependent on fixture type, it is considered a suitable approximation for the purposes of this study.

The study used the LEDA base case store lighting audit to determine fixture type and base case wattage. Base case energy costs were calculated by multiplying base case wattage by hours of operation and PG&E's rate schedule. Retrofit energy costs were determined in a similar manner for retrofit fixtures. Annual energy savings were calculated by subtracting retrofit energy costs from base case energy costs. Although the fixture lifetime varies per fixture, when weighted by retrofit energy consumption, the average rated lifetime of the products is 13.8 years, weighted by energy savings. The study assumed a more conservative 12 year average project lifetime. While some fixtures, such as the LED A-lamps, may have a shorter lifetime while others, such as the CR24 LED troffers, which have a rated 16.7 year lifetime, may be much longer.

LED fixture costs were estimated based on budgetary estimates from distributors of each product. The estimates did not include any adders and are estimates of what an Electrical Contractor could expect to pay for these luminaires through Electrical Distribution. The prices used may vary as a result of quantity and/or date of purchase and they do not include freight, tax or lamps where applicable. Base case lamp and ballast costs were based on online price research from Google Shopping or www.1000bulbs.com. Both resources used were based on a single fixture purchase. To more accurately estimate pricing achieved by purchasing in volume (both for base case replacement lamps and new LED fixtures), product costs were reduced by 30%. Energy costs are assumed to increase annually at the rate of inflation.

To calculate maintenance savings, the life cycle costs of the base case and retrofit case were determined for the life of the LED retrofit fixture. The life cycle costs include the number of replacement lamps (and labor cost to install them) necessary to match the rated lifetime of the LED fixture. Maintenance costs are assumed to increase annual at the rate of inflation.

The financial analysis used the following rates for financial calculations:

- Inflation Rate: 3%
- Discount Rate: 7%
- Financing Rate: 0% (based on PG&E OBF program)
- Project Lifetime: 12 years
- Re-investment Rate: 5%

[26] PG&E E19 rate schedule last updated July 1, 2012. For a full description of PG&E's rate schedules, visit: http://www.pge.com/tariffs/rateinfo.shtml

DECISION MAKING AND SATISFACTION SURVEY

To develop the satisfaction survey, Energy Solutions conducted an initial interview with key decision makers within Fry's to develop an understanding of their internal decision making structure and how energy efficiency opportunities are evaluated. Based on this initial interview, the project team developed a survey which covered the following topics:

- Existing Operation
- Financial Metrics when considering energy savings opportunities
- Product Evaluation and fixture selection process
- Evaluating the impact of utility programs and external agencies in the selection process
- Scaling comprehensive store retrofits across all Fry's stores
- Lighting Controls strategies such as Demand Response and occupancy based dimming
- Employee response to lighting retrofit

Based on the feedback from this interview, Energy Solutions conducted two follow up interviews with Fry's representatives to discuss survey responses in further detail.

LABORATORY PHOTOMETRIC TESTING

In order to quantify the degree to which LED fixture output will decrease over time ("lumen depreciation"), lab photometric testing was completed for two CREE CS14 fixtures after 2,200 hours and 6,000 hours of operation. Photometric testing was conducted by the California Lighting Technology Center (CLTC) at the University of California, Davis.

These tests include:

- Correlated Color Temperature (CCT) (Kelvin)
- Color Rendering Index (CRI)
- Light Output (lumens)
- Power (watts)
- Efficacy (lumens/watt)

Tests were performed with both a goniophotometer and an integrating sphere. Integrating Sphere measurements were taken in accordance with LM-79, on a Yokogawa PZ4000 power analyzer and made with a SMS-500 Spectrometer in a 2 meter integrating sphere. Auxiliary correction was applied for fixture self absorptions. Goniophotometer measurements were presented in accordance with LM-63-2002 and taken on a Xitron 2802 power analyzer with a T-10 Konica Minolta Illuminance meter. Stray light correction was applied.

FIGURE 6. CLTC SUMMARY OF PHOTOMETRIC REPORT FOR CREE CS14

Note: All testing conducted at 277V by the California Lighting and Technology Center.

INSTRUMENTATION PLAN

Power measurements were obtained using a Summit Technologies PowerSight PS-3000 for electrical loads above 0.5 amps. For electrical loads below 0.5 amps, a Fluke FLU-434 series power analyzer was used. Photometric measurements were obtained using a Konica Minolta CL-200. The PS-3000 and CL-200 were obtained on a loan from the PG&E Pacific Energy Center Tool Lending Library. The FLU-434 was obtained from an equipment rental company. All instruments were initially checked to ensure they were functioning correctly. Instrumentation specifications are provided in Table 4 below.

TABLE 4. STUDY INSTRUMENTATION

Variable	Illumination	Correlated Color Temperature	Power, Power Quality	Current	Voltage
Instrument	Konica Minolta CL-200	Konica Minolta CL-200	PowerSight PS-3000; Fluke FLU-434	PowerSight PS-3000; Fluke FLU-434 w/ i400s current clamps	PowerSight PS-3000; Fluke FLU-434
Units	Foot-candles	Kelvin	Watts, PF, THD	Amps	Volts
Measurement Range	0.01-9,999 fc	0.5 fc or above	Not given	1mA-5000A_{rms}; 0A-400A_{rms};	1-15,000 V_{rms} ;1-1,000 V_{rms}
Accuracy (%)	±0.002	±2%±1 digit of displayed value	±1%; ±1%;	±0.5%, ±1%	±0.5%; ±0.5%
Response time	0.5 seconds	0.5 seconds	16 µsec	16 µsec	16 µsec
Last Calibrated	2011; 2012	2011; 2012	2011; 2012	2011; 2012	2011; 2012

Lighting simulations for this report were completed using AGi32, a software program published by Lighting Analysts, Inc. This program creates three-dimensional models and integrates light fixture data to create accurate simulations of how light sources perform within a modeled space.

PRODUCT BACKGROUND

This study evaluated LED technologies used in various lighting applications in a retail setting, listed by technology and fixture type below. These lighting use cases are all common in retail environments and are areas where LED technology is at various stages of maturity in terms of readiness to compete with or exceed incumbent lighting technology performance.

GENERAL SERVICE LIGHTING: LINEAR FLUORESCENT

2x4 Surface Mounted Fixtures and 2x4 Recessed Troffers with Prismatic Lens with Linear Fluorescent Lamps

The predominate base case lighting fixture used for general illumination in office, training, stock room, break room, and hallways in the study location was 2' X 4' (2x4) linear fluorescent troffers – mostly 4 lamp fixtures. The LED replacement technology selected by FRY's for these applications is the CREE CR24 series LED troffer. Ninety such fixtures were installed during the lighting retrofit at Fry's.

TABLE 5. CREE CR24 LED TROFFERS (CR24-40L-40K, CR24-40LHE-40K)

DESCRIPTION	OUTPUT	WATTAGE	EFFICACY	CCT	CRI	LIFETIME
High-performance integrated 2x4 LED troffers	4,000 lm	36 to 44 W	90 - 130 lm/W	4000K	>90	50-100,000 HOURS

The CREE CR troffers are amongst the highest performance interior LED light fixtures on the market, with efficacy up to 130 lm/W being at the highest range for products found on the Design Lights Consortium (DLC) Qualified Product List.[27] For 2x4 troffer replacement kits and integrated fixtures on the list, the average efficacy is currently around 88 lm/W with average output of 4,800 lm. Average CRI is 83, whereas the CREE CR troffers exhibit very high CRI for this product class, at over 90. The stated design life of 50,000 to 100,000 hours is also very attractive.[28]

1x4 Suspended and Surface Mounted Wrap and Strip Fixtures with Fluorescent Lamps

These types of fluorescent fixtures are more industrial or utilitarian in nature and are normally used in areas where fixture aesthetics are less of a concern. The fixture body is very basic and there is little optical or reflector design; often the fixtures simply run one (1X4) to two (1X8) bare fluorescent lamps, installed in long strings to cover a space with general illumination. In the study location, these fixtures were in the storage, electrical, auto install, and restroom areas.

[27] The DesignLights Consortium (DLC) is a project of Northeast Energy Efficiency Partnership (NEEP), a group that promotes efficient and high quality lighting.

[28] The CR24 troffers installed at Fry's have a rated lifetime of 100,000 hours.

For the LED retrofit option, Fry's chose the CREE CR-LE-40L-40K-S, which uses the same LED light engine found in the CR24-40L-40K 2x4 LED troffer, but without the accompanying 2' wide fixture form and housing. Around 120 strip and wrap fixtures were retrofitted in this way.

1x4 Suspended Box Louver Fixtures with Fluorescent Lamps[29]

These types of fixtures are used in the cash register and customer check out area of the study location. Fry's installed 163 1x4 LED fixtures in place of the suspended box louver fluorescent fixtures.

TABLE 6. CREE CS14 LED TROFFERS (CS14-40LHE-40K)

DESCRIPTION	OUTPUT	WATTAGE	EFFICACY	CCT	CRI	LIFETIME
High-performance integrated 1X4 LED troffers	4,000 lm	36 W	111 lm/W	4000K	92	50,000 - 75,000 HOURS

The average efficacy of DLC qualified 1x4 replacement fixtures and kits is 88 lm/W. Average output on the list for these products is around 3500 lm, with average wattage of 40W. The high efficacy CS14 installed for this retrofit comes in with higher output, lower wattage, and amongst the best efficacy ratings on the DLC list. It is described by CREE as a compact, lightweight fixture design, easy to install in grocery, retail, and light industrial applications.

GENERAL SERVICE LIGHTING: INCANDESCENT

In the customer checkout area as well as in select locations on the sales floor (TV sales, café area), the base case lighting fixture is a unique suspended chandelier with five candelabra-style globes that each contain a 60W candelabra lamp. There are 70 such fixtures at the Fry's location, with a total of 350 lamps. It was found that there was a mix of CFL and incandescent type B lamps installed in these fixtures (IESNA 2011).[30] Fry's chose the Philips EnduraLED 12W LED A lamp to replace the CFL and incandescent lamps.

[29] Over 240 1x4 and 1X8 strip fixtures were retrofitted with 4 foot LED replacement lamps with internal drivers in the existing fluorescent fixtures. This product category is not eligible for the LEDA program at this time and therefore was not included in this study.

[30] B type incandescent fixture as defined in the IESNA Handbook. Although Fry's uses a 60W B lamp in this decorative fixture, a standard A lamp is also suitable.

FIGURE 7. 60W INCANDESCENT A LAMPS WITH STANDARD SCREW BASE IN SUSPENDED CANDELABRA CHANDELIER

The EnduraLED A lamps are dimmable, though this feature is not used in the study location. They are designed for 25,000 hours of operation which is significantly longer than the rated life of incandescent lamps (1,000 hours) and CFLs (6,000-15,000 hours). Energy Star -listed A lamps range in wattage from 6W to 12W and average 720 lm output. Efficacies for LED A lamps on the list range from 50 to 100 lm/W with an average around 65lm/W, close to the rated performance of the EnduraLED A lamp used at Fry's.

TABLE 7. PHILIPS ENDURALED 12W A LAMP

DESCRIPTION	OUTPUT	WATTAGE	EFFICACY	CCT	CRI	LIFETIME
Warm white LED A lamp, 60W incandescent replacement	800 lm	12.5 W	64 lm/W	2700K	80	25,000

DOWNLIGHTING: HIGH INTENSITY DISCHARGE

100W Metal Halide Replacement in a Cylinder Pendent Fixture

There were 16 100W metal halide (120W connected load) pendant mounted cylinder downlights suspended from the 20′ ceiling in the customer returns area of the store. These were replaced with CREE Essentia high output LED downlights.

TABLE 8. CREE ESSENTIA 75W LED DOWNLIGHT (ESA-C10-WD-42-D)

DESCRIPTION	OUTPUT	WATTAGE	EFFICACY	CCT	CRI	LIFETIME
10" cylinder downlight with 42 high output LEDs	3829 lm	75 W	50 lm/W	4000K	80	50,000 HOURS

These fixtures carry an impressive ten year warranty and are designed for very high lumen maintenance over the fixture lifetime (90% output at 50,000 hours), meaning that this product should last significantly longer than the base case MH (typically rated for a maximum of 15,000 - 20,000 hours).

Energy Star maintains a qualified product list for LED downlights, with recessed, pendant, and surface mounted options; both residential and commercial. The fixtures on that list range in output from 300 to over 7,000 lm. The average output is 940 lm and the average wattage is 17W; both considerably lower than the 75W Essentia, which is intended for higher output applications than many residential models included in the list. The average efficacy of the Energy Star listed LED downlights is 56 lm/W, and for fixtures with lumen output higher than 3,000 lm, average efficacy is 66 lm/W. The Essentia fixture is then on the lower end of the range in terms of efficacy.

175W Metal Halide Replacement in a Recessed Can Fixture

There were 40 175W metal halide (210W connected load) recessed can fixtures mounted in the 15' ceiling in the computer sales area of the store. These were retrofitted with CREE Essentia cylinder fixtures using a CREE's "Hangstraight Pendant" mount to attach to the sloped ceiling.

TABLE 9. CREE ESSENTIA 100W LED DOWNLIGHT (ESA-C10-MD-56-D)

DESCRIPTION	OUTPUT	WATTAGE	EFFICACY	CCT	CRI	LIFETIME
10" cylinder downlight with 56 high output LEDs	5432 lm	100 W	54 lm/W	4000K	80	50,000 HOURS

These are essentially a higher wattage, higher output version of the Essentia LED cylinder fixtures installed in the customer service area. Again, they carry a 10-year warranty and are specified for over 50,000 hours of operation.

DIRECTIONAL LIGHTING: PARABOLIC ALUMINIZED REFLECTOR (PAR)

50W Halogen PAR20 Lamps

There are roughly 45 directional lighting fixtures installed in audio sections of the store to highlight merchandise on the sales floor. These fixtures were operating 50W halogen PAR20 lamps on track fixtures and some 37W R40 CFL lamps in recessed cans. The lamps in these track and recessed fixtures were replaced with Green Creative Titanium 2.0 7W LED PAR lamps.

TABLE 10. TITANIUM SERIES 2.0 LED PAR20 7W DIM (GC.7PAR20TITDIM830FL40)

DESCRIPTION	OUTPUT	WATTAGE	EFFICACY	CCT	CRI	LIFETIME
7 W warm white flood angle PAR20	350 lm	7 W	50 lm/W	3000K	85	40,000 HOURS

For LED PAR style replacement lamps, the Energy Star lists almost 1,300 qualified products, ranging in output from 200 lm to 1,600 lm, with an average output of 800 lm. The Titanium PAR20s are on the lower end of the output scale, but the smaller PAR20 form factor is naturally a lower output option than the PAR38 form that is also common on the list. Efficacy of PAR lamps on the list range from 39 to 86 lm/W, with an average of 58 lm/W; again, higher than the Titanium PAR20s.

BASE CASE TECHNOLOGY PERFORMANCE

General service lighting is often provided by linear fluorescent lamps in troffers, wrap fixtures and strip fixtures, as well as simple incandescent and compact fluorescent A-lamps in downlights and very basic fixtures and sockets. In some higher output general lighting fixtures, a high intensity discharge light source may be used, such as large high bay metal halide fixtures. Table 11 below lists the efficacy and color rendering properties of the most common base case sources for interior lighting.[31]

TABLE 11. EFFICACIES AND COLOR RENDERING ABILITY OF BASE CASE LIGHTING TECHNOLOGIES

LAMP TECHNOLOGY	EFFICACY RANGE (LUMENS PER WATT)	COLOR RENDERING
Standard Incandescent	7 to 15	Excellent (100)
Tungsten Halogen	15 to 25	Excellent (100)
Compact Fluorescent	25 to 75	Good (70+) to Excellent (80+)
Fluorescent Tubes	65 to 95+	Medium (60+) to Excellent (80+)
Metal Halide	45 to 95+	Fair (50+) to Good (70+)

LED lighting options have to target equivalent or better performance relative to each base case source and application in order to provide a competitive alternative. In the past several years, LED chip technology as well design developments for the integration of LED chips into lighting service products have advanced considerably. LED lighting products from LED fixtures for replacing existing light fixtures to LED lamps that can be used in existing fixtures, are proliferating in the commercial and consumer market. These products have shown that in many cases they can meet or exceed base case lighting technology performance. LEDs also carry the promise of much longer lifetimes – the solid state, low

[31] Adapted from Table 1 on page 4 of Green Seal Choose Green Report – Linear Fluorescent Luminaires. http://www.wbdg.org/ccb/GREEN/REPORTS/cgrlinearfluor.pdf

voltage nature of the light emitting diode is simple and robust and can result in products with rated lifetimes of 50,000 hours or more.

DIRECTIONAL LIGHTING

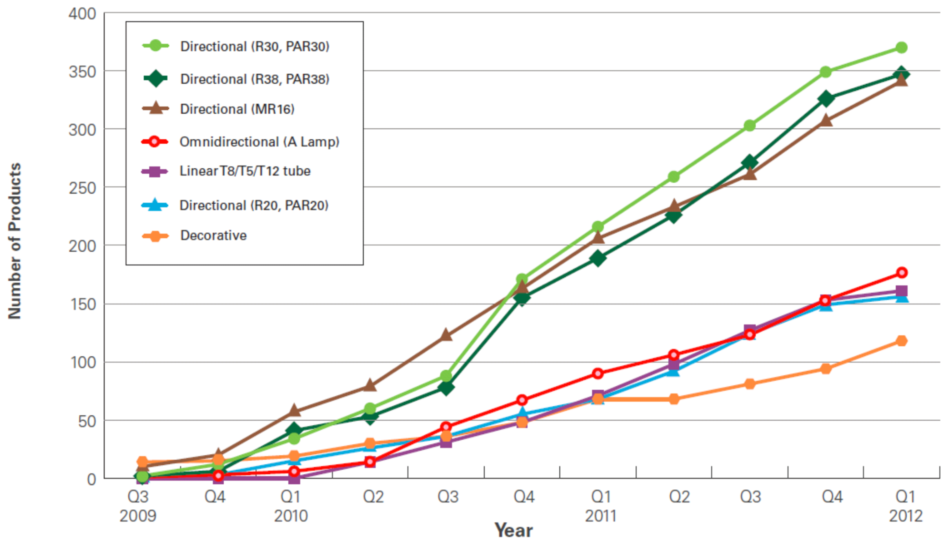
The nature of the LED light source, a diode that emits light from only one side of a silicon semiconductor, is quite different than filament-based technologies in bulbs, and gas/electrode combinations in fluorescent tubes. Whereas LEDs are inherently directional, the base case sources emit light roughly in all directions ("omnidirectional" sources). The directionality of LED lighting and its high efficacy has made accent lighting an early target for LED replacement lamps. Accent lighting has traditionally been provided by incandescent lamps with an aluminized reflector (most commonly halogen-filled) to concentrate the beam spread. Because LEDs are already directional in nature, less optical management is necessary to direct the light toward the target.

FIGURE 8. INCANDESCENT HALOGEN PAR LAMP (LEFT) AND LED PAR REPLACEMENT LAMP (RIGHT)

LED Photo Credit: Green Creative

For several years, lighting manufacturers have been developing and refining LED directional lamps to replace incumbent incandescent reflector lamp technologies. Today, LED options are quite competitive in terms of lighting and energy performance. In 2012, LEDs accounted for 4.6% of the installed base for directional lighting, up from less than 1% in 2010 (DOE 2013a). The DOE Lighting Facts Product Snapshot reports for replacement lamps (2010, 2011 and 2012) and the Lighting Facts database of products depicts the growth in the LED market and the wide availability of products. In 2010, directional LED lamps comprised almost 75% of the products listed in Lighting Facts, and they continue to dominate the lamps listed today. In Figure 9, the green and brown trend lines show the historic dominance of LED directional lighting relative to all listed LED lighting products.

FIGURE 9. CUMULATIVE LED REPLACEMENT LAMPS IN LIGHTING FACTS DATABASE[32] (DOE 2012B)



Sources:
LED: DOE LED Lighting Facts Products List, March 2012, www.lightingfacts.com/products.
Analysis and figure: D&R International.

Source: DOE 2012b

According to a recent DOE lighting fact sheet, "a wide variety of LED directional lamps are now available [and] compare favorably to conventional directional lamps, having higher efficacy, acceptable color quality, and a range of available luminous intensity distributions."[33]

Energy Star currently lists over 1,500 qualified LED PAR replacement lamps, with average efficacy over 57 lumens per watt,[34] which compares very favorably to the high end efficacy of 25 lumens per watt for halogen PAR lamps, from Table 11. LED options have also increasingly focused on the ever-important color rendering properties of directional lighting for retail applications and LED lamps are now available with high CRI and R9 values.[35]

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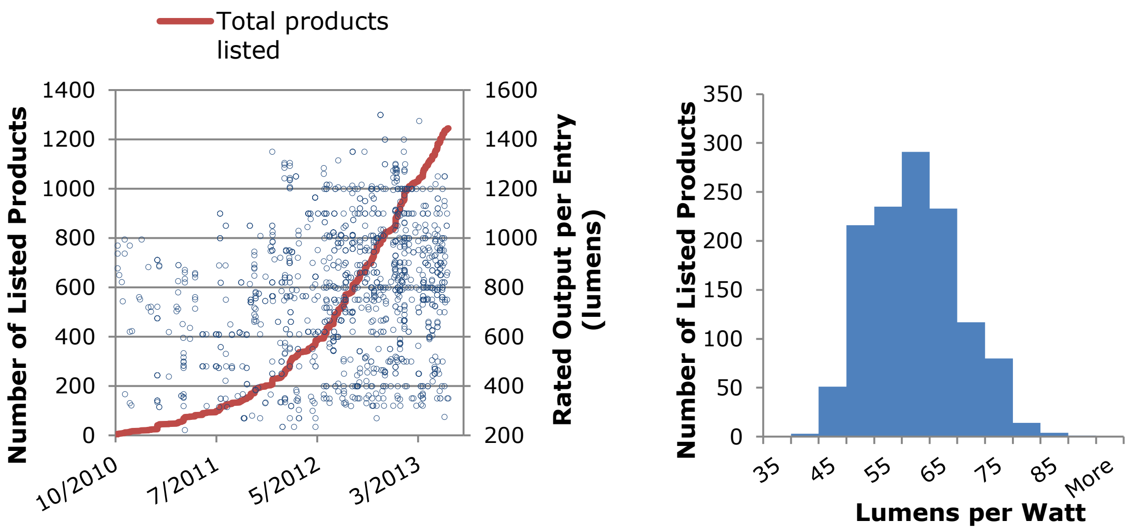
[32] Based on a March 2012 Product Snapshot. http://www.lightingfacts.com/downloads/July_2012_LF_Product_Snapshot.PDF

[33] LED Directional Lamps Fact Sheet http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_directional_lamps.pdf

[34] ENERGY STAR Light Bulbs for Consumers: http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=LB

[35] The Color Rendering Index is the method of measurement to standardize how well colors from a light source are rendered compare with light from a reference source such as sunlight. CRI combines rendering results from standard pigment samples R1 – R8. The R9 value is not accounted for in the CRI value, but is important to characterize color performance for strong, vibrant reds prevalent in skin tones, clothes, food items, and more. Therefore R9 is beginning to receive attention as an important color rendering property for LEDs.

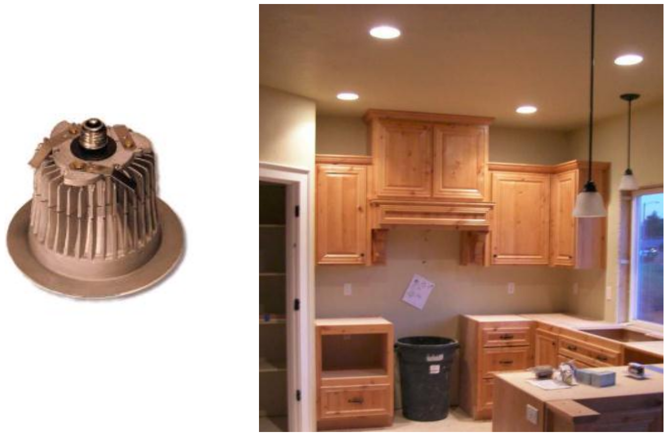
FIGURE 10. ENERGY STAR LISTED COMMERCIAL LED DIRECTIONAL DOWNLIGHTS AND EFFICACY DISTRIBUTION



DOWNLIGHTING

Downlighting is another category of lighting service that was targeted early on by LED manufacturers and designers. Downlight fixtures are often recessed into a ceiling plenum, providing light downward into the illuminated space. Pendant mounted can-style downlights are another common option. Downlighting is considered "ambient lighting," in that it is not generally targeted at a specific object. Though not as concentrated as accent lighting, it is still somewhat directional in nature; the intensity distribution from a downlight will be focused only or mostly in the downward direction. The semi-directional nature of downlights made them an early target for LED replacements. Figure 11 shows an example of an integrated LED downlight fixture and how it appears installed in a residential application.

FIGURE 11. LED DOWNLIGHT FIXTURE AND RESIDENTIAL INSTALLATION EXAMPLE (DOE GATEWAY DEMONSTRATION)



Source: DOE GATEWAY Demonstration[36]

Integrated downlight fixtures with LED light sources have been available for residential and commercial applications for several years, and even early fixtures exhibited high efficacy and performance. A DOE study from 2008 on a commercially available LED downlight fixture found energy savings of over 80% compared to incandescent and halogen options, and consistently higher light levels as well.[37]

Energy Star maintains a list of qualified LED fixtures including LED integrated downlight fixtures and replacement kits, with requirements such as a) at least 75% of output being in the downward direction (0° to 60° from nadir) and b) an efficacy of greater than or equal to 45 lumens per watt. There are over 1,500 LED commercial and residential downlights (recessed, pendant, and surface mounted) currently listed with Energy Star, as shown in Figure 12, with average efficacy of around 56 lumens per watt.[38]

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[36] http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_eugene.pdf

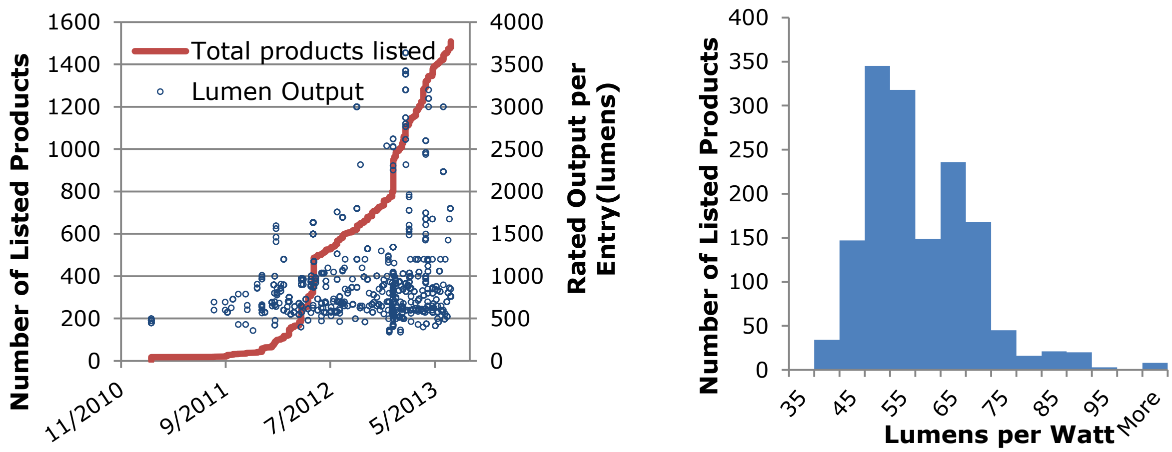
[37]Pacific Northwest National Laboratory. *Demonstration Assessment of Light-Emitting Diode (LED) Residential Downlights and Undercabinet Lights*. Rep. Pacific Northwest National Laboratory, Oct. 2008. Web. June 2012. <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_eugene.pdf>

[38] ENERGY STAR fixture specifications:

http://www.energystar.gov/ia/partners/product_specs/program_reqs/Final_Luminaires_V1_2.pdf?eb95-8a31

ENERGY STAR Light Fixtures for Consumers:
http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=LU

FIGURE 12. ENERGY STAR LISTED RESIDENTIAL AND COMMERCIAL LED DOWNLIGHTS AND EFFICACY DISTRIBUTION



GENERAL SERVICE LIGHTING

The movement of LEDs from directional lighting service and downlights to general service lighting applications with more broadly distributed illumination has lagged behind more directional applications, but is now well underway. The largest targets are standard "Edison" based A lamps, the ubiquitous light bulb used in residential desk lamps, ceiling fixtures, and some commercial applications, as well as fluorescent lamps widely used for general office lighting and ambient lighting in retail spaces. Screw-in A lamps are the most common light source in the U.S., with over 2 billion incandescent and another billion CFL A lamps currently installed (DOE 2012a). They are also the least efficient, especially in terms of incandescent lamp efficacy, only 10 -17 lumens per watt[39] and CFL efficacy of 25 - 75 lumens per watt. The four foot T8 fluorescent lamps used in general service lighting fixtures primarily for commercial spaces are the next most common light source in terms of lamp numbers, totaling over 1 billion in the U.S. Four foot T8 lamps alone account for roughly one third of lighting energy in the commercial sector and linear fluorescent lamps as a whole, including all lamp sizes and styles, account for 72% of lighting energy (123 TWh per year) in the commercial sector and 36% of all lighting in the U.S. (DOE 2012a). Much of the high annual energy use of this lighting category is not only attributable to the high number of installed fixtures but also to their high annual operating hours.

LED chip-level efficacies, at well over 100 lumens per watt, compare very favorably to the low efficacy of incandescent technology and are also competitive to the higher efficacy of fluorescent lamps, which can range from 80 to 100 lumens per watt (bare lamp). Relative to the incumbent general service lighting technologies, LEDs are quite efficient at turning electric power into visible light. However, the light from fluorescent and incandescent sources is roughly isotropic; light is emitted at roughly the same intensity in all directions. To provide similar lighting distribution to incandescent A lamps or fluorescent tubes, LED lighting must be skillfully directed by innovative product design to provide omnidirectional or near-omnidirectional output.

[39] http://energy.gov/energysaver/articles/incandescent-lighting

General Service Lighting: A Lamps

Given the state of LED technology and new product designs, it appears that the opportunity for general service LED lighting has arrived. In fact, LED offerings in these categories are advancing rapidly. For example, in 2008 the DOE launched the L-Prize to spur innovation in the LED A lamp replacement market and develop a suitable replacement for the 60W incandescent.[40] The first winner, from Philips Lighting North America, was announced in August of 2011, and provides a 910 lumen output and 93.4 lumen per watt efficacy. The L-Prize lamp is perhaps one of the most rigorously tested products in the history of lighting. Figure 13 shows stress testing during the evaluation process. Note that 100% of the CFLs have burned out, while none of the Philips lamps have burned out yet.

FIGURE 13. PHILIPS L PRIZE LED LAMP STRESS TESTING ALONGSIDE CFL A LAMPS

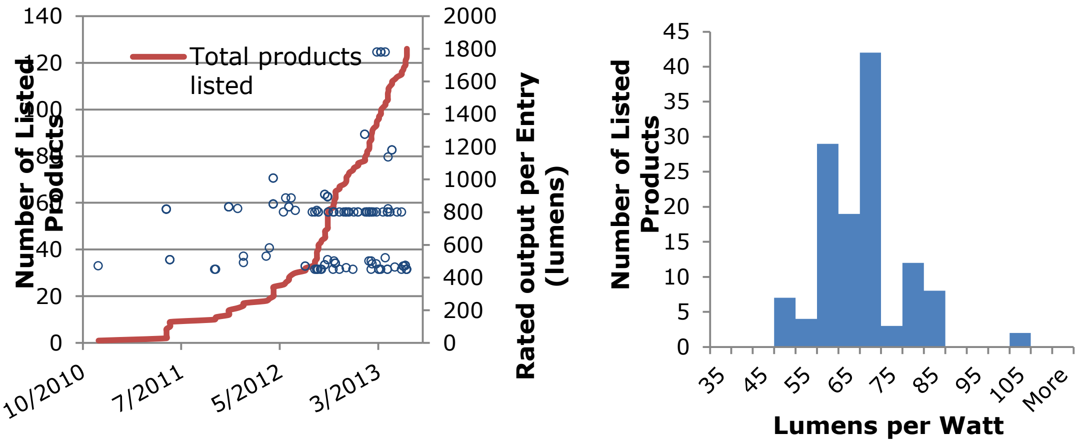
Source: Department of Energy[41]

As of July 2013, there were over 120 A lamp products that meet Energy Star's lighting and energy performance requirements available, as seen in Figure 14. The red trend line shown previously in Figure 12 demonstrates growth in DOE Lighting Facts listings for this product category.

[40] http://www.lightingprize.org/60watttest.stm

[41] ibid

FIGURE 14. ENERGY STAR LISTED LED A LAMPS AND EFFICACY DISTRIBUTION



General Service Lighting: Linear Fluorescent

LED products are making rapid progress in the fluorescent lighting space. Fluorescent lighting includes 1, 2, and 3 lamp T8 "troffer" style fixtures typically used to illuminate office spaces, as well as the more utilitarian fluorescent "strip" fixture, essentially a bare lamp socketed along a suspended metal channel. Strip and wrap fixtures are typically used in spaces where aesthetics and glare are less of a concern, such as industrial applications, some big box retail environments, and garages. All of these fixture types can either be ceiling or wall surface mounted or suspended from pendants that bring the fixture closer to the space needing to be illuminated in a higher ceiling location.

For fluorescent products, LED options are evolving along several different paths. There are LED replacement lamps, essentially long tubes mimicking the form factor of the T8 lamp, which are designed for installation in existing troffers and strip fixtures. There are also integrated LED fixtures that have been designed around use of the LED light source, directing the light, managing thermal issues, etc. These are not retrofits for existing fixtures but rather are products intended to completely replace them in existing spaces or in new construction. A third path in the troffer market is the LED replacement kit, which is typically an LED light engine and components that are designed to be inserted into an existing fluorescent fixture housing from which the fluorescent components (sockets, ballast housing, etc.) have been removed.

FIGURE 15. EXAMPLE LED REPLACEMENT OPTIONS FOR FLUORESCENTS: CREE CR FIXTURE AND UPKIT AND UR REPLACEMENT LAMPS

Photo Credit: CREE, Inc.

The challenge with LED replacement lamps is that the directional output of LED chips must be adapted to a fluorescent fixture that was designed around reflecting and directing light from an isotropic lighting source downward into the illuminated space. However fluorescent troffers are typically only 60% to 70% efficient in getting the fluorescent lamp lumens out of the fixture, so even though fluorescent lamps may have efficacies of 80 to 100 lumens per watt, fixture level efficacy may be in the 50 to 70 lumen per watt range. If LEDs can do a better job of emitting light out of the fixture than fluorescent options that involve inherent fixture losses associated with re-directing an isotropic source , they should be able to improve on troffer efficacy and compete well with fluorescents.

Another challenge with LED replacement tube lamps is that fluorescent tubes are powered by magnetic or electronic ballasts that must be either bypassed to provide line voltage to the lamp sockets or replaced with an LED driver in the fixture in order for LED replacements to work. Fluorescent ballasts supply AC current at a frequency and voltage incompatible with LED drivers that are designed to accept mains voltage and frequency.

Both of those issues are addressed by integrated LED fixture and retrofit kit design, where optics are designed specifically around the LED light source and wiring and electronics are also engineered for LEDs. Indeed, integrated LED troffers are proving to be the most competitive linear fluorescent replacement offering on the market in terms of lighting performance, as elucidated by a recent DOE study comparing the performance of LED replacement lamp options with integrated LED fixtures and LED retrofit kits. Overall, the study found that the newest integrated LED troffers were the most competitive with fluorescents on efficacy and various lighting quality metrics; with efficacy over 90 lumens per watt achievable and quality color rendering available as well. For fixtures retrofitted with LED tube lamps, the study found the same efficacy and wattage range as fluorescent benchmarks, but concluded that the LED options did not necessarily offer an energy savings opportunity when compared to fluorescent troffers equipped with 25 or 28 W high-performance lamps and electronic dimming ballasts. Color quality from the LED replacement lamps also ranged widely so the report recommended that specifiers exercise care when selecting products.

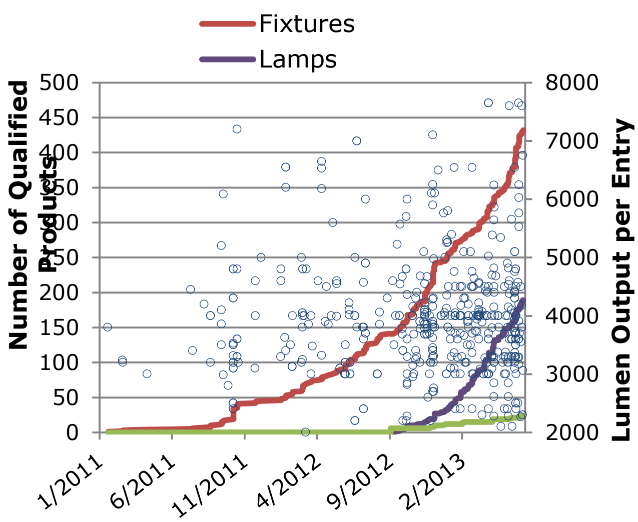
Given the proliferation of LED products in the three paths for replacement of linear fluorescents (fixtures, kits, and replacement lamps), the DesignLights Consortium (DLC), a project of Northeast Energy Efficiency Partnership (NEEP) that promotes efficient and high quality lighting, has developed lighting and energy performance criteria for LED replacement products for fluorescents. The rigorous requirements ensure that light output, distribution, color quality, and lifetime are robust enough to provide customer satisfaction and match or improve over incumbent fluorescent energy performance. Some of the DLC lighting quality and output requirements for LED replacement options for fluorescents are provided in Table 12 below.

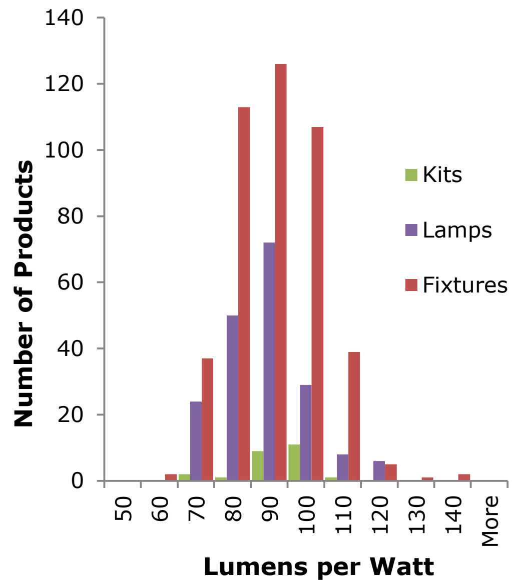
TABLE 12. DESIGN LIGHT CONSORTIUM LIGHTING QUALITY REQUIREMENTS FOR LED FLUORESCENT REPLACEMENT PRODUCTS

APPLICATION	MINIMUM LIGHT OUTPUT	MINIMUM EFFICACY	CCTS	MINIMUM CRI
2x2 Luminaires and Retrofit Kits for 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces	2,000 lm	85 lm/W	≤5000K	80
1x4 Luminaires and Retrofit Kits for 1x4 Luminaires for Ambient Lighting of Interior Commercial Spaces	1,500 lm	85 lm/W	≤5000K	80
2x4 Luminaires and Retrofit Kits for 2x4 Luminaires for Ambient Lighting of Interior Commercial Spaces	3,000 lm	85 lm/W	≤5000K	80
Four-foot Linear Replacement Lamps	2 Lamps in Fixture: 3,000 lm Bare Lamp: 1,600 lm	In Fixture: 85 lm/W Bare Lamp: 100 lm/W	≤5000K	80

For the fluorescent replacement products that have qualified for the DLC qualified products list, integrated fixtures have been the most successful at meeting the performance requirements; nearly 450 models have been qualified so far (see Figure 16). LED replacement lamps are beginning to pick up steam as well, with most products qualifying only in the past six months. This too is an encouraging development, since many of the first LED tube lamps available on the market were shown to often under deliver on performance claims, in some cases reducing light output, decreasing color quality, and/or exhibiting unacceptable light distribution and glare (DOE 2013b).

FIGURE 16. DESIGN LIGHTS CONSORTIUM LED QUALIFIED PRODUCTS: LED TUBES, KITS, AND INTEGRATED TROFFERS





PRODUCT RESULTS

This section of the report is broken into six parts; one for each product evaluated in the Fry's San Jose store. The following products were evaluated:

- General Service Lighting: Linear Fluorescent
  1) CREE CS14 LED Linear Luminaire
  2) CREE CR24 LED Architectural LED Troffer
  3) CREE CR-LE LED Light Engine
- General Service Lighting: Incandescent
  4) Philips LED 12W A19 Retrofit Lamp
- Downlighting: High Intensity Discharge
  5) CREE Essentia (ESA) Downlight Cylinder
- Directional Lighting: Parabolic Aluminized Reflector (PAR)
  6) Green Creative PAR 20 7W Lamps

Table 13 compares the fixture wattages of the base case and retrofit case, based on product specification sheets.

TABLE 13. BASE CASE VS. RETROFIT WATTAGE

Base Case vs. Retrofit Wattage			
Base Case	**Connected Load (W)**	**LED Retrofit**	**Connected Load (kW)**
GE Ecolux F32 T8 SP41	59	CREE CS14 LED Linear Luminaire	36
GE Ecolux F32 T8 SP41	112	CREE CR24 LED Architectural LED Troffer	22
GE Ecolux F32 T8 SP41	112	CREE CR-LE LED Light Engine	22
60W A-lamp; 19W CFL	60; 19	Philips LED 12W A19 Retrofit Lamp	12
M175/U or M100/U/MED	210; 120	CREE Essentia (ESA) Downlight Cylinder	134; 75
EYE Lighting 50PAR20	50	Green Creative PAR 20 7W Lamps	7

Product evaluation consists of results from the study of these six products. For details regarding the test methodology, please see the Methodology section above. The following results are presented for each product in this section of the report:

A. Product Description and Emerging Technology Assessment

B. Power Measurements

C. Photometric Measurements
   i. Photometric Field Measurements of Illuminance
   ii. Model Derived Illuminance Diagram
   iii. Color Temperature

D. Photographic Comparison

E. Lighting Simulation- 3D Rendering of Study Area

F. Energy Savings and Economic Impact Assessment
    i. Energy and Cost Savings
    ii. Maintenance Savings
    iii. Simple Payback Period (Equipment Costs Only)[42]

G. Laboratory Photometric Testing (CS14 Fixtures Only)

Note that the measured and calculated results from the study are presented in this section with limited analysis and discussion. The Data Analysis and Evaluation sections that follow discuss the product results with respect to how lighting and energy performance compare as well as the implications for project economics.

[42] Simple payback period estimates are highly dependent on product costs, which may differ based on the scale of each project. For a complete description of the methodology for estimating product costs, see section "Energy Savings and Economic Impacts Assessment".

GENERAL SERVICE FLUORESCENT LIGHTING: CREE CS14

A. Product Description and Emerging Technology Assessment

In the Register Area, existing suspended 1x4 box louvers with 2-lamp, second generation T8 lamps (GE Ecolux F32 SP41) and a two-lamp, general electronic ballast were replaced with the CREE CS14.

FIGURE 17. CREE CS14

Photo Credit: CREE, Inc.

B. Power Measurements

The base case power measurements were 42.7 watts, which was significantly lower than expected due to the high degree of lamp failures (27%) within the study area. Adjusting for lamp failures, the average lamp wattage was as expected. The LED retrofit measurements were consistent with expected wattage from product specification sheets. Both the linear fluorescents base and LED retrofit had a similar power factor (0.98 PF vs. 0.95 PF) and levels of THD (15% vs. 16%).

TABLE 14. POWER MEASUREMENTS: CREE CS14 AND LINEAR FLUORESCENT BASE CASE

Checkout Register Area Linear Fluorescents/ LED Fixtures		
	Base case Fixture	LED Retrofit
Average power/fixture (Watts)	42.7	36.3
Adjusted Average power/fixture (Watts)	59.0	36.3
Average current/fixture (Amps)	0.16	0.14
Weighted Avg. Power Factor	0.98	0.95
Weighted Avg Harmonic Distortion	15%	16%
# of fixtures on circuits	163	163

C. Photometric Measurements

i. Photometric Field Measurements

Illuminance measurements for the Register Area base case ranged from 23.9 to 48.3 footcandles. The LED retrofit had a smaller range from 59.0 to 75.0. The IES footcandle recommendation for merchandised service area is 30-100 footcandles (IESNA 2011). The retrofit is within the IES recommended range.

TABLE 15. ILLUMINANCE MEASUREMENTS: CREE CS14 AND LINEAR FLUORESCENT BASE CASE

Register Area: Base case

Register 54-64	23.9	30.2	40.9	48.3	39	34.6

Register Area: LED Retrofit

Register 54-64	59.0	61.1	68.5	75.0	62.6	61

ii. Model-Derived Illuminance Diagram

No model was completed for this area, as described in Methodology – Lighting Simulation above.

iii. Color Temperature

TABLE 16. MEASURED COLOR CORRELATED TEMPERATURE

Correlated Color Temperature (Kelvin)		
Store Area	**Base case**	**LED Retrofit**
Checkout Register	3660	3742
Register Area Average	3646	3751

D. Photographic Comparison

FIGURE 18. PHOTOGRAPHIC COMPARISON OF REGISTER AREA

Base case: Linear Fluorescent and Incandescent

Retrofit: LED Strip fixture

Base case: Linear Fluorescent and Incandescent

Retrofit: LED Strip fixture

E. Lighting Simulation- 3D Rendering

No model was completed for this area, as described in the Methodology – Lighting Simulation section above.

F. Energy Savings and Economic Impact Assessment

The existing Register Area had 163 1x4 fixtures with (2) 4 foot F32T8 lamps. They were replaced with CREE CR14 LED fixtures. By replacing the 163 fixtures with LED fixtures, the Register Area will save 22,438 kWh/year or about $3,141/year in energy savings.

Payback per fixture, including the LEDA incentive is 12.7 years, or 15.7 years without the incentive. Payback per fixture, including the incentive and the maintenance cost savings is 10.4 years.

G. Laboratory Photometric Testing Study

Laboratory testing of two CS14 fixtures showed performance to be very stable. Lamps were tested initially at 2200 hours and again after 6000 hours of operation. In that time, lumen output decreased by less than 2.9% and 3.6%, respectively. CCT decreased by 10 and 4

Kelvin (imperceptibly warmer), respectively, while CRI varied by 0.2. In terms of color shift, the fixtures had a Δu'v' of 0.0003 and 0.0002, respectively. This is well within the bounds of ENERGY STAR's 6000 hour Color Maintenance requirements which require a change of chromaticity (Δu'v') of less than 0.007.[43]

TABLE 17. MEASURED COLOR CORRELATED TEMPERATURE

Fixture 1	Light Output (lumen)	Color Temperature (CCT)	CRI	System Power (Watts)	System Efficacy (Lumen/Watt)	Power Factor	Color Shift (Δu'v')
2200 Hour Testing	4144	3914	91.9	35.9	115.4	0.92	-
6000 Hour Testing	4022	3904	92.1	35.3	113.9	0.99	0.0003
% change	-2.9%	-0.3%	0.2%	-1.7%	-1.3%	7.8%	-

Fixture 2	Light Output (lumen)	Color Temperature (CCT)	CRI	System Power (Watts)	System Efficacy (Lumen/Watt)	Power Factor	Color Shift (Δu'v')
2200 Hour Testing	4172	3915	92.0	35.8	116.5	0.92	-
6000 Hour Testing	4021	3911	92.2	35.1	114.6	0.99	0.0002
% change	-3.6%	-0.1%	0.2%	-2.0%	-1.6%	7.8%	-

[43] ENERGY STAR Program Requirements for SSLs Version 1.4 http://www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf?2fe9-86db

GENERAL SERVICE FLUORESCENT LIGHTING: CREE CR24

A. Product Description and Emerging Technology Assessment

The existing 2x4 lensed troffer with four GE Ecolux F32 T8 SP41 lamps in the Break Room was replaced with the CREE CR24-40L-40K.

FIGURE 19. CREE CR24

Photo Credit: CREE, Inc.

B. Power Measurements

The base case had 4 lamps per 2x4 recessed troffer fixture. However, there were 3 lamps in fixtures throughout the room that were burned out and not operating. In addition, one of the nine total fixtures is on a separate emergency circuit and is not included in the measurements. Power measurements are presented below: 'Average power' represents actual measurements, while 'adjusted average power' adjusts expected power measurements to account for the three burned out lamps. The LED retrofit had a lower power factor and higher levels of THD than listed on the product specification sheet because the fixtures were wired to half power. Under normal operation at 100% of rated power, it is expected that power factor would be greater than 0.9 and THD would be less than 20%. However, the overall low line noise due to the lower wattage makes the effect of the increased THD negligible.

TABLE 18. PHOTOMETRIC FIELD MEASUREMENTS OF BREAK ROOM

Break Room Fluorescents/Linear LED Fixtures		
	Base case Fixture	LED Retrofit
Average power/fixture (Watts)	96.7	20.7
Adjusted Average power/fixture (Watts)	108.3	20.7
Average current/fixture (Amps)	0.4	0.1
Weighted Avg. Power Factor	0.99	0.81
Weighted Avg Harmonic Distortion	5%	34%

C. Photometric Measurements

i. Photometric Field Measurements

The illuminance measurements for the Break Room base case ranged from 44.0 to 102.0 footcandles, and was generally over lit for a break room. The wide range of values is partly due to three lamps which were burned out. The LED retrofit had a much smaller range from 22.5 to 40.7 footcandles and had light levels more appropriate level for a break room. The IES footcandle recommendation for an office lounge is 0-20 footcandles and a kitchen is 50-100 footcandles. Because this break room has kitchen facilities, it is appropriate for the footcandle measurements to be higher than the lounge recommendation, but still substantially reduced from the base case.

TABLE 19. PHOTOMETRIC FIELD MEASUREMENTS OF BREAK ROOM

Break Room: Base case

	Ceiling Panel 1 (near West wall)	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Ceiling Panel 7 (near door)
Near Door	45.0	73.8	83.5	97.8	102.0	100.8	72.3
	45.1	66.3	83.0	92.5	83.9	86.5	56.7
Near Lockers	44.0	72.3	85.2	99.4	99.4	94.0	49.4

*Bold lines indicate the location of a fixture

Break Room: LED Retrofit

	Ceiling Panel 1 (near West wall)	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Ceiling Panel 7 (near door)
Near Door	25.7	37.0	40.2	40.7	39.3	36.0	26.6
	24.4	34.4	37.9	34.4	37.7	27.4	24.2
Near Lockers	22.6	31.7	36.3	38.1	36.5	33.5	22.5

*Bold lines indicate the location of a fixture

ii. Model Derived Illuminance Diagram

The Break Room characteristics posed challenges for modeling. Base case fixtures were equipped with four T8 lamps, and the room had two switches to activate either two or four of those lamps. Auditors discussed the preferred configuration with Fry's staff, who universally agreed that the half lighting was preferred, and that the full lighting was too bright. Measurements were taken at both the half lighting and full lighting modes.
The base case model below depicts the full lighting mode, which should be considered as an over-lit scenario. The retrofit model below shows a decrease in the overall lighting compared to the base case, but this brings the lighting in the room closer to the desired level and required values for the task. Additionally, the retrofit installation was manually configured to further reduce light output. The field measurements of the LED fixtures confirm that the light levels in the room were slightly lower than shown in the model.

The illuminance diagram, Figure 20, for the base case below shows high levels of illuminance (values in red) in the middle of the room, with slightly lower values (in yellow and green) around the perimeter of the room. The retrofit diagram shows a similar pattern but with reduced light levels in green around the center of the room, with light levels tapering off around the perimeter, shown in blue.

FIGURE 20. BREAK ROOM BASE CASE MODEL

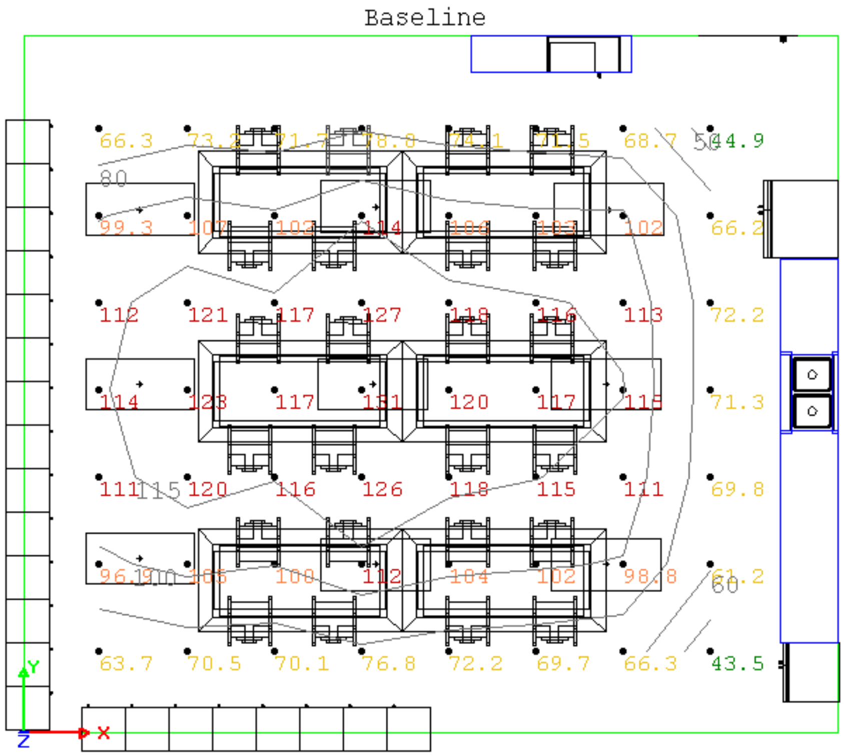
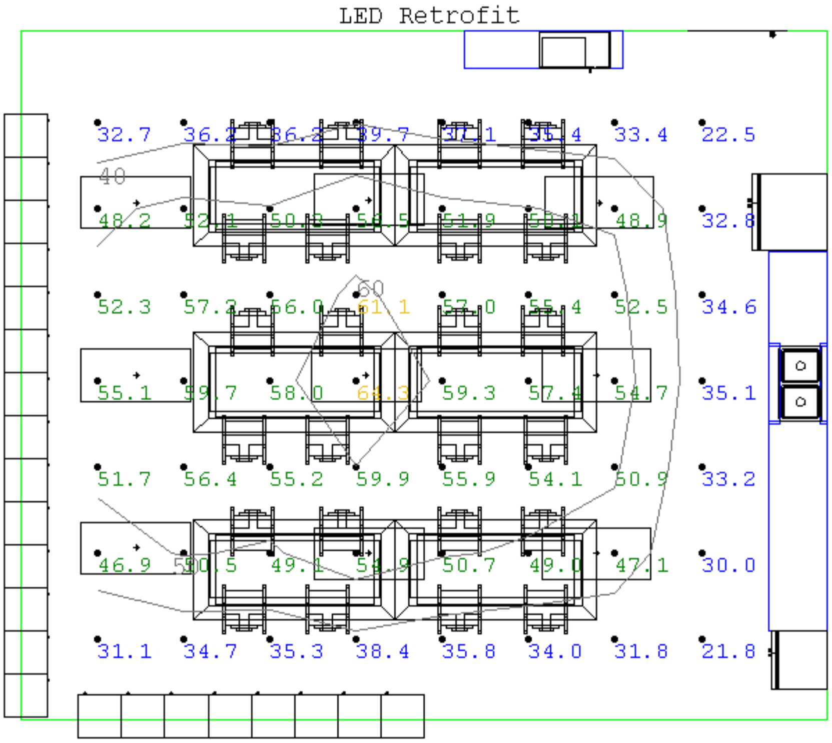


FIGURE 21. BREAK ROOM RETROFIT MODEL



iii. Color Temperature

The Correlated Color Temperature (CCT) in the break room was measured before and after the LED retrofit. The measured CCT was slightly higher after the LED retrofit.

TABLE 20. COLOR CORRELATED TEMPERATURE OF BREAK ROOM

Correlated Color Temperature (Kelvin)		
Store Area	**Base case**	**LED Retrofit**
Break Room	3730	3846

D. Photographic Comparison

The photographs of the base case and the LED retrofit illustrate the more uniform illuminance levels and slightly cooler CCT in the Break room.

FIGURE 22. PHOTOGRAPHIC COMPARISONS OF BREAK ROOM

Base case: Linear Fluorescent

Retrofit: LED

Base case: Linear Fluorescent

Retrofit: LED

E. Lighting Simulation- 3D Rendering of Study Area

The model rendering image below depicts the LED retrofitted space for the Break Room.

FIGURE 23. RETROFIT RENDERING OF BREAK ROOM

F. Energy Savings and Economic Impact Assessment

The existing break room had (9) 2x4 fixtures with (4) 4 foot F32T8 lamps. They were replaced with CREE CR24 LED fixture. By replacing the 9 fixtures with LED fixtures, the break room will save 4,848 kWh/year or about $679/year in energy savings.

Payback per fixture, including the LEDA incentive is 0.9 years or 2.8 years without the incentive. Payback per fixture, including the incentive and the maintenance cost savings is 0.8 years.

GENERAL SERVICE FLUORESCENT LIGHTING: CREE CR-LE-40L LIGHT ENGINE

A. Product Description and Emerging Technology Assessment

The existing 1x4 strip fixtures with GE Ecolux F32 T8 SP41 in the Restroom and Auto Install Garage were replaced with the CREE CR-LE-40L light engine. The CREE CR-LE light engine delivers the same light and energy savings as the CR troffers, but is a lightweight and compact alternative that can be suspended or surface mounted.

FIGURE 24. CREE CR-LE

Photo Credit: CREE, Inc.

B. Power Measurements

Power measurements in the restroom were 62.5 watts for the base case and 20.7 watts for the retrofit. Measurements were taken at the switch, one of the fixtures was an emergency circuit and not included in the measurements. The LED retrofit had a lower power factor and higher levels of THD than listed on the product specification sheet because the fixtures were wired to half power. Under normal operation at 100% of rated power, it is expected that power factor would be greater than 0.9 and THD would be less than 20%. However, the overall low line noise due to the lower wattage makes the effect of the increased THD negligible.

TABLE 21. POWER MEASUREMENTS OF RESTROOM

Restroom		
	Base case Fixture	LED Retrofit
Average power/fixture (Watts)	62.5	20.7
Average current/fixture (Amps)	0.23	0.09
Power Factor	0.99	0.84
Total Harmonic Distortion	15%	34%
# of fixtures on circuit	4	4

Power measurements in the Auto Install Garage were as expected based on standard fixture wattages for a two lamp linear fluorescents and standard ballast. There were no lamps burned out for the base case, and the average fixture wattage was close to the value expected for a two lamp fluorescent fixture. The LED retrofit had a lower power factor and higher levels of THD than listed on the product specification sheet because the fixtures were wired to half power. Under normal operation at 100% of rated power, it is expected that power factor would be greater than 0.9 and THD would be less than 20%. However, the overall low line noise due to the lower wattage makes the effect of the increased THD negligible. There were fewer fixtures measured in the retrofit case than the base case because two fixtures were originally installed on the main circuit and then put onto an emergency circuit in the retrofit case.

TABLE 22. POWER MEASUREMENTS OF AUTO INSTALL GARAGE

Auto Install Garage		
	Base case Fixture	LED Retrofit
Average power/fixture (Watts)	59.8	21.3
Average current/fixture (Amps)	0.22	0.09
Power Factor	0.99	0.79
Total Harmonic Distortion	7%	31%
# of fixtures on circuit	16	14

C. Photometric Measurements

i. Photometric Field Measurements

The restroom base case had illuminance measurements that ranged from 20.0-58.0 footcandles. The LED retrofit had a similar range from 32.0-63.7. The IES footcandle recommendation for a restroom is 20-50 footcandles. The retrofit had higher illuminance measurements along the counter than recommended by IES, but was similar to the existing conditions.

TABLE 23. PHOTOMETRIC FIELD MEASUREMENTS OF RESTROOM (FOOTCANDLES)

Base case

On Counter	30.0	58.0	50.0
Mid-Restroom	20.0	28.0	20.0

LED Retrofit

On Counter	49.4	63.7	55.0
Mid-Restroom	33.2	32.0	35.0

The Auto Install Garage base case had illuminance measurements that ranged from 30.1 to 49.6 footcandles. The LED retrofit had a smaller range from 25.6 to 42.0. The IES footcandle recommendation for Garages with Motor Vehicle Repair is 50-100 footcandles. The retrofit illuminance is lower than the IES recommendations, but similar to the existing levels.

TABLE 24. PHOTOMETRIC FIELD MEASUREMENTS OF AUTO INSTALL GARAGE (FOOTCANDLES)

Base case

Near door under fixture	30.1	40.0	44.1
Between fixtures	33.3	41.2	49.6
Under fixture by wall	32.2	41.5	46.5
2.5 ft. from wall	27.8	35.4	38.1

LED Retrofit

Near door under fixture	31.7	37.8	41.7
Between fixtures	38.5	36.3	40.8
Under fixture by wall	35.6	36.4	42.0
2.5 ft. from wall	29.4	25.6	32.3

ii. Model- Derived Illuminance Diagram

For the restroom area, the model and the field data report consistent conclusions. The LED retrofit slightly increased overall light levels, concentrated in the center of the counter where the fixtures' coverage overlap, and decreasing slightly when moving away from that point. As shown in the models below, light is concentrated on the task area of the restroom (urinals, toilets and sinks) and dims closer to the entrance. The retrofit system maintains the light levels in room while providing efficiency improvements.

FIGURE 25. BASE CASE AND LED RETROFIT MODEL OF RESTROOM

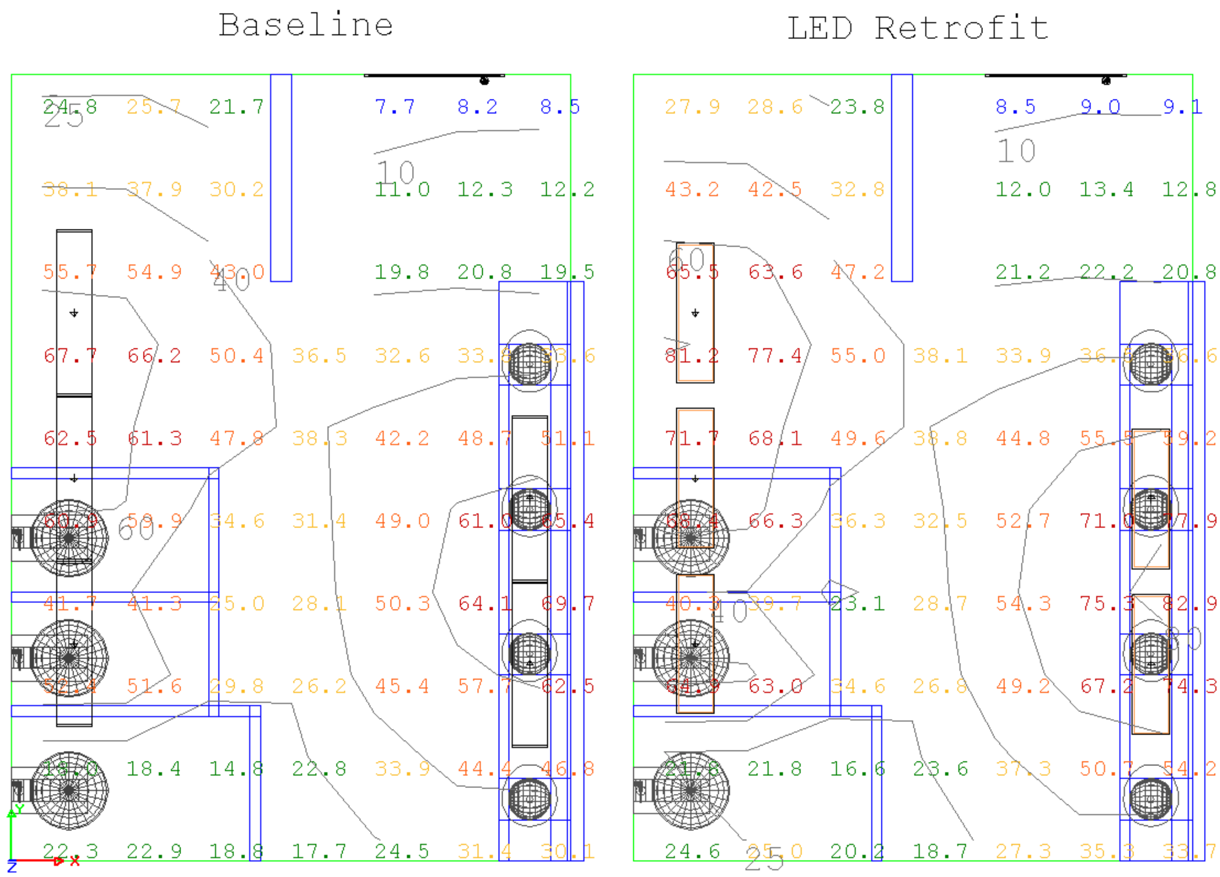
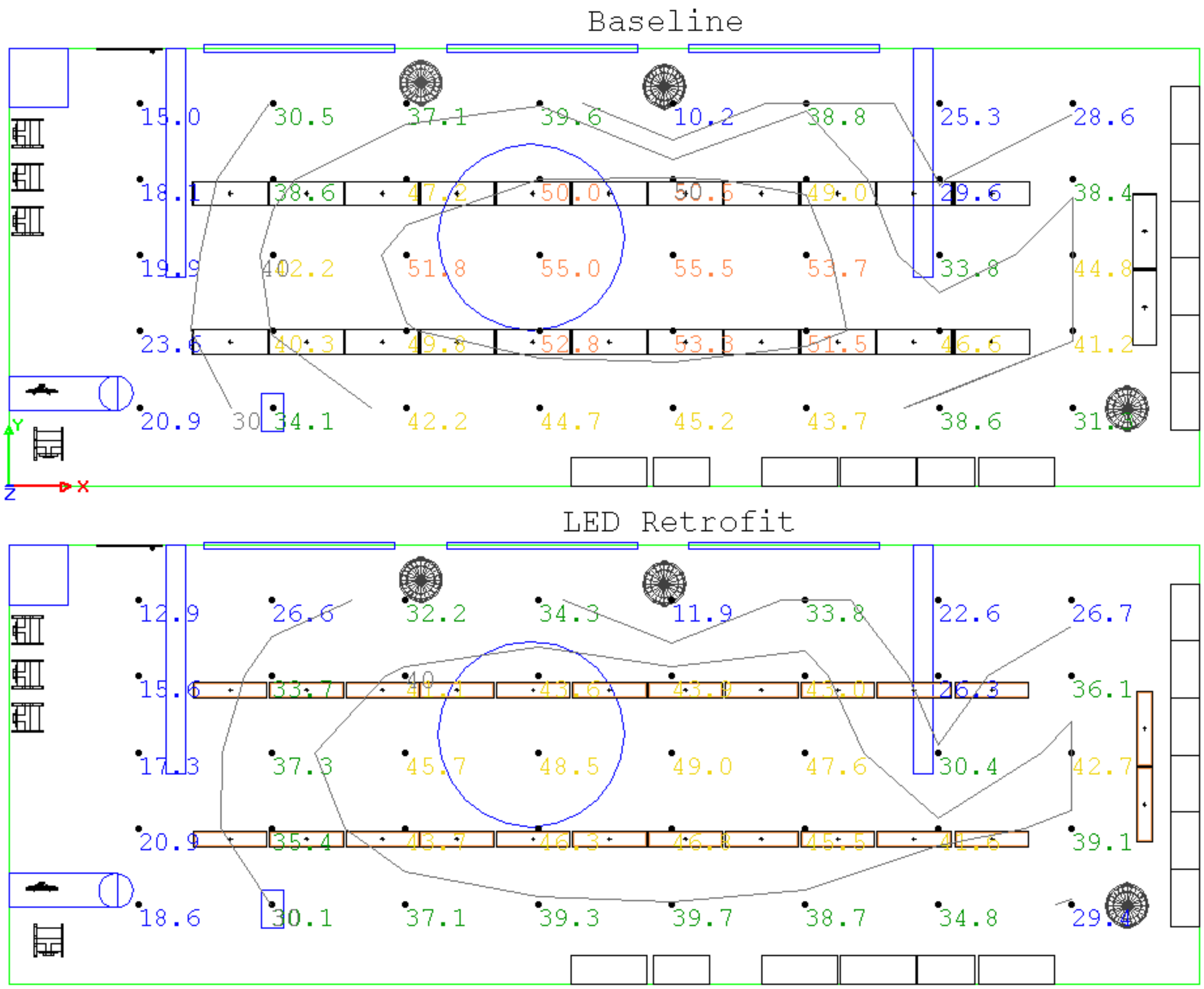


FIGURE 26. BASE CASE AND LED RETROFIT MODEL OF AUTO INSTALL



iii. Color Temperature

The Correlated Color Temperature (CCT) in the restroom was measured before and after the LED retrofit. The measured CCT was slightly higher after the LED retrofit.

TABLE 25. CORRELATED COLOR TEMPERATURE OF RESTROOM

Correlated Color Temperature (Kelvin)		
Store Area	**Base case**	**LED Retrofit**
Restroom	3600	3804
Auto Install Garage	3638	3802

D. Photographic Comparison

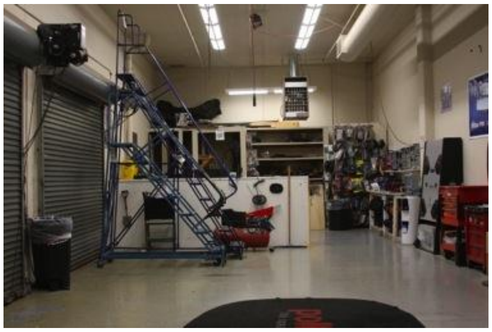
No photographic images were taken in the Restroom to maintain customer privacy. Please see the Illuminance Measurement section for data on illuminance levels.

FIGURE 27. PHOTOGRAPHIC COMPARISON OF AUTO INSTALL GARAGE

Auto Install Garage

Base case: Linear Fluorescent

Retrofit: LED



E. Lighting Simulation- 3D Rendering of Study Area

Below are rendering images produced from AGi32 models for the Restroom and Auto Install Garage.

FIGURE 28. RETROFIT RENDERING OF RESTROOM

FIGURE 29. RETROFIT RENDERING OF AUTO INSTALL GARAGE

F. Energy Savings and Economic Impact Assessment

The existing restrooms had (16) 1x4 fixtures with (2) 32 watt T8 lamps. They were replaced with CREE CR14 LED fixtures. By replacing the 16 fixtures with LED fixtures, the restrooms will save 3,543 kWh/year or about $496/year in energy savings.

Payback per fixture, including the LEDA incentive is 5.6 years or 6.9 years without the incentive. Payback per fixture, including the incentive and the maintenance cost savings is 4.4 years.

The existing Auto Install Garage had (12) 1x8 fixtures with (4) 32 watt T8 lamps and (1) 1x4 fixtures with (2) 32 watt T8 lamps. They were replaced with (24) 1x4 CREE CR-LE-40L LED fixtures. By replacing the fluorescent fixtures with LEDs, the Auto Install garage will save 6,685 kWh/year or about $936/year in energy savings.

Payback per fixture, including the LEDA incentive is 1.8 years or 2.8 years without the incentive. Payback per fixture, including the incentive and the maintenance cost savings is 1.6 years.

GENERAL SERVICE INCANDESCENT LIGHTING: PHILIPS 12W A19

FIGURE 30. PHILIPS 12W A19 LAMP

Photo Credit: Philips, Inc

A. Product Description and Emerging Technology Assessment

The existing chandeliers had incandescent B lamps or Compact Florescent Lamps (CFLs). They were all replaced with 12 W Philips Endura A19 lamps (Model Number 12A19/END/800LM/2700/120V/DIMM).

B. Power Measurements

Original pre-audit data suggested that there were 60W incandescent lamps in the chandelier fixtures. However, high levels of THD suggested that CFLs were also installed on the circuit. Further verification revealed that roughly 90% of all original base case lamps had been replaced with CFLs. Two chandeliers (10 fixtures) were on a separate emergency circuit and not included in these calculations.

TABLE 26. POWER MEASUREMENTS OF REGISTER AREA

Register Area Chandelier Lamps		
	Base case Fixture	LED Retrofit
Average power/fixture (Watts)	17.5	12.4
Adjusted Average power/fixture (Watts)	22.3	12.4
Average current/fixture (Amps)	0.20	0.12
Weighted Avg. Power Factor	0.71	0.81
Weighted Avg Harmonic Distortion	96%	70%
# of fixtures on circuit	125	125

C. Photometric Measurements

i. Photometric Field Measurements

The Chandelier lamps located in the Register Area provide decorative lighting. Photometric measurements were not taken exclusively on the chandelier fixtures.

ii. Model-Derived Illuminance Diagram

No model was completed for this area, as described in Methodology – Lighting Simulation above.

iii. Color Temperature

No color temperature measurements were made for the Checkout Incandescent Fixtures, since they are dominated by linear fluorescent fixtures above them. For color temperature measurements within this area, see the section 1) General Service Fluorescent Lighting: CREE CS14.

D. Photographic Comparison

FIGURE 31. PHOTOGRAPHIC COMPARISON OF CHECKOUT INCANDESCENT AREA

Base case: Incandescent

Retrofit: LED

E. Lighting Simulation- 3D Rendering of Study Area

No model was completed for this area, as described above in the Methodology – Lighting Simulation section.

F. Energy Savings and Economic Impact Assessment

The 27 existing checkout chandeliers had a blend of 60W B lamps and 19W CFLs in each chandelier. They were replaced with Philips A19 lamps. By replacing the 135 lamps with LED lamps, the checkout chandeliers will save 3,274 kWh/year or about $458/year in energy savings.

Payback per fixture, including the LEDA incentive is 7.9 years or 11.9 years without the incentive. Payback per fixture, including the incentive and the maintenance cost savings is less than 1 year.

HIGH INTENSITY DISCHARGE DOWNLIGHTING: CREE ESA

A. Product Description and Emerging Technology Assessment

The existing 175W MH cylinder downlights (210W connected load) above the Computer Sales Area were replaced with 134 Watt CREE CREE.ESA-C10-10-MD-HP-56-D-U-BZ-SSGC-700-40K fixtures. The existing 100W MH cylinder downlights (120W connected load) above the Customer Service Area were replaced with 75W CREE ESA-C10-10-MD-P-42-D-U-BK-SSGC-525-40K fixtures. These fixtures are part of the same product family, but have a different light output and energy consumption due to the number of LEDs used (56 vs. 42).[44] This product was selected because Fry's required a very specific, high output LED fixture.[45]

FIGURE 32. CREE ESA

Photo Credit: CREE, Inc.

B. Power Measurements

Electrical panels for the Customer Service and Computer Sales areas were not accessible, and therefore no power measurements were taken in these locations.

[44] For more information on this product, see CREE ESA Specification sheet: http://www.CREE.com/~/media/Files/CREE/Lighting/Architectural/Essentia%20Surface%20Cylinder/ESAC10MD56.pdf

[45] The CREE fixtures did not qualify for a LEDA incentive because it does not meet Energy Star or DLC requirements for downlighting. This is primarily due to the fact the Energy Star's downlighting requirements are suited to lower output products, so although the fixture have sufficient efficacy for their application, they do not meet Energy Star downlight efficacy requirements.

C. Photometric Measurements

i. Photometric Field Measurements

The illuminance measurements for the Computer Sales base case ranged from 14.2 to 108 footcandles. The LED retrofit had a smaller range from 62.0 to 120.0. The IES footcandle recommendation for serviced merchandising area is 30-100 footcandles. Some sections in the Computer Sales Area do exceed the IES recommendations and in general the illuminance levels are higher than in the base case.

TABLE 27. PHOTOMETRIC FIELD MEASUREMENTS OF COMPUTER SALES AREA (FOOTCANDLES)

Computer Sales Area: Base case

	Near wall		Near computer tables
Right of room		22.0	
Center-right	14.2	108	24.5
Center-left		20.0	24.6
Left of room		43.5	30.0

Computer Sales Area: LED Retrofit

	Near wall		Near computer tables
Right of room		93.0	
Center-right	66.0	120.0	76.0
Center-left		86.0	62.0
Left of room		106	91.0

The Customer Service Area base case had illuminance measurements that ranged from 13.5 to 24.4 footcandles. The LED retrofit had a wider and higher range from 61.2 to 78.9 footcandles. The IES footcandle recommendation for serviced merchandising area is 30-100 footcandles. The retrofit illuminance levels are within the IES recommended levels and higher than the base case.

TABLE 28. PHOTOMETRIC FIELD MEASUREMENTS OF CUSTOMER SERVICE AREA (FOOTCANDLES)

Customer Service Area: Base case

Near wall	17.5	22.8	20.0
Middle	24.4	20.3	13.5
Near entrance	17.6	16.1	14.3

Customer Service Area: LED Retrofit

Near wall	76.9	75.5	78.9
Middle	61.2	69.5	78.3
Near entrance	68.8	77.5	78.0

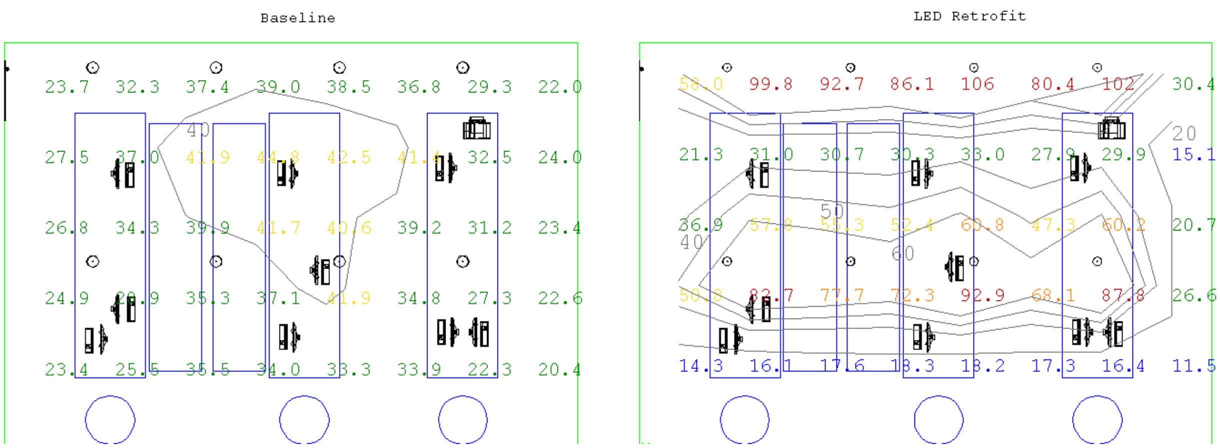
ii. Model-Derived Illuminance Diagram

The customer service area posed some unique complications when comparing the base case and retrofit installations.

Auditors discussed the lighting retrofit with Fry's staff, who described the retrofit installation as initially being too bright, but that the fixtures were later adjusted to reduce light output.

The retrofit model supports this, as areas underneath the light fixtures are higher than field measurements in similar locations.

FIGURE 33. BASE CASE AND RETROFIT MODEL OF CUSTOMER SERVICE AREA



iii. Color Temperature

The Correlated Color Temperature (CCT) in the Computer Sales Area and Customer Service Area was measured before and after the LED retrofit. The measured CCT after the LED retrofit was lower in the Computer Sales Area and higher in the Customer Service Desk area.

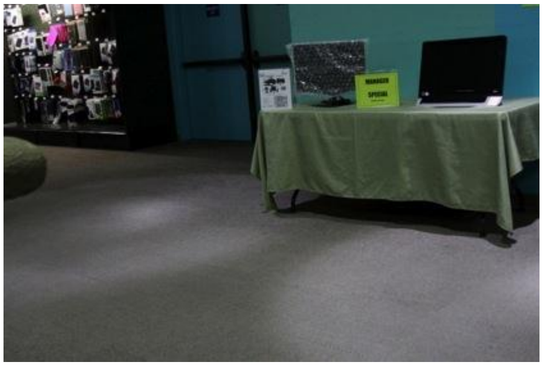
TABLE 29. CORRELATED COLOR TEMPERATURE OF COMPUTER SALES AREA AND CUSTOMER SERVICE AREA

Correlated Color Temperature (Kelvin)		
Store Area	Base case	LED Retrofit
Computer Sales Area	4800	3986
Customer Service Area	3300	3826

D. Photographic Comparison

FIGURE 34. PHOTOGRAPHIC COMPARISON OF COMPUTER SALES AREA

Base case: Metal Halide



Retrofit: LED

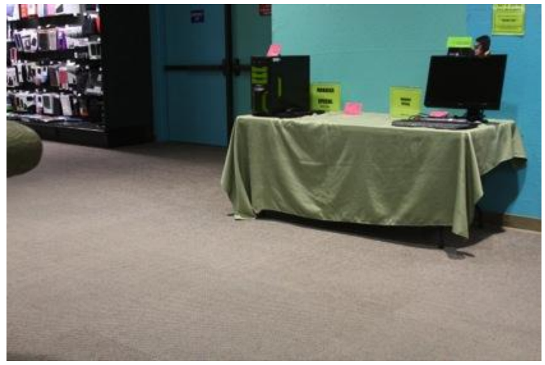


FIGURE 35. PHOTOGRAPHIC COMPARISON OF CUSTOMER SERVICE AREA

Base case: Metal Halide

Retrofit: LED

E. Lighting Simulation- 3D Rendering of Study Area

FIGURE 36. RETROFIT RENDERING OF CUSTOMER SERVICE AREA

F. Energy Savings and Economic Impact Assessment

The existing Computer Sales area had (40) 175W MH downlight that were replaced with 134W CREE Essentia (ESA) LED fixtures. By replacing the 40 existing fixtures with LED fixtures, the Computer Sales area will save 18,194 kWh/year or about $2,547/year in energy savings.

Payback per fixture without an incentive is 13.8 years. The CREE ESA fixture was not eligible for the LEDA incentive. Payback per fixture, including maintenance cost savings is 9.1 years. This is based on best available information on fixture costs and may not be reflective of actual fixture costs obtained from a bulk purchase.

The existing Customer Service Area had (16) cylinder pendants with metal halide lamps. They were replaced with CREE ESA LED Fixtures. By replacing the 16 fixtures with LED fixtures, the Customer Service Area will save 4,309 kWh/year or about $603/year in energy savings.

Payback per fixture without an incentive is 23.1 years. The CREE ESA fixture was not eligible for the LEDA incentive. Payback per fixture, including maintenance cost savings is 15.4 years. This is based on best available information on fixture costs and may not be reflective of actual fixture costs obtained from a bulk purchase.

Parabolic Aluminized Reflector (PAR) Directional Lighting: Green Creative 7W PAR20

FIGURE 37. GREEN CREATIVE 7W PAR20

Photo Credit: Green Creative, Inc.

A. Product Description and Emerging Technology Assessment

The existing Capsylite fixtures with EYE Lighting 50PAR20/HAL/FL/120V lamps were replaced with GC.7PAR20/TIT/DIM/830FL40 lamps.

B. Power Measurements

The base case measurements were lower than expected due to 3 lamp burnouts. However, after adjusting for burnouts, lamp wattage was still significantly lower than expected. This suggests that similar to the Chandelier Fixtures, these lamps were replaced with 11W PAR20 CFL equivalents or lower wattage PAR20 lamps over time, such as 20W or 35W PAR 20 bulbs. Retrofit measurements indicate that the LED was drawing significantly more power than expected due to a low power factor of 0.57.

TABLE 30. POWER MEASUREMENTS OF REGISTER AREA

Audio Room		
	Base case Fixture	LED Retrofit
Average power/fixture (Watts)	28.0	11.1
Adjusted power/fixture (Watts)	31.2	11.1
Average current/fixture (Amps)	0.35	0.11
Weighted Average Power Factor	0.73	0.57
Weighted Average Harmonic Distortion	60%	58%
# of fixtures on circuit	29	29

C. Photometric Measurements

i. Photometric Field Measurements

The Audio Room base case had illuminance measurements that ranged from 1.8 to 12.0 footcandles. The LED retrofit had a smaller range from 4.1 to 43.7. The IES footcandle recommendations for Serviced Merchandising is 30-100 footcandles. The retrofit illuminance is within the IES recommendation and also higher than existing levels.

TABLE 31. PHOTOMETRIC FIELD MEASUREMENTS OF AUDIO ROOM

Audio Room: Base case

h=6'	11.3	10.0	7.7	9.0	12.0
h=5'	10.6	8.3	5.6	6.0	7.8
h=4'	8.4	6.5	5.2	4.3	4.7
h=3'	6.0	5.0	4.2	3.6	3.0
h=2'	5.6	3.8	3.2	2.6	2.3
h=0	3.09	2.7	2.2	2.0	1.8

Audio Room: LED Retrofit

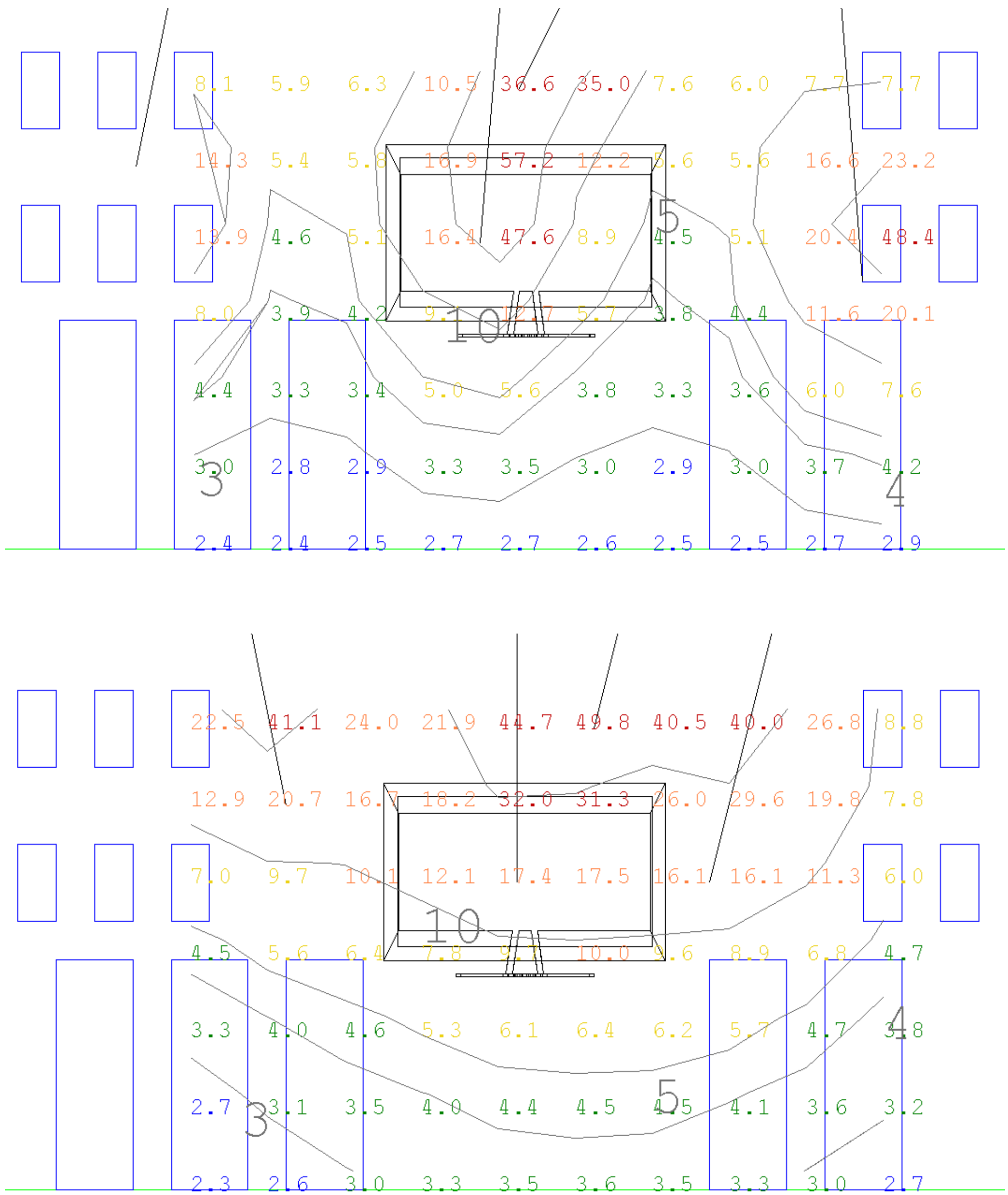
h=6'	27	29.6	36.7	43.7	38
h=5'	16.5	18.5	22	29.9	27.4
h=4'	12.3	12.7	15.3	17.6	16.3
h=3'	8.1	8.9	11	10.8	9.0
h=2'	6.0	6.6	7.6	7.4	6.7
h=0	4.3	4.1	4.5	5.1	5.1

ii. Model-Derived Illuminance Diagram

The simulation and measured field data of the audio room both point identify similar trends in the change in the lighting environment. In both cases, the LED retrofit provides brighter light nearer the fixtures, with a gradual dimming as you approach a height of zero and a similar, but less even distribution of light for the base case. The base case model identified much higher values than the field measurements when the simulated measurement points fell directly within the lamp's beam angle. Field measurements did not show these high values for several reasons: lamps had lower light output due to age and depreciation, and some lamps were burned out entirely.

As the name "Audio Room" suggests, the purpose of the lighting in the space is not to brightly illuminate the space, but rather to create an appropriate aesthetic experience for customers to experience audio systems. The dim general lighting and brighter spot lighting focuses the customers' attention on the speaker systems. Additionally, the adjustable track lighting allows Fry's to redirect the fixtures as the speaker display changes to make sure the speakers are properly illuminated. The base case fixture and LED both achieve this effect in a similar fashion. The LED replacement provides an equivalent customer experience with significantly reduced energy demands.

FIGURE 38. BASE CASE AND LED RETROFIT MODEL OF AUDIO ROOM



iii. Color Temperature

The Correlated Color Temperature (CCT) in the Audio Room was measured before and after the LED retrofit. The measured CCT after the LED retrofit was higher in the Audio Room.

TABLE 32. CORRELATED COLOR TEMPERATURE OF AUDIO ROOM

Correlated Color Temperature (Kelvin)		
Store Area	**Base case**	**LED Retrofit**
Audio Room	2625	3103

D. Photographic Comparison

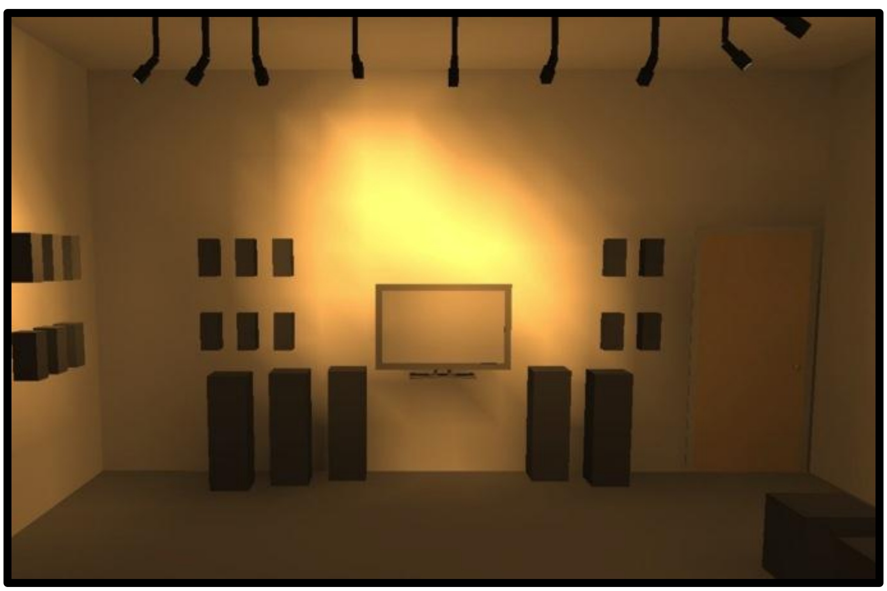
FIGURE 39. PHOTOGRAPHIC COMPARISON OF AUDIO ROOM

Base case: Halogen

Retrofit: LED

E. Lighting Simulation- 3D Rendering

FIGURE 40. RETROFIT RENDERING OF AUDIO ROOM



F. Energy Savings and Economic Impact Assessment

The existing audio room had (29) 50 Watt Par 20 lamps that were replaced with Green Creative 7 Watt PAR 20 lamps. By replacing the 29 lamps with LEDs, the audio room will save 7,463 kWh/year or about $1,045/year in energy savings.

Payback per fixture without an incentive is 3.9 years. This product was not eligible for the LEDA rebate program. Payback per fixture, including the maintenance cost savings is 1.0 years.

DATA ANALYSIS

ANALYSIS OF POWER DATA

Power measurements for the base case were as expected, although the number of burned out lamps reduced measured power consumption. Power measurements for the retrofit case were as expected. The results for the nominal and measured power factor for the base case and retrofit lamps are shown below in Table 33. Incandescent lamps used in the base case for the checkout chandeliers and the Audio Room are expected to have a power factor of 1.00. For the checkout chandeliers, the measured base case power factor was lower than the nominal value because of the use of CFLs as spot replacement lamps. The Audio Room also had lower measured power factors for both the base case and retrofit, which is suspected to be due to the presence of other lamps on the circuit. The power factor of the metal halide in the customer service base case is estimated to be .90, but actual product data was not available. The CS14 fixture measured higher power factor than rated, and the Philips A19, Green Creative PAR 20, CREE CR24, and CR LE-40L all had slightly lower power factors than rated. Low power factor may impact incentive eligibility and result in surcharges on electricity bills. The CREE CR24 and CREE CR-LE-40L were wired to 50% of total power output, which is the cause of the lower power factor for these products. Under normal operation at 100% of rated power, it is expected that power factor would be greater than 0.9 and THD would be less than 20%. However, the overall low line noise due to the lower wattage makes the effect of the increased THD negligible.

TABLE 33. POWER FACTOR COMPARISON

LED Retrofit Lamp	Location	Base case (Rated)	Base case (Measured)	Retrofit (Rated)	Retrofit (Measured)
Philips A19	Checkout Chandeliers	1.00 (Incandescent)	.71	.95	0.81
CREE CR24	Break Room	.99	1.00	0.9	0.83
CREE CR-LE-40L	Auto Install Garage	.99	1.00	0.9	0.79
CREE CS14	Checkout Fluorescents	.99	.98	0.9	0.95
CREE ESA	Customer Service	.90 (est.)	No data	0.9	No data
Green Creative PAR20	Audio Room	1.00	.73	0.7	0.57

Total Harmonic Distortion data, shown below in Table 34, shows changes from the base case fixture to the LED retrofits. THD is a concern for newer LED products, and is disclosed on all CREE product literature, but was not available for any of the other fixtures. For retrofit fixtures, the THD was calculated based on the weighted average of individual circuits and aggregated together for a single study area. Results show that THD went up for the CR 24, CR-LE-40L, and remained at similar levels for the CS14 and PAR20 lamps. THD went down for the checkout chandeliers after the retrofit. It is expected that the high THD levels measured for the CR24 and CR-LE 40L fixtures were due to wiring at 50% power. Under normal operation at 100% of rated power, it is expected that power factor would be greater than 0.9 and THD would be less than 20%. However, the overall low line noise due to the lower wattage makes the effect of the increased THD negligible.

TABLE 34. TOTAL HARMONIC DISTORTION COMPARISON

LED Retrofit Lamp	Location	Base case (Rated)	Base case (Measured)	Retrofit (Rated)	Retrofit (Measured)
Philips A19	Checkout Chandeliers	Nominal THD data not available for base case fixtures	96%	No data	70%
CREE CR24	Break Room		5%	<20%	34%
CREE CR-LE-40L	Auto Install Garage		7%	<20%	31%
CREE CS14	Checkout Fluorescents		15%	<20%	16%
CREE ESA	Customer Service		No data	<20%	No data
Green Creative PAR20	Audio Room		60%	No data	58%

ANALYSIS OF ILLUMINANCE DATA

The comparison of the average of both the retrofit and base case measurements is included in Table 35. Increases in overall illumination can be seen in all the study areas except the auto install garage and break room. In each area, these changes improved overall lighting quality.

TABLE 35. AVERAGE ILLUMINATION (FOOTCANDLES)

	Average Illumination (footcandles)						
	Audio Room	Auto Install	Restroom	Break Room	Register Area	Computer Sales	Customer Service
Base case	5.6	38.3	34.3	77.8	36.2	35.9	18.5
LED Retrofit	15.6	35.7	44.7	32.7	64.5	83.9	73.8

The base case and retrofit conditions can be compared using an average to minimum ratio, which gives a single metric for the total range of lighting values. A lower value means more consistent, uniform light levels. As shown in Table 34, the LED fixtures have more evenly distributed lighting in all applications in the store, except for the Audio Room which uses directional lighting. This improvement is primarily due more even lighting distribution from the light source. The Audio Room has an increase in the average to minimum ratio and has significantly uneven light levels compared to the rest of the store. This is due to the directional nature of PAR lamps, where a higher avg/min ratio is desirable because the highly focused light gives specific products 'pop'.

TABLE 36. ILLUMINANCE AVG/MIN RATIOS

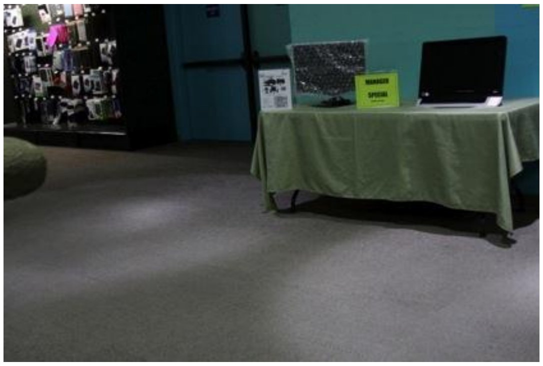
Illuminance Avg/Min Ratios							
	Audio Room	Auto Install	Restroom	Break Room	Register Area	Computer Sales	Customer Service
Base case	3.1	1.4	1.7	1.8	1.5	2.5	1.4
LED Retrofit	3.8	1.4	1.4	1.5	1.1	1.5	1.2

In most applications of the store, the retrofit LED fixtures provided a more evenly distributed light level and higher illumination levels than the base case, as depicted in Figure 41 below. While this is to some degree due to the lumen depreciation from the base case lamps, the LED fixtures produced a much more even distribution throughout the study areas.

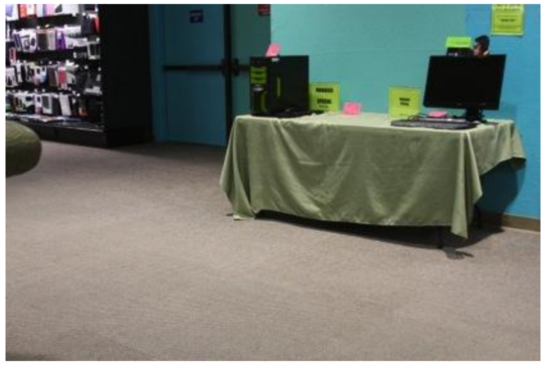
FIGURE 41. UNEVENLY DISTRIBUTED BASE CASE FIXTURES VS. LED RETROFIT

Computer Sales

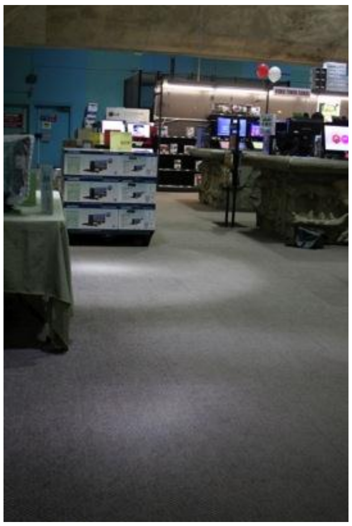
Base case: Metal Halide



Retrofit: LED



Base case: Metal Halide



Retrofit: LED

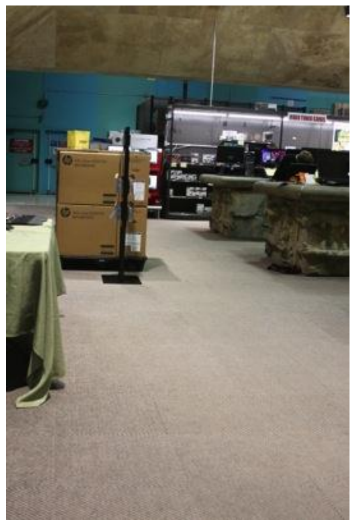


Table 37, provides a comparison between the color rendering index ratings for the base case and retrofit fixtures covered in this study. Values were taken from product specification sheets or other product literature. In all cases, the retrofit CRI is very good (>80). For LED replacements of linear fluorescents, CRI for the retrofit is even higher than the base case.

TABLE 37. COLOR RENDERING INDEX (CRI)

LED Retrofit Lamp	Base case CRI (Rated)	Retrofit CRI (Rated)
Philips A19	100	81
CREE CR24	82	90
CREE CR14	82	90
CREE CS14	82	90
CREE ESA	65	80
Green Creative PAR20	100	85

CUSTOMER DECISION AND SATISFACTION SURVEY RESULTS

CUSTOMER DECISION MAKING PROCESS

Fry's began exploring potential LED applications when they decided to retrofit their high bay metal halide fixtures in 2009 in all Northern California locations under PG&E's New Efficiency Options (NEO) incentive program.[46] At the time, Fry's considered LEDs primarily for high bay applications, but ultimately chose to retrofit existing fixture's electronic ballasts instead of selecting an LED retrofit. After this retrofit, Fry's considered LED fixtures for all possible fixture types, although it did not find products that met their requirements until 2011. For recessed 2x4 replacements, Fry's considered both LED replacement fixtures and LED linear tubes in existing troffers. From 2009 until Fry's made their final product selection, Fry's considered a number of products that did not meet their quality standards for 2x4 troffer replacements, 1x4 strip fixture replacements, MR16 replacement lamps, and other A19 replacement lamps.[47] For example, Fry's considered LED linear tubes with integrated ballasts, but they achieved poor color rendering, inadequate light output, and premature failure. Although Fry's was approached by numerous manufacturers and completed mockup installations in both office and retail applications, none of those products met Fry's requirements. In their decision making process, Fry's relied on their lighting distributor to provide high quality product recommendations.

From a technical perspective, Fry's selection criteria required a high-efficacy fixture with good light distribution and reliable color temperature and CRI that was equivalent to the existing fixture. For example, Fry's required recessed troffers to have an efficacy greater than 90 lumens per watt. To ensure long-term reliability, manufacturer reputation was a major consideration in the selection process. For example, Fry's began to seriously consider lay-in LED replacements for 2x4 recessed troffers once CREE entered the market with its CR24 product. Fry's required a 50,000 hour rated lifetime, which at store operating hours equates to a 8.4 year fixture lifetime.

From a financial perspective, Fry's requires the retrofit to have a simple payback of less than two years, which includes equipment costs and energy interactive effects. Fry's did not require a specific reduction in energy use, only that the retrofit met their payback requirement. While the store retrofit did not meet the two year payback requirement on its own, it achieved a two year payback when bundled with the corporate office retrofit.[48] Similar to other businesses, Fry's compares retrofit opportunities based on ROI. According to Fry's, utility incentives played a critical role in the decision to complete the project because the incentives allowed the project to meet the two year payback requirements.

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[46] Fry's retrofitted their high bay fixtures in four stores within PG&E territory, and 30 stores nationwide.

[47] Although MR16 LED replacement lamps are not included in the scope of the San Jose store retrofit, but LED MR16 replacement lamps were part of the comprehensive retrofit of Fry's corporate headquarters.

[48] For the corporate office retrofit, 68% of the base case fixtures consisted of recessed 2x4 fixtures with 3 F34T12 lamps. An additional 7% of fixtures were recessed 2x4 fixtures with 4 F34T12 lamps. While the high base wattage may provide an exceptionally quick payback in this case, a standard recessed 2x4 fixture with 3 F32T8 lamps would still achieve a 2.0 year payback with the incentive, and a 3.8 year payback without the LEDA incentive.

About 61% of the total project cost (retail and corporate office retrofit) was covered by project incentives.

CUSTOMER SATISFACTION SURVEY RESULTS

Fry's Energy Manager, who is responsible for all energy related retrofits throughout Fry's stores, was very satisfied with the new lighting atmosphere. The manager noted that the product color rendering was significantly improved under the LED fixtures. A store manager interviewed noted that the lights were "much brighter" and required some getting used to, but believed that the retrofit was a significant visual improvement because it was easier for customers to see store merchandise.

In addition to the comprehensive store retrofit, Fry's also completed a comprehensive office retrofit to their corporate headquarters, where they replaced linear fluorescent, MR16, PAR lamps, CFLs, and incandescent lamps. Similar to most commercial spaces, the vast majority (86%) of fixtures were comprised of linear fluorescent lamps. Fry's was highly satisfied with this office retrofit due to the high energy savings achieved, reduced maintenance costs, and improved lighting environment.

Overall, the installation process was straightforward and satisfactory, although Fry's reported some lack of contractor experience with the new LED technologies.[49] To date, Fry's has been very satisfied with the retrofit results and plans to expand LED retrofits to additional store locations where it meets its two year payback requirement. This is highly dependent on the availability of incentives for advanced LED retrofits. In 2013, Fry's plans to scale this same retrofit to four other stores within PG&E territory, where the LED Accelerator incentive is available. However, there are no plans to expand beyond PG&E territory at this point, due to the lack of available financial incentives. Fry's indicated that they plan to wait until fixtures costs come down sufficiently to achieve a two year project payback without incentives.

FRY'S EXPERIENCE WITH EXTERNAL AGENCIES AND UTILITY ENERGY EFFICIENCY PROGRAMS

Fry's had a very positive experience with external agencies and found them very helpful in their decision making process. Fry's relied primarily on their lighting distributor to make specific fixture recommendations that met LEDA program requirements.

Overall, Fry's was very satisfied with PG&E's third party LED Accelerator (LEDA) program. Fry's indicated that the LEDA program assisted their project in two key areas: 1) Financial assistance through tiered energy efficiency incentives; and 2) Stringent product qualifications requirements which assured product quality[50]. Fry's recommended that the

[49] While LED linear tubes were not included in the scope of this study, Fry's staff noted that to date they have had a generally positive experience with LED linear tubes using internal drivers. Fry's staff did report some initial product failures which were attributed to improper installation, and stressed that correct installation is critical to correct performance.

[50] Although Fry's did not directly rely on external resources such as DOE, ENERGY STAR and the DLC, these resources ultimately serve as the basis for LEDA product qualifications and therefore play a key role in helping ensure high product quality.

LEDA program continue to offer tiered incentives to defray the initial costs of high quality LED fixtures.

AESTHETIC REQUIREMENTS

Aesthetically, Fry's required that LED retrofit lamps and fixtures minimize changes to the look and configuration of existing fixtures. Fry's staff were satisfied with the look of retrofit fixtures.

EVALUATIONS

ENERGY, PEAK DEMAND AND COST SAVINGS

Based on the results of this scaled field placement, the selected fixtures demonstrate that a comprehensive LED store retrofit can be effective in maintaining or improving lighting quality while reducing power demand and creating energy savings. On storewide basis, the comprehensive retrofit achieved 47% savings in demand and energy. A number of products had lower power factor and higher THD levels than listed of product specification sheets. For the CREE CR24 and CR-LE-40L products, this was because all fixtures were wired down to half power to achieve additional energy savings. However, the overall low line noise due to the lower wattage makes the effect of the increased THD negligible. It is expected that the CR24 and CR-LE-40L products would meet rated PF and THD values if wired to full power.

LIGHTING PERFORMANCE

The comprehensive store retrofit improved light levels and lighting distribution through most applications. Overall, we can conclude that the LED fixtures installed provided equivalent or better lighting performance to the base case fixtures.

SATISFACTION SURVEY RESULTS

Fry's representatives were very satisfied with the lighting quality and energy and maintenance saving achieved from the comprehensive LED retrofit. At this point in time, LED product quality is competitive in common lighting applications; however, the comparatively high cost of LED fixtures remains the most significant adoption barrier. Utility incentive programs can continue to reduce the initial cost and make lighting projects feasible. Without aggressive utility incentives, market adoption may be slow until price comes down sufficiently to meet commercial payback periods.

ENERGY SAVINGS, PEAK DEMAND REDUCTION, AND ECONOMIC IMPACT

For qualifying equipment only, the retrofit achieved a 58% reduction in energy use, or 121,041 kWh savings, a peak demand reduction of 20.2 kW, and energy cost savings of $16,946.[51] Including interactive effects, the project achieved energy savings of 132,883 kWh, a peak demand reduction of 22.2 kW, and $18,604 in cost savings (see Table 38 below). Annual maintenance savings due to the installation of qualifying equipment are $11,277 year for the duration of the estimated 12 year average project lifetime.

[51] Energy Costs are estimated based on rates per kWh listed in PG&E's E19 rate schedule and do not include demand charges.

TABLE 38. PROJECT ENERGY SAVINGS AND PEAK DEMAND REDUCTION (QUALIFYING EQUIPMENT ONLY) [52]

	Energy Use (kWh)	Peak Demand Reduction (kW)	Energy Costs ($)
Base case	207,021	34.6	$28,983
Retrofit case	85,981	14.4	$12,037
Project Savings	**121,041**	**20.2**	**$16,946**
Project Savings (with interactive effects)	**132,883**	**22.2**	**$18,604**

For the storewide retrofit, the project achieved 47% reduction in energy use, or 176,929 kWh savings, a peak demand reduction of 29.6 kW, and energy cost savings of $24,770. Including interactive effects, the project achieved energy savings of 194,004 kWh, a peak demand reduction of 32.4 kW, and $27,161 in energy cost savings (see Table 39 below). Annual maintenance savings are estimated at $20,005 per year for the duration of the estimated 12 year average project lifetime.

TABLE 39. PROJECT ENERGY SAVINGS AND PEAK DEMAND REDUCTION (STOREWIDE RETROFIT) [53]

	Energy Use (kWh)	Peak Demand Reduction (kW)	Energy Costs ($)
Base case	378,150	63.2	$52,941
Retrofit case	201,222	33.6	$28,171
Project Savings	**176,929**	**29.6**	**$24,770**
Project Savings (with interactive effects)	**194,004**	**32.4**	**$27,161**

FINANCIAL ANALYSIS

Fry's payback requirements are based on equipment costs and do not include labor costs for installation, which is typical for the commercial sector. For products that were eligible for a LEDA incentive, Fry's achieved a simple project payback (SPP) of 5.8 years without an incentive. If these same products had gone through the statewide Customized Retrofit Incentive instead of LEDA, the project would have achieved a 5.1 year SPP. With the LEDA incentive, the qualifying products achieved a 4.1 year SPP. Table 40 provides a comparison of financial metrics below, including simple payback, return on investment (ROI), modified internal rate of return (MIRR) and net present value (NPV). All calculations include interactive effects.

TABLE 40. FINANCIAL ANALYSIS OF PRODUCT COSTS FOR LEDA ELIGIBLE EQUIPMENT (NOT INCLUDING INSTALLATION)[54]

	SPP (Years)	ROI	MIRR	NPV ($)
No Incentive	5.8	17.3%	10.2%	$63,982
Customized Retrofit Incentive	5.1	19.5%	11.3%	$76,154
LEDA Incentive	4.1	24.2%	13.3%	$94,944

[52] Numbers may not add up evenly due to rounding.

[53] Numbers may not add up evenly due to rounding.

[54] All financial calculations assume a 3% inflation rate, 7% discount rate, and 5% reinvestment rate.

Accounting for installation costs and including and maintenance savings, Fry's achieved a simple payback of 4.3 years without an incentive. If these same products had gone through the statewide Customized Retrofit Incentive instead of LEDA, the project would have achieved a 3.9 year SPP. With the LEDA incentive, the qualifying products achieved a 3.3 year SPP. Table 41 provides a comparison of financial metrics below, including SPP, ROI, MIRR and NPV.

TABLE 41. FINANCIAL ANALYSIS OF PROJECT COSTS FOR LEDA ELIGIBLE EQUIPMENT (INCLUDING INSTALLATION COSTS AND MAINTENANCE SAVINGS)

	SPP (Years)	ROI	MIRR	NPV ($)
No Incentive	4.3	23.2%	12.9%	$146,732
Customized Retrofit Incentive	3.9	25.6%	13.9%	$158,903
LEDA Incentive	3.3	30.5%	15.5%	$177,693

LEDA eligible products accounted for roughly 50% of the entire project on a cost basis. Of the non-eligible products, 88% of these costs came from the LED linear tubes and downlights. Including these non-eligible products and accounting for installation costs and maintenance savings, the entire project achieved an estimated SPP of 5.0 years without incentives, 4.8 years with a Customized Retrofit Incentive, and 4.4 years with a LEDA incentive. Table 42 provides a comparison of financial metrics below, including SPP, ROI, MIRR and NPV.

TABLE 42. FINANCIAL ANALYSIS OF PROJECT COSTS FOR THE STOREWIDE RETROFIT, INCLUDING INSTALLATION COSTS AND MAINTENANCE SAVINGS

	SPP (Years)	ROI	MIRR	NPV ($)
No Incentive	5.0	19.8%	11.4%	$194,557
Customized Retrofit Incentive	4.8	20.9%	11.9%	$206,564
LEDA Incentive	4.4	22.8%	12.7%	$225,518

SPP is included in the financial analysis due to its prevalence in corporate calculations of financial returns. However, simple payback requirements obscure long-term financial returns. While there has been significant discussion on the limitations of SPP, the value of SPP as a financial metric is diminished due to the significantly longer lifetime of LEDs. Prior to LED retrofits, the measure lifetime of most efficiency measures, such as a ceramic metal halide or 3rd generation T8 fluorescent lamp, was between 20,000-40,000 hours. LED lifetimes are significantly longer than previous retrofit measures, and it is expected that LED products will spend far more time operating and generating energy savings than previous technologies. Under the Fry's operating hours, even long-life T8 fluorescent lamps, with a rated lifetime of 40,000 hours would last 6.7 years. In this case, the products spend roughly 30% of their lifetime recouping the investment cost through energy savings, and the remaining 70% of their lifetime providing "free" operating cost savings. The CREE LED CR series replacements for linear fluorescents installed at Fry's have a 100,000 hour rated lifetime[55] and a ten-year warranty.[56] This translates to an estimated lifetime of 16.7 years at Fry's, almost ten years longer than a long-life fluorescent T8. With a two year payback, these LEDs roughly 12% of their lifetime recouping their investment cost, and 88% of their estimated lifetime generating "free" savings. Because of the long lifetime of LED retrofits, we recommend facilities managers treat LED lighting retrofits as large infrastructure retrofit projects, which typically have longer acceptable payback periods.

THE ROLE OF ON-BILL FINANCING TO REDUCE INITIAL PROJECT COSTS

Despite the tremendous energy and maintenance cost savings that LED retrofits can provide, the high initial project cost of LEDs remains the most significant barrier to widespread LED adoption (DOE 2013a; DOE 2012a). On-Bill Financing (OBF) may be a way to significantly reduce or even eliminate initial product costs, and may be as or more important as incentives to increasing market adoption of comprehensive retrofits (Cadmus 2012). For measures eligible for energy efficiency rebates and incentives, the California IOUs currently offer 0% interest loans up to $100,000 with a 3-5 year maximum payback for commercial customers, $250,000 for tax-payer funded customers ($1 million for state agencies) with a 10 year maximum payback as part of their On-Bill Financing program.[57] This financing is integrated with, and is meant to complement, existing incentive offerings, not to serve as a replacement.

If the Fry's project only considered products that were eligible for LEDA incentives, the project would require a $39,705 upfront cost, and OBF for three years, after which the project would generate positive cash flow for until the end of the estimated 12 year measure life. In this case, the project's initial costs can be lowered from an upfront cost of roughly $100,000, including incentives, to under $41,000 (see Table 43). Alternately, the upfront cost could be spread out over three years and require no upfront cost.

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55 Rated LED lifetimes are measured under the IES guideline TM-21. Due to their long projected lifetimes, there is some debate over the actual lifetimes. These lifetimes are not yet field proven because no products have been installed for their complete lifecycle.

56 http://www.CREE.com/news-and-events/CREE-news/press-releases/2013/january/crtrofferseries

57 In March 2013, the California IOUs' OBF program for non-residential customers was recognized by ACEEE as an 'Exemplary Program' in the On-Bill Financing' category. http://www.aceee.org/sites/default/files/publications/researchreports/u132.pdf For more information on PG&E's OBF program, visit: http://www.pge.com/en/mybusiness/save/rebates/onbill/index.page.

TABLE 43. CASH FLOW ANALYSIS OF LEDA ELIGIBLE EQUIPMENT (EXCLUDING MAINTENANCE SAVINGS)[58]

Cash Flow	Initial Cost	Year 0 (today)	End of Year 1	End of Year 2	End of Year 3	End of Year 4
Outflows	Single Investment	$(71,472)				
	Financed Investment		$(18,653)	$(19,213)	$(19,789)	$ -
Inflows	LEDA Incentive	$30,962				
	Energy Savings		$18,858	$19,424	$20,006	$20,607
	Maintenance Savings					
Total Cash flows		**$(40,510)**	**$0**	**$0**	**$0**	**$20,607**

Including project maintenance savings, the project requires zero down and has a negative cash flow totaling less than $6000 for the first three years (see Table 44 below). While we acknowledge that capital expense and maintenance budgets are typically separate and do not share budgets, as well necessary capital to float a loan while incentives and OBF loans are processed, this example demonstrate the potential impact of incentives and OBF to the overall company bottom line.

TABLE 44. CASH FLOW ANALYSIS OF LEDA ELIGIBLE EQUIPMENT (INCLUDING MAINTENANCE SAVINGS)

Cash Flow	Initial Cost	Year 0 (today)	End of Year 1	End of Year 2	End of Year 3	End of Year 4
Outflows	Single Investment	$(36,600)				
	Financed Investment		$(30,140)	$(31,044)	$(31,975)	$-
Inflows	LEDA Incentive	$30,962				
	Energy Savings		$18,858	$19,424	$20,006	$20,607
	Maintenance Savings		$11,282	$11,620	$11,969	$12,328
Total Cash flows		**$(5,638)**	**$0**	**$0**	**$0**	**$32,935**

The widespread grouping and use of OBF in project finance could dramatically increase adoption of LED retrofit projects. While the Fry's project is specific to the retail environment and has very specific lamp types and operating hours, a similar approach could be employed to target the broader commercial sector. As Table 45 suggests, the lamp distribution in retail is fairly representative of the broader commercial lighting sector. Therefore, a comprehensive LED retrofit would likely be successful in much of the commercial sector, provided product quality is ensured as part of the fixture selection process.

[58] Energy and maintenance savings costs are adjusted assuming a 3% inflation rate.

TABLE 45. LAMP DISTRIBUTION BY COMMERCIAL BUILDING TYPE IN 2010 (DOE 2012A)

	Incandescent	Halogen	CFL	Linear Fluorescent	HID	Other	Total
Education	1%	2%	10%	85%	1%	2%	100%
Food Service	20%	1%	8%	67%	1%	3%	100%
Food Store	1%	1%	3%	94%	1%	1%	100%
Health Care - Inpatient	1%	1%	13%	84%	0%	1%	100%
Health Care - Outpatient	1%	1%	9%	88%	0%	1%	100%
Lodging	18%	2%	25%	53%	0%	2%	100%
Offices (Non-medical)	1%	1%	14%	82%	0%	1%	100%
Public Assembly	8%	1%	21%	58%	3%	9%	100%
Public Order and Safety	1%	1%	6%	89%	1%	2%	100%
Religious Worship	4%	1%	8%	84%	1%	2%	100%
Retail - Mall & Non-Mall	5%	6%	6%	79%	3%	1%	100%
Services	1%	1%	4%	90%	3%	1%	100%
Warehouse and Storage	0%	2%	6%	86%	5%	1%	100%
Other	2%	4%	9%	79%	2%	3%	100%
Average	**4%**	**2%**	**10%**	**80%**	**2%**	**2%**	**100%**

Commercial facilities dominated by 3 lamp, 2x4 recessed troffers and operating hours similar to that of Fry's could easily achieve a two year payback if LED products were eligible for the Tier 2 incentives offered by the LEDA program. As LED product costs continue to decrease and efficacy improves, comprehensive LED retrofits should meet short payback requirements in an increasing number of facilities.

FINDINGS

Based on the results and evaluations of this study, we have six primary findings for PG&E:

Finding#1: Utility incentive programs can continue to address LED market barriers by providing appropriate incentives and services, such as rigorous product qualification standards.

LED lamps and fixtures remain in the early commercialization stage and require utility program intervention to address market barriers including high initial product costs as well as variability in product quality. The high initial product cost remains the most significant barrier to widespread of LED replacement lamps and fixtures. Without aggressive utility incentives, these projects may not meet corporate payback requirements, which in this case was two years (not including installation costs). Product quality also continues to be a concern; although Fry's was very satisfied with the fixtures they ultimately selected, they went through a multi-year fixture selection process in which many fixtures performed poorly during mockups.

Utility incentive programs can continue to address these market barriers by providing incentives to reduce initial cost, coupled with rigorous product qualification standards. In this pilot case, over 75% of the fixtures that Fry's selected qualified for LEDA incentives that reduced the project cost and made the retrofit possible,[59] demonstrating the influence incentive programs can have in product selection. We recommend utility programs continue to couple incentives and rigorous product qualification standards to accelerate the adoption of high quality products in the market. The long lifetime of LED products means that retrofits will occur far less frequently than before, increasing the importance of selecting high quality products.

Finding#2: Due to the long lifetime of LED retrofits, consumers and utility programs should consider lifecycle costs and benefits rather than simply first cost and simple payback period in evaluating LED retrofit projects and options.

High initial product cost can also be addressed through reframing those costs as lifetime financial benefits. The long lifetime of LED fixtures means energy and maintenance savings are much longer than previous efficiency retrofits. While simple payback period may be useful for retrofits with an expected lifetime of 4-6 years, it does not adequately account for the fact that the LED product is actually generating savings for operational costs for many years over its useful life. In the case of the Fry's comprehensive LED retrofit, because the LED measure lifetime is so long, the focus on short payback periods obscure the fact that the investment has an ROI of 24.2% and NPV of $94,944 for equipment only, and an ROI of 30.5% and NPV of $177,693 when including installation costs and projected maintenance savings.[60]

[59] This does not account for LED Linear Tubes, which are not eligible for PG&E incentives at this time.

[60] ROI and NPV values for LEDA eligible equipment only. NPV calculations assume a 7% discount rate and inflation rate of 3%.

Finding #3: On-bill financing can reduce high initial project costs of LED retrofits and encourage adoption of comprehensive lighting retrofits.

The primary barrier to widespread LED adoption is the high initial cost (DOE 2013a). To reduce or eliminate upfront project costs, we recommend utility programs continue to integrate non-incentive services such as On-Bill Financing (OBF) into LED incentive programs. OBF complements existing incentives to address the primary market barrier to LED adoption by further reducing upfront capital costs, allowing customers to pay for the retrofit through their energy bill, based on energy savings achieved. OBF encourages a comprehensive approach to building retrofits by encouraging customers to bundle retrofits and address fixtures that may not have been cost-effective on their own. If Fry's had utilized PG&E's OBF for its comprehensive store retrofit, the LEDA eligible portion of the project would have reduced upfront capital costs by 60%. This would change the project economics from $100,000 upfront to $40,000 up front, or $40,000 phased over 3 years, while the remaining $60,000 would be paid through energy savings from the store utility bill. Accounting for maintenance savings and utilizing OBF, the project requires less than $6,000 up front and achieves an NPV of $177,693 (including maintenance savings), while the OBF loan is repaid through energy and maintenance savings. While this does not address structural issues such as separated capital expense and operations and maintenance (O&M) budgets or the need to float a loan while waiting for incentive and OBF loan processing, it highlights the potential of OBF to reduce capital costs.

Finding #4: LED Linear Tubes, which have significant savings potential, merit evaluation to determine whether these products should be considered for future program incentives.

While LED linear tubes have had product quality concerns in the past, their quality is rapidly improving. Roughly 12% of the Fry's LED retrofit budget was used for the purchase of LED linear tubes. As LED linear tubes continue to improve in quality and efficacy, their use will likely continue to grow. The Design Lighting Consortium now has a category of LED linear tubes on their national recognized Qualified Product List, and many products have been listed in the past six months. Linear tubes with external drivers which replace the existing fluorescent ballasts and do not use existing lamp sockets have fewer electrical and safety concerns. We recommend conducting further evaluation to determine whether these products have sufficiently addressed prior quality and safety concerns and should be considered for future program incentives.

Finding #5: Utility programs can expand LED commercialization incentive programs and encourage a comprehensive retrofit approach.

The comprehensive retrofit approach reduces costs by achieving economies of scale on equipment and installation costs, allowing companies to complete retrofits that may not otherwise be cost effective. Utilities can expand early commercialization to non-retail commercial buildings, where comprehensive retrofits may also be cost effective, particularly for facilities with high hours of operation or large quantities of recessed fixtures with three and four linear fluorescent lamps.

Finding #6: Utility programs can integrate lighting controls within existing LED incentive programs to achieve deeper savings and improved facility asset management through operational efficiency.

Advanced controls allow facilities to realize additional benefits that extend beyond a simple retrofit. Advanced controls play an important role in not only saving energy, but also by providing data inputs to intelligently operate and control facility assets. They also provide opportunities to achieve additional financial benefits by participating in utility Automated Demand Response (ADR) programs and grid ancillary services. A recent study estimated the global advanced lighting controls market will grow to over $5 billion by 2020, and is driven by increased demand for both task tuning, via dimmable ballasts and drivers, and occupancy information via occupancy sensors (Navigant 2013). The long lifetime of LED products means that lighting LED retrofits likely represent the last major retrofit opportunity for much of the lighting market,[61] so once a business has completed a comprehensive LED retrofit, it is unlikely that they will conduct another major lighting retrofit for at least ten years. During this time, we expect advanced lighting controls to achieve widespread market adoption and play a major role in facility asset management. We recommend that utility programs bundle future advanced controls installations with comprehensive retrofits, which will give customers greater control of their facility assets and participate in future demand management programs.

[61] CREE, a major LED manufacturer, recently extended its warranty for certain products to 100,000 hours, which is over 16 years, even with Fry's high hours of operation

APPENDICES

APPENDIX A. FRY'S LED RETROFIT SURVEY

These questions are designed to better understand Fry's decision process in fixture selection and regional implementation. These questions will help PG&E better understand how commercial entities select LED fixtures and how they decide to scale them across many store locations.

The results of this survey inform the Emerging Technology (ET) Demonstration Report. Some of this information may be included in the report. We understand that certain answers may contain sensitive or proprietary information that Fry's does not wish to publish or would prefer the report discuss more generally. For each answer in which confidentiality is a concern, please note those concerns or specific answers you would like to omit in the external report. Once the report is drafted, Fry's will have one week to review the rough draft and request any changes to the report.

1. **Existing Operation**
    a. What are Fry's normal operating hours, excluding stores operating 24/7?

    b. What fraction of Fry's stores are open 24 hours? Do all stores that are not on a 24/7 schedule have identical hours?

    c. How many holidays per year have amended store hours? Do holidays impact stores that are open 24/7?

    d. Please describe any additional activities, such as stocking and maintenance, that impact the operating hours of the LED fixtures. Do they differ by fixture type?

    e. How often do you currently conduct scheduled replacements where you re-lamp existing fixtures? Roughly what fraction of these lamps had pre-mature failures that require spot-replacement? How often do you perform spot replacements?

    f. What is the estimated cost of re-lamping a fixture for a scheduled, store-wide replacement? Spot replacement?

    g. What is your average electric utility rate ($/kWh)?

    h. Do you expect any other changes to costs from adopting a new LED fixture, such as increased/decreased installation time?

    i. What is your expected re-lamp frequency for LEDs?

2. **Fixture Selection Process**
    a. What were the key factors that influenced your decision to install LED fixtures? Indicate all that apply.

   i. Energy/cost savings
   ii. Lamp replacement time/cost savings
   iii. Light distribution
   iv. Other: ______________________________________

b. What were your key concerns about switching to LED fixtures in this specific retail application?

c. What other lighting products did you consider installing? How did you differentiate between similar products on the market?

d. What were the performance criteria in your selection of the specific product? Indicate all that apply.
   i. Efficacy (Lumens per Watt)
   ii. Light distribution
   iii. Color rendering of products
   iv. Lamp field performance
   v. Lamp replacement labor costs
   vi. Other

e. Did external *agencies* help inform your selection process (ex. DOE, MSSLC, CALiPER, ENERGY STAR, DLC, utility programs, etc.)? If so, how did they help?

f. What external *companies* helped inform your selection process (Lighting contractors, designers, sales representatives, etc.)? If so, how did they help?

g. What was your experience of the installation process?

h. Have you seen a reduction in energy bills since installation of the new lighting?

3. Influence of utility incentive programs

a. How did the presence of a utility incentive program affect your decision to move forward?

b. On a scale of 1-5, 1 being not important at all, and 5 being very important, how did utility support in the following areas affect your decision to move forward?

i. Incentive	1	2	3	4	5
ii. Project assistance	1	2	3	4	5

c. Are there any additional utility program services that would assist you in future decisions?

4. Decision to scale to other stores

a. Do you plan to implement this at other retail locations?

b. Describe the field-testing process you completed prior to your decision to scale new lighting technologies to several stores.

c. What were your criteria for approval to scale? Were the criteria the same as the initial fixture selection? (ex. Payback, maintenance, upfront costs, etc.)

d. Please rank the following in order of importance in selecting new retrofit locations:
   i. Age of Existing Fixtures
   ii. Store energy use
   iii. Availability of utility incentives
   iv. Other: ________

5. Demand Response and Dimming

a. Does your lighting control system allow fixture dimming? If so, is this feature used in the store? When and where is it used?

b. Would you consider using dimming capability on fixtures in the future?

c. Are your lights controlled through an energy management system? Is this system able to accept automated demand response (DR) signals?

d. Would Fry's be willing to participate in an automated DR program for LED lighting fixtures? Are there additional lighting sources you would consider implementing DR for?

6. Store Employee or Customer Survey

a. Did you (employee/customer) notice the lighting replacement?
   i. Do you think the new lighting improves or worsens the retail atmosphere?
   ii. Overall, how satisfied are you with the new lighting atmosphere?
   iii. Would you recommend that Fry's adopt the same new lighting in other stores?

APPENDIX B. SCALED FIELD PLACEMENTS FOR PG&E EMERGING TECHNOLOGY PROGRAM

a. Description - These projects consist of placing a number of measures at customer sites as a key step to gain market traction and possibly gain market information. The measures will typically have already undergone an assessment or similar evaluation to reduce risk of failure. While the number of units in scaled field placements will vary widely, numbers typically larger than in an assessment of the technology are expected. A very simple example of a scaled field placement would be to give 50 office managers a LED task light. Monitoring activities on each scaled field placement will be determined as appropriate.

The following table highlights the distinctions between technology assessments, scaled field placements, and demonstration showcase.

Parameter	**Technology Assessments**	**Scaled Field Placements**	**Demonstration Showcases**
Purpose	performance, cost data → EE programs	market traction	Visibility
Theme	evaluation	first-hand experience	Exposure
Units installed	one to a few (exceptionally, many)	a few to many	one (or entire floor/building/facility)
Number or sites	one to a few (exceptionally, many)	a few to many	One or more as strategically valuable
Unique measures	One	one	more than one measure up to whole systems (exceptionally, just one)
Customer impact	one or a few users	few to many users	large number of viewers
Visibility	very little	targeted	Public
Duration	as needed for data collection	life of measure	duration of public interest / impact
Data collection	Detailed	none to moderate	none to moderate
Dissemination mechanism	printed report & other media	first-hand experience and word of mouth	short-term exposure and word of mouth

b. Rationale - Scaled field placements work under the premise that end-users or stakeholders with adoption influence (installers, builders, and procurement officers) will be positively influenced by first-hand experience utilizing a measure and that this

first-hand experience will lead to future measure purchases/use. This method of influence is fundamentally different from assessments that influence through information dissemination via a report or other results media.
Scaled field placements will be most effective when:

- The stakeholder gaining exposure has the potential to influence a large number of future purchases/uses. Example: Placing a high-efficiency air conditioning unit with several large HVAC contractors. "Potential to influence" is a broad term. Influence of the participant stakeholder could stem from purchase decision power, high frequency of interactions with other potential adopters, or status as a thought leader.

- First-hand experience is projected to be more influential for a measure than less costly dissemination mechanisms such as printed information or media. Technology complexity and concern regarding human factors are potential causes for first-hand experience to be more influential than printed media. Example: Placing energy efficient retail lighting at a Wal-Mart, Target, and Home Depot store.

c. Barriers addressed – Scaled field placements address Information or Search Costs, Performance Uncertainties, Organizational Practice or Customs, as well as contributing to efforts by others to overcome Hidden Costs and Asymmetric Information and Opportunism.

For instance, scaled field placements reduce the time that large-scale decision makers and decision influencers must spend looking for and confirming the performance of EE measures – as first-hand experience eliminates these needs.

d. Expected outcomes – Scaled field placements will contribute to increased measure awareness, market knowledge and reduced performance uncertainties for ETP stakeholders and large scale customer decision makers and decision influencers. This will lead to changes in organizational practices and customs that may otherwise limit EE measure procurement and application.

Scaled field placements can also contribute to a market tipping point, in which an influential buyer or decision maker responsible for large volume purchase decides to specify the EE measure – thus creating a spike in market demand and exposure for many people who experience the measure once it is implemented. Over time, scaled field placements may support increasing use of measures by customers, aiding EE programs in achieving energy and demand savings targets, and meeting long term Strategic Plan and policy objectives.

Figure 42. Lamp Distribution by Commercial Building Type 2010

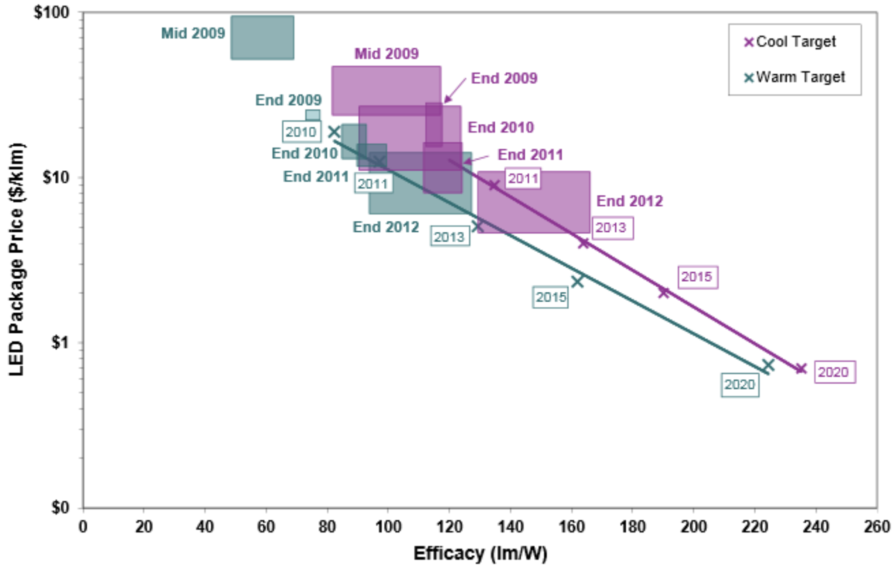


FIGURE 2.5 PRICE-EFFICACY TRADEOFF FOR LED PACKAGES AT 35 A/CM^2 AND 25 °C

Notes:

1. Cool-white packages assume CCT=4746-7040 K and CRI >70; warm-white packages assume CCT=2580-3710 K and CRI >80.
2. Rectangles represent region mapped by maximum efficacy and lowest price for each time period.
3. The MYPP projections have been included to demonstrate anticipated future trends.

Source: DOE 2012a. Table 4.18 Lamp Distribution by Commercial building Type 2010.

APPENDIX C. LIGHTING SIMULATION DESIGN DETAILS

For each simulation comparison, two identical models of the space were placed side-by-side and equipped with the base case and retrofit light fixtures. This allowed for comparison viewing base case and retrofit scenarios. By their nature, simulations are intended to capture major lighting characteristics of a given space, and are not intended to serve as detailed representations of the space. The most important lighting characteristics of the space are those that affect the way the light is distributed or reflected by surfaces within the model. As such, a precise color of a given wall or object is not as important as the level of reflectance that it creates. Objects such as internal walls, chairs and tables, and computer monitors were added to the models where appropriate to model their effect on lighting within the space.

Lighting models often use a standard set of assumptions for the reflectance of the ceiling, walls, and floor of a space as 80%, 50%, and 20%, respectively. Auditors used these default values except in cases where visual inspection of the area indicated these default values were not appropriate. In those cases, the model reflectance values were changed to match the reflectance of the surface. For example, a 20% reflectance for the floors is based on a typical building carpet. However, the Break room, Auto Install garage, and Customer Service Area in this study had off-white tiled floor, which was estimated to have a reflectance of 50%.

AGi32 Lighting models rely on .ies files containing fixture performance data to represent the fixture in the model. These files, named after the Illuminating Engineering Society (IES), provide data on the intensity and distribution of the illuminance of a certain fixture, which allows modeling software like AGi32 to calculate how the fixture will illuminate a modeled space. These simulation files are based on test data, and are typically provided by the manufacturer on their website. All .ies files for the LED retrofits were obtained in the specific configuration used for the retrofit, either from the manufacturer's website or through a direct request to the manufacturer. However, .ies files for base case fixtures were not as easily available, and not all fixture files were available in the same configuration as the actual base case fixtures identified through the on-site audit. The two fixtures affected by this included the Break Room 2x4 fluorescent troffer and the metal halide lamps in the Customer Service Area. In those cases, close approximation fixture files were chosen, and their performance specifications were manually adjusted to match the installed products. For example, the 2x4 fluorescent troffer file used in the Break Room was based on a fixture with greater lumen output than the actual base case fixture, so the lumen output was adjusted down on the .ies file to match expected lumen output for the installed fixtures.

Within the model, Light Loss Factors (LLF), provide a more accurate representation of fixture performance by taking into account different impacts to lamp performance. Three primary Light Loss Factors were used in the model for this report.

1. Lamp Lumen Depreciation (LLD) – The light output of all lamps degrade over time, and an estimate of LLD allows models to show how the lamps will perform after being placed in service. LLD was assumed to be .90 for all lamps (Benya 2011).
2. Luminaire Dirt Depreciation (LDD) – Lamp performance can degrade over time with the buildup of soot, dirt, dust or other particulate matter (Benya 2011). The fixtures present in the retail environment of Fry's are not greatly affected by these factors, and the LDD is estimated to be .95 for all areas with one exception. The auto install garage is exposed to car exhaust, which contributes to greater particulate buildup. The LDD for the auto install garage is estimated to be .90.

3. Ballast Factor (BF) – For base case fluorescent and metal halide lamps, a ballast factor of .87 was added which compensates for the performance of the ballast on the lamp itself (Benya 2011). A ballast factor was not applied to LED fixtures or the PAR lamps, which use drivers to regulate line voltage and do not have ballasts.

The total Light Loss Factor is determined by multiplying all the factors together, a method described in The Lighting Handbook (IESNA 2011). For example, for this report, the base case T8 fixture in the break room would have the following light loss factor:

$$.90\, LLD \times .95\, LDD \times .87\, BF = .74\ \ LLF$$

Whereas the retrofit LED fixture in the break room would have the following light loss factor:

$$.90\, LLD \times .95\, LDD = .855\ \ LLF$$

Similar to actual in-store photometric measurements, simulated measurement points were taken at the task height relevant to the area, such as the height of the customer service desk, or the surface of the tables in the break room. For the auto install garage, where there was no clear task plane, measurements were completed at a height of 30 inches above the finished floor, in accordance with IESNA field measurement guidelines for garages (IESNA 2011).

APPENDIX D. RETROFIT CUT SHEETS

A. CS14

CS14™
4' LED Linear Luminaire

Product Description

The CS14™ LED linear luminaire delivers up to 4000 lumens of exceptional 90 CRI light. This breakthrough performance is achieved by combining the high efficacy and high-quality light of Cree TrueWhite® Technology and Cree MicroMixing™ Optics with a unique thermal management approach. The CS14 is available in neutral or cool color temperatures and has 0-10V dimming as standard option. Its compact, lightweight design makes it easy to instal, making the CS14 perfect for use in grocery retail, showrooms and light industrial applications in new or upgrade construction.

Performance Summary

- Utilizes Cree TrueWhite® Technology
- Active Color Management
- Room-Side Heat Sink
- Made in the U.S.A. of U.S. and imported parts
- **Delivered Light Output**: 2200-4000 lumens
- **Input Power**: 33-38 watts
- **CRI**: 90
- **CCT**: 3500K, 4000K
- **Input Voltage**: 120-277 VAC
- **Warranty**: 10 years†
- **High Efficacy Lifetime**: Designed to last 75,000 hours minimum
- **Base Lifetime**: Designed to last 50,000 hours minimum
- **Dimming**: 0-10V Dimming to 5%*
- **Mounting**: Suspended or Surface with Tong Hangers (Standard)
- **Dimensions**: L 48" x W 10" x H 5.8"
- **Weight**: max 8 lbs.

Accessories

Reference CS Series Accessories document for more details.

Accessories	
TMM Metal Tong Hanger (Pair) - Recommended for surface mount	**AC5-18/5-48-Q14B-JB** Adjustable Power Feeds with Cable Support Canopy Kits **AC5-12/3-48-Q14B-JB** Adjustable Power Feeds with Cable Support Canopy Kits **AC5-18/2-48-Q14B-JB** Adjustable Power Feeds with Cable Support Canopy Kits
AC5-48-Q14B-TB Adjustable Cable Support Kits **AC2-48-Q14B-TB** Adjustable Cable Support Kits	
PC5-18/5-24-JB Adjustable Power Feed Canopy Cable Kits **PC5-12/3-24-JB** Adjustable Power Feed Canopy Cable Kits **PC5-18/2-24-JB** Adjustable Power Feed Canopy Cable Kits	**AC-144-Q14B-LP** Adjustable Loop Cable Kits

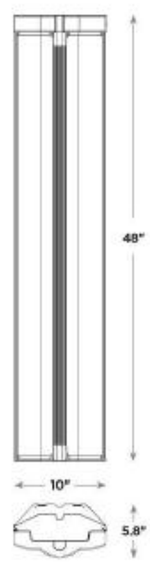
Ordering Information

Example: CS14-40L HE-35K-10V

Product	Lumen Output	Color Temperature	Voltage	Control
CS14	**40L HE** 37W 4000 lumens **38L HE** 33W 3800 lumens **38L** 38W 3800 lumens **22L** 22W 2200 lumens	**35K** 3500 Kelvin **40K** 4000 Kelvin	**Blank** 120-277 Volt	**10V** 0-10V Dimming to 5%

*Reference www.cree.com/lighting for recommended dimming control options.
†See www.cree.com/lighting for warranty terms.

CS14



CREE TRUE WHITE TECHNOLOGY
c UL US LISTED
www.cree.com/lighting T (800) 236-6800 F (262) 504-5415

Rev. Date 04/02/2013

CREE®

CS14™

Product Specifications

CREE TRUEWHITE® TECHNOLOGY

A revolutionary way to generate high-quality white light, Cree TrueWhite® Technology mixes the light from the highest performing red and unsaturated yellow LEDs. This patented approach delivers an exclusive combination of 90+ CRI, beautiful light characteristics, and lifelong color consistency, all while maintaining high luminous efficacy—a true no compromise solution.

THERMAL MANAGEMENT

An innovative thermal management system designed to maximize cooling effectiveness by allowing free air movement around the heat sink and through the fixture. This breakthrough design and operating drive current of less than 350mA enables the LEDs to consistently run cooler, providing significant boosts to lifetime, efficacy, and color consistency.

LUMEN MAINTENANCE FACTORS

- Designed to a minimum of L85 at 75,000 hours with HE option and L88 at 50,000 hours with base option.
- Reference www.cree.com/lighting for detailed lumen maintenance factors.

CONSTRUCTION & MATERIALS

- High strength, lightweight polymer forms the reflector and driver housing.
- Multi-functional heat sink and light bar doubles as the wireway for through wiring harness.
- Two plastic tong hangers provided for surface or suspended installations. One tong hanger per unit plus one per row is required.
- Hangers are adjustable along fixture to accommodate existing mounting points for upgrade projects. Hanger support required within 18 inches of end of fixture.
- Individual fixtures may be connected end to end for continuous row mounting. Easy removal of individual fixtures mounted in continuous row.
- Not intended for use in environments containing airborne corrosive agents such as chemical solvents, cleaners, or cutting fluids.

OPTICAL SYSTEM

- High-efficiency reflector with MicroMixing™ Optics which integrates the intense direct LED light and distributes optimally mixed indirect white light resulting in a comfortable appearance while maintaining high-efficiency optics.
- Indirect LED strip eliminates direct view of highly efficient, lighting quality LEDs.

ELECTRICAL SYSTEM

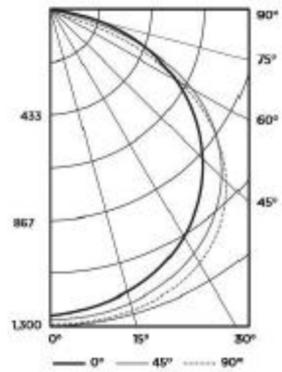
- Room-side wiring access chamber with hinged door for easy electrical access.
- Integral through wiring harness (3#12 AWG power and 2#18 0-10V) with quick-connect plug connectors for easy and efficient continuous row installations while minimizing branch circuit wiring.
- Integral, high-efficiency driver and power supply.
- **Power Factor** = 0.9 nominal
- **Input Power:** Stays constant over life.
- **Input Voltage:** 120V-277V, 50/60Hz
- **Dimming:** Dimmable to 5% with 0 to 10V DC control protocol. Class 1 or Class 2 wiring. Use only lighting controls with relay or FET-based outputs, or lighting controls with neutral connection. Reference www.cree.com/lighting for recommended dimming controls.
- **Temperature Rating:** Designed to operate in temperatures 0 C to 35 C
- **Total Harmonic Distortion:** < 20%
- **Operating Humidity:** < 80% non-condensing

REGULATORY & VOLUNTARY QUALIFICATIONS

- cULus listed
- DLC qualified
- Suitable for damp locations

Photometry

CS14
CS14-40LHE-40K-10v



Coefficients Of Utilization

RCC %:	80			
RW %:	70	50	30	0
RCR: 0	119	119	119	119
1	108	104	99	95
2	98	90	83	77
3	89	79	70	64
4	82	69	60	54
5	75	62	53	46
6	69	55	46	40
7	64	50	41	35
8	59	46	37	31
9	55	42	33	28
10	52	38	30	25

Effective Floor Cavity Reflectance: 20%

Average Luminance Table (cd/m2)

Vertical Angle	Horizontal Angle 0°	45°	90°
45°	874	1005	1030
55°	711	828	816
65°	516	578	504
75°	288	225	195
85°	48	64	73

Zonal Lumen Summary

Zone	Lumens	Luminaire
0-30	1,027	25.00%
0-40	1,722	41.90%
0-60	3,194	77.80%
0-90	4,077	99.20%
0-180	4,100	100%

Reference www.cree.com/lighting for detailed photometric data.

www.cree.com/lighting T (800) 236-6800 F (262) 504-5415

CREE®

B. CR24

CR24™

2'x4' Architectural LED Troffer

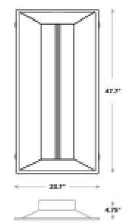
Product Description

The CR24 Architectural LED High Efficiency (HE) troffer delivers up to 130 lumens per watt of exceptional 90 CRI light at 4000 lumens. This breakthrough performance is achieved by combining the high efficacy and high-quality light of Cree TrueWhite® Technology with a unique thermal management design. The CR24 High Definition (HD) option delivers enhanced spectrum 80+ CRI color quality. The CR24 product family is available in warm, neutral, cool, or daylight color temperatures and has step, 0-10V, or Lutron EcoSystem® Enabled dimming options. Its compact, lightweight design makes the CR24 perfect for use in commercial new construction or renovated spaces.

Performance Summary

- Utilizes Cree TrueWhite® Technology
- Active Color Management
- Room-Side Heat Sink
- Assembled in the US & Mexico
- **Efficacy**: 90-130 LPW
- **Delivered Light Output**: 2200, 3100, 4000, 5000 lumens
- **Input Power**: 22-50 watts
- **CRI**: 80-90
- **CCT**: 3000K, 3500K, 4000K, 5000K
- **Input Voltage**: 120-277 VAC
- **Warranty**: 10 years
- **Lifetime**: Designed to last from 50,000 hours up to 100,000 hours with HE Option
- **Controls**: Step Level to 50%, 0-10V Dimming or Lutron EcoSystem Enabled to 5%
- **Mounting**: Recessed

CR24



NOTE: Use of Expanded Junction Box will expand the depth to 6.67" and Emergency Backup will expand the depth to 6.20".

Housings & Accessories

Accessories			
CPLCR Chicago Plenum Field Kit **CPLCR-EM** Chicago Plenum Field Kit-Emergency	**CR-347V** 347 Volt **CR-347V-SD** Step Dimming to 50% **SMK-24** Surface Mount Kit	**PW-18/4-06-9T/55-CR** Power Whip **AC5-18/4-72-PD8-JB** Adjustable Cable	**AC5-72-PD8-JB** Adjustable Cable **EJBCR-5PK** Expanded size junction box for through wiring (5 pack)

Ordering Information

Example: CR24-40L-35K-S

CR24					
Product	**Lumen Output**	**Color Temp**	**Voltage**	**Control**	**Options**
CR24	**22L** 22W 2200 lumens – 100 LPW **31L** 34W 3100 lumens – 90 LPW **40L** 40W 4000 lumens – 100 LPW **40L HE** 30.5W 4000 lumens – 130 LPW (30K) 32W 4000 lumens – 125 LPW (35K) 33W 4000 lumens – 120 LPW (40K) 34.5W 4000 lumens – 115 LPW (50K) **50L** 50W 5000 lumens – 100 LPW	**30K** 3000 Kelvin **35K** 3500 Kelvin **40K** 4000 Kelvin **50K** 5000 Kelvin	**Blank** 120-277 Volt (Standard)	**S** Step Dimming to 50% **10V** 0-10V Dimming to 5% **LES** Lutron EcoSystem® Enabled to 5%	**HD**[6] High Definition Color - CRI 80+ (44W 4000 lumens - 90 LPW) **EB14**[2,4] Emergency Backup - 1400 lumens **EB14 SMK**[3,5] Emergency Backup with surface mount kit - 1400 lumens

1. Reference www.cree.com/lighting for recommended dimming control options. 2. Not available with 50L or LES option. 3. Not available with EB14 option. Use EB14 SMK. 4. EB14 not for use with SMK Kits 5. Includes surface mount kit accessory (SMK-CR24). 6. HD only available in 40L. Suggested MSRP for the adder over the standard CR Series fixture for the Lutron EcoSystem® Enabled feature is $49. *See www.cree.com/lighting for warranty terms.

US: www.cree.com/lighting T (800) 236-6800 F (262) 504-5415
Canada: www.cree.com/canada T (800) 473-1234 F (800) 890-7507

CR24™

Product Specifications

CREE TRUEWHITE® TECHNOLOGY
A revolutionary way to generate high-quality white light, Cree TrueWhite® Technology mixes the light from the highest performing red and unsaturated yellow LEDs. This patented approach delivers an exclusive combination of 90+ CRI, beautiful light characteristics, and lifelong color consistency, all while maintaining high luminous efficacy—a true no compromise solution.

ROOM-SIDE HEAT SINK
An innovative thermal management system designed to maximize cooling effectiveness by integrating a unique room-side heat sink into the diffusing lens. This breakthrough design creates a pleasing architectural aesthetic while conducting heat away from LEDs in a temperature-controlled environment. This enables the LEDs to consistently run cooler, providing significant boosts to lifetime, efficacy, and color consistency.

LUMEN MAINTENANCE FACTORS
- Reference www.cree.com/lighting for detailed lumen maintenance factors.

CONSTRUCTION & MATERIALS
- Durable 20-gauge steel housing with standard troffer access plate for electrical installation.
- Field replaceable light engine integrates LEDs, driver, power supply, thermal management, and optical mixing components.
- One-piece lower reflector finished with a textured high reflectance white polyester powder coating creates a comfortable visual transition from the lens to the ceiling plane.
- Provided t-bar clips and holes for mounting support wires enable recessed or suspended installation.
- Individual fixtures may be mounted end to end for a continuous row of illumination.

NOTE: Reference www.cree.com/lighting for detailed instructions on field replacement of the light engine.

OPTICAL SYSTEM
- Unique combination of reflective and refractive optical components achieves a uniform, comfortable appearance while eliminating pixelation and color fringing.
- Components work together to optimize distribution, balancing the delivery of high illuminance levels on horizontal surfaces with an ideal amount of light on walls and vertical surfaces. This increases the perception of spaciousness.
- Diffusing lens integrated with upward-facing LED strip eliminates direct view of LEDs while lower reflector balances brightness of lens with the ceiling to create a low-glare high angle appearance.

ELECTRICAL SYSTEM
- Integral, high-efficiency driver and power supply.
- **Power Factor** = 0.9 nominal
- **Input Power**: Stays constant over life.
- **Input Voltage**: 120V-277V, 50/60Hz
- **Battery Backup**: Consult factory.
- **Temperature Rating**: Designed to operate in temperatures 0-35 C and below room side and plenum side.
- **Total Harmonic Distortion**: < 20%

CONTROLS
- Step dimming to 50% comes standard.*
- Optional continuous dimming to 5% with 0-10V DC control protocol.*
- Optional Lutron EcoSystem® Enabled option allows seamless integration with Lutron EcoSystem controls.*

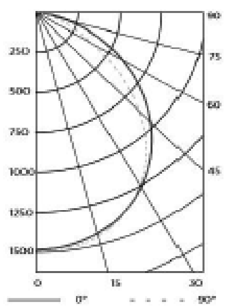
REGULATORY & VOLUNTARY QUALIFICATIONS
- UL924 (EB14 option).
- cULus Listed.
- DLC qualified.**
- Suitable for damp locations.
- Designed for indoor use.

*Reference www.cree.com/lighting for recommended dimming controls and wiring diagrams.
**Does not apply to -LES models.

US: www.cree.com/lighting T (800) 236-6800 F (262) 504-5415

Photometry

CR24-4000L BASED ON ITL REPORT TEST #: 22421
Fixture photometry has been conducted by a NVLAP accredited testing laboratory in accordance with IESNA LM-79-08. IESNA LM-79-08 specifies the entire luminaire as the source resulting in a fixture efficiency of 100%.



Coefficients Of Utilization

RCC %:	80			
RW %:	70	50	30	0
RCR: 0	119	119	119	119
1	109	105	101	97
2	100	92	85	79
3	91	80	72	66
4	83	71	63	56
5	76	64	55	48
6	71	57	48	42
7	65	52	43	37
8	61	47	39	33
9	57	43	35	30
10	53	40	32	27

Effective Floor Cavity Reflectance: 20%

Average Luminance Table (cd/m2)

Vertical Angle	Horizontal Angle 0°	45°	90°
0°	2174	2174	2174
45°	1976	2116	2152
55°	1807	2018	2074
65°	1553	1889	1879
75°	1149	1501	1119
85°	424	62	62

Zonal Lumen Summary

Zone	Lumens	% Lamp	Luminaire
0-30	1,116	27.9%	27.9%
0-40	1,835	45.9%	45.9%
0-60	3,245	81.1%	81.1%
0-90	4,000	100%	100%

Reference www.cree.com/lighting for detailed photometric data.

Application Reference

Open Space					
Spacing	Lumens	Wattage	LPW	w/ft²	Average fc
8 x 8	2200L	22W	100	0.35	30
	4000L	40W	100	0.69	54
	4000L	30.5W	130	0.56	54
	5000L	50W	100	0.78	68
8 x 10	2200L	22W	100	0.28	25
	4000L	40W	100	0.55	45
	4000L	30.5W	130	0.45	45
	5000L	50W	100	0.62	57
10 x 10	2200L	22W	100	0.22	21
	4000L	40W	100	0.44	38
	4000L	30.5W	130	0.36	38
	5000L	50W	100	0.50	48
10 x 12	2200L	22W	100	0.19	17
	4000L	40W	100	0.37	30
	4000L	30.5W	130	0.30	30
	5000L	50W	100	0.42	38

9' ceiling: 80/50/20 reflectances; 2.5' workplane, open room. LLF: 1.0 initial.
Open Space: 50' x 40' x 10'

Rev. Date 3/14/2013

Canada: www.cree.com/canada T (800) 473-1234 F (800) 890-7507

C. CR-LE

CR-LE

1'x4' or 1'x2' LED Light Engine

Product Description

The CR-LE LED light engine delivers up to 130 lumens per watt of exceptional 90 CRI light at 4000 lumens. This breakthrough performance is achieved by combining the high efficacy and high-quality light of Cree TrueWhite® Technology with a unique thermal management design. The CR22 High Definition (HD) option delivers enhanced spectrum 80+ CRI color quality. The CR-LE product family is available in warm, neutral, cool, or daylight color temperatures and has step, 0-10V, or Lutron EcoSystem® Enabled dimming options. Its compact, lightweight design easily accommodates recessed, surface mount, or suspended installations, making the CR-LE perfect for use in commercial new construction or renovated spaces.

Performance Summary

Utilizes Cree TrueWhite® Technology
Active Color Management
Room-Side Heat Sink
Assembled in the US & Mexico
Efficacy: 90-130 LPW
Delivered Light Output: 2000, 2200, 3100, 3200, 4000, 5000 lumens
Input Power: 22-50 watts
CRI: 80-90
CCT: 3000K, 3500K, 4000K, 5000K
Input Voltage: 120-277 VAC
Warranty: 10 years
Lifetime: Designed to last from 50,000 hours up to 100,000 hours with HE Option
Dimming: Step Level to 50%, 0-10V Dimming or Lutron EcoSystem Enabled to 5%
Mounting: Recessed

CR-LE (1'x4')

CR-LE (1'x2')

NOTE: Use of Expanded Junction Box will expand the depth to 6.67" and Emergency Backup will expand the depth to 6.30".

Ordering Information

Example: CR-LE-40L-35K-S

CR-LE					
Product	**Lumen Output**	**Color Temp.**	**Voltage**	**Control**	**Options**
CR-LE	**20L (1x2)** 22W 2000 lumens - 90 LPW **32L (1x2)** 32W 3200 lumens - 100 LPW **22L (1x4)** 22W 2200 lumens - 100 LPW **31L (1x4)** 34W 3100 lumens - 90 LPW **40L (1x4)** 40W 4000 lumens - 100 LPW **40L HE (1x4)** 30.5W 4000 lumens - 130 LPW (30K) 32W 4000 lumens - 125 LPW (35K) 33W 4000 lumens - 120 LPW (40K) 34.5W 4000 lumens - 115 LPW (50K) **50L (1x4)** 50W 5000 lumens - 100 LPW	**30K** 3000 Kelvin **35K** 3500 Kelvin **40K** 4000 Kelvin **50K** 5000 Kelvin	**Blank** 120-277 Volt (Standard)	**S** Step Dimming to 50% **10V** 0-10V Dimming to 5% **LES** Lutron EcoSystem® Enabled to 5%	**HD**[5] High Definition Color - CRI 80+ 35W 3200 lumens - 90 LPW 44W 4000 lumens - 90 LPW **EB14**[3] Emergency Backup - 1400 lumens **EB14 SMK**[4] Emergency Backup with surface mount kit - 1400 lumens

1. Reference www.cree.com/lighting for recommended dimming control options. 2. Not available with EB14 option. Use EB14 SMK. 3. EB14 nor for use with SMK Kits 4. Includes surface mount kit accessory (SMK-LE-L or SMK-LE-S) SMK-LE-EL must be ordered separately. 5. HD only available in 32L or 40L. Suggested MSRP for the adder over the standard CR Series fixture for the Lutron EcoSystem® Enabled feature is $49. *See www.cree.com/lighting for warranty terms.

CR-LE

Product Specifications

CREE TRUEWHITE® TECHNOLOGY
A revolutionary way to generate high-quality white light, Cree TrueWhite® Technology mixes the light from the highest performing red and unsaturated yellow LEDs. This patented approach delivers an exclusive combination of 90+ CRI, beautiful light characteristics, and lifelong color consistency, all while maintaining high luminous efficacy—a true no compromise solution.

ROOM-SIDE HEAT SINK
An innovative thermal management system designed to maximize cooling effectiveness by integrating a unique room-side heat sink into the diffusing lens. This breakthrough design creates a pleasing architectural aesthetic while conducting heat away from LEDs in a temperature-controlled environment. This enables the LEDs to consistently run cooler, providing significant boosts to lifetime, efficacy, and color consistency.

LUMEN MAINTENANCE FACTORS
- Reference www.cree.com/lighting for detailed lumen maintenance factors.

CONSTRUCTION & MATERIALS
- Light engine integrates LEDs, driver, power supply, thermal management, and optical mixing components.
- Hanging tabs enable suspended installation.

NOTE: Reference www.cree.com/lighting for detailed instructions on field replacement of the light engine.

OPTICAL SYSTEM
- Unique combination of reflective and refractive optical components achieves a uniform, comfortable appearance while eliminating pixelation and color fringing.
- Components work together to optimize distribution, balancing the delivery of high illuminance levels on horizontal surfaces with an ideal amount of light on walls and vertical surfaces. This increases the perception of spaciousness.
- Diffusing lens integrated with upward-facing LED strip eliminates direct view of LEDs while lower reflector balances brightness of lens with the ceiling to create a low-glare high angle appearance.

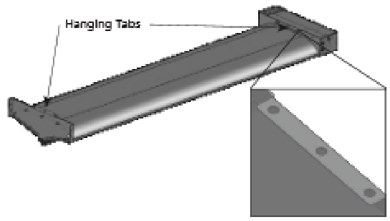
ELECTRICAL SYSTEM
- Integral, high-efficiency driver and power supply.
- **Power Factor** = 0.9 nominal
- **Input Power**: Stays constant over life.
- **Input Voltage**: 120V-277V, 50/60Hz
- **Battery Backup**: Consult factory.
- **Temperature Rating**: Designed to operate in temperatures 0-35C and below room side and plenum side.
- **Total Harmonic Distortion**: < 20%

CONTROLS
- Step dimming to 50% comes standard.*
- Optional continuous dimming to 5% with 0-10V DC control protocol.*
- Optional Lutron EcoSystem® Enabled option allows seamless integration with Lutron EcoSystem controls.*

REGULATORY & VOLUNTARY QUALIFICATIONS
- cULus Listed.
- DLC qualified.**
- Suitable for damp locations.
- Designed for Indoor use.

*Reference www.cree.com/lighting for recommended dimming controls and wiring diagrams.
**Does not apply to -LES models.

Installation

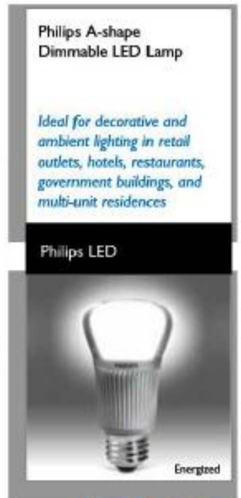


NOTE: Hanging materials not included. Must be purchased separately.

Housings & Accessories

Accessories			
SMK-LE-L² Surface Mount Kit for CR Series 1'x4' Light Engines 2200, 4000 and 5000 lumens	**SMK-LE-EC** End Caps (2 pack, required for all SMK installations, must be ordered separately)	**CR-347V** 347 Volt	**ACS-18/4-72-PD8-JB** Adjustable Cable
SMK-LE-S² Surface Mount Kit for CR Series 1'x2' Light Engines 2000 and 3200 lumens	**SMK-LE-JP** Joiner Plate (optional for continuous row installation)	**CR-347V-SD** Step Dimming to 50%	**ACS-72-PD8-JB** Adjustable Cable
		PW-18/4-06-9T/SS-CR Power Whip	**EJBCR-5PK** Expanded size junction box for through wiring (5 pack)

D. Phillips LED A-Lamp



Attract ve, d mmab e LED a ternat ve to popu ar ncandescents

Philips A-shape Dimmable LED Lamps are the smart LED a ternative to standard incandescent A-shape lamps. The uni que amp design provides omni-directional light w th excellent dimming performance.

High efficacy LED accent light

- First 60W incandescent equivalent A 9 LED bulb to be ENERGY STAR® Qualified
- New 8W design is ENERGY STAR® Qualified, and replaces a 40W incandescent equivalent A 9 LED bulb
- 7W A2 ENERGY STAR® Qualified bulb replaces a 75W standard incandescent equivalent A2 bulb**
- 22W A2 bulb replaces a 00W standard incandescent equivalent A2 bulb†
- Smooth dimming to 0% of full light levels*
- 25,000 hour rated average life[2]
- Emits virtually no UV/IR light in the beam
- Contains no mercury
- Remote phosphor (yellow) disappears when energized to create even, soft, white light

Easy to experience

- Long life properties—lowers maintenance costs by reducing re-lamp frequency
- Will not fade colors, avoids inventory spoilage
- 3-year or 5-year limited warranty depending upon operating hours

(2, *, **, † See back page for footnotes)

PHILIPS

Philips A-shape Dimmable LED Lamp

Ordering, Electrical and Technical Data (Subject to change without notice)

Product Number	Ordering Code	Nom. Watts	Volts	Lamps per SKU	Description	Bulb Type	Base	Rated Avg. Life (Hrs.)²	Approx. Lumens³	CRI	Color Temp. (Kelvin)	MOL (In.)
A 9												
■ 4 483-9	8A 9/END/2700-470 DIM 6/	8	120		20V Philips LED Dimmable 8W A 9	A 9	Med.	25,000	470	8	2700	4.3
■ 40994-6	12A 9/END/2700-800 DIM 6/	2.5	120		20V Philips LED Dimmable 2W A 9	A 9	Med.	25,000	800	80	2700	4.2
A21												
■ 4 859-0	17A2 /END/2700-1 00 DIM 6/	7	120		20V Philips LED Dimmable 7W A2	A2	Med.	25,000	00	80	2700	4.8
42352-5	22A2 /END/2700 DIM	22	120		20V Philips LED Dimmable 22W A2	A2	Med.	25,000	780	80	2700	4.8

Shipping Data (Subject to change without notice)

Product Number	SKU UPC (0-46677)	Outer Bar Code (5-00-46677)	Case Qty.	Case Weight (lbs.)	Case Cube (cu. ft.)	Pallet Qty.	SKUs Per Layer	Layers High	SKU Dimensions (W x D x H)(In.)	Case Dimensions (W x D x H)(In.)	Pallet Dimensions (W x D x H)(In.)
A19											
4 483-9	4 483-2	4 483-7	6	2.45	0. 3	1224	204	6	2.72 x 2.72 x 4.80	8.40 x 5.60 x 4.80	47.20 x 39.40 x 34.90
40994-6	40994-4	40994-2	6	3.27	0. 55	1224	204	6	2.72 x 2.72 x 4.80	5.83 x 8.62 x 5.3	39.40 x 47.20 x 35.00
A21											
4 859-0	4 859-5	4 859-0	4	0.843	0.297	384	96	4	4.02 x 3.23 x 7.87	4.92 x 4.02 x 8.62	39.97 x 47.24 x 40.20
42352-5	42335-3	42335-8	4	0.843	0.297	384	96	4	4.02 x 3.23 x 7.87	4.92 x 4.02 x 8.62	39.97 x 47.24 x 40.20

) When comparing this 8W LED A 9 having 470 lumens to the standard 40W incandescent A 9 having 400 lumens.
2) Rated average life is based on engineering testing and probability analysis.
3) Based on photometric testing consistent with IES LM-79.
* Dimmable when using leading edge dimmers (see Philips Website: www.philips.com/ledtechguide for compatible leading edge dimmers).
** When comparing this 7W LED A2 having 00 lumens to the standard 75W incandescent A2 having 00 lumens.
† When comparing this 22W Philips LED A2 having 780 to the standard 00W incandescent A2 having 440 lumens.
■ This lamp is ENERGY STAR® Qualified.

Energy Efficiency

Estimated Lighting Costs Using a Standard 100W Incandescent A21 Lamp			
Present Wattage		00	W
x Annual Operating Hours		4,000	hrs
	=	400,000	watt-hours
÷ 1,000	=	400	kWh per year
x kWh rate of $0.	=	$44.00	per year
x 00 lamps per space	=	$4,400	annual energy cost per space
Estimated Lighting Costs Using a Philips 22W Philips A21 LED Lamp			
Present Wattage		22	W
x Annual Operating Hours		4,000	hrs
	=	88,000	watt-hours
÷ 1,000	=	88	kWh per year
x kWh rate of $0.	=	$9.68	per year
x 00 lamps per space	=	$968	annual energy cost per space
Total Estimated Annual Savings¹	=	$3,432.00	

¹ Based on 00 lamps per space operating at 4,000 hours per year.

This energy saving example shows an application of 00 lamps in a space currently using 00 incandescent 00W, 780 lumen A2 lamps, operating 4,000 hours per year at a cost of $0. per kWh.† Your actual savings may vary depending on the energy costs in your geographic location.

Replacing 00 standard incandescent 00W 780 lumen A-lamps with Philips 22W Philips LED A2 lamps can provide significant energy cost savings of $3,432.00 per year! Potential savings from the reduction in HVAC costs as a result of using a lower wattage lamp that emits less heat is an additional benefit not included in this example.

† Light output of the 22W Philips A21 1780 lumens compares to the 100W standard incandescent A21 at 1780 lumens

WARNINGS AND CAUTIONS
- Suitable for damp locations.
- Not for use in totally enclosed luminaires (fixtures).
- This device is not intended for use with emergency exit fixtures or emergency lights.
- Before replacing, turn off power and let lamp cool to avoid electrical shock or burn.

CAUTION: Risk of electric shock. Do not use where directly exposed to water.

NOTES: This device complies with Part 5 of the FCC Rules. Operation is subject to the following two conditions: ( ) This device may not cause harmful interference, and (2) This device must accept any interference that may cause undesired operation. This Class B digital apparatus complies with Canadian ICES-003.

c UL us LISTED LED LAMPS 3PMS E326184

PHILIPS

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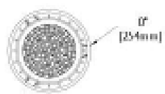
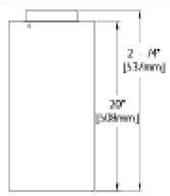
E. CREE ESA

Rev. Date: 0 / /I 2

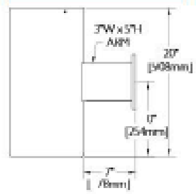
ESA-C 0-MD- -56 Essentia® LED Downlight - Cylinder - Medium



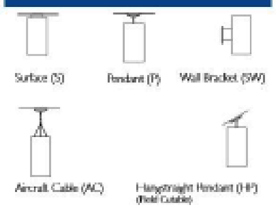
SURFACE MOUNT



WALL BRACKET



MOUNTING



FAMILY	PRODUCT	OPTIC	MOUNTING	LED COUNT (# OF LEDS)	SERIES	VOLTAGE	COLOR	REFLECTOR/ CONE FINISH[3]	DRIVE CURRENT	OPTIONS Please type additional options in manually on the lines provided below
ESA	**C 0**	**MD**		**56**	**D**	**U**				
Essentia	0" Cylinder	Medium	**S** Surface	56	D	Universal 20-277V	**BK** Black	**SSGC** Clear	**525** 525mA	**LM** Lens Media
			P Pendant[1]				**BZ** Bronze	**SSGGR** Graphite	**700** 700mA	**FS** Fusing
			SW Wall Bracket				**CS** Camaro Silver	**SSGBR** Bronze		**27K** 2700K[4]
			HP Hangstraight Pendant[2]				**WH** White	**SSGCG** Champagne Gold		**30K** 3000K[4]
			AC 5' Aircraft Cable					**SSGPE** Pewter		**40K** 4000K[4]
			AC2 0' Aircraft Cable					**SSGWH** Wheat		
			AC3 5' Aircraft Cable					**SSGB** Black		
								W White		

FOOTNOTES

. 24" standard, consult factory for other lengths
2. 24" standard; 45° max slope, field cutable (consult factory for other lengths)
3. SSG = Soft Satin Glow Anti-iridescent
4. Color temperature per fixture; 3500K Standard

LED PERFORMANCE SPECS

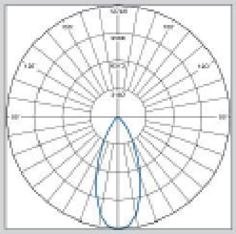
# OF LEDS	INITIAL DELIVERED LUMENS						SYSTEM WATTS 20-277V	TOTAL CURRENT				L70 HOURS* @ 25°C (77°F)	50K HOURS LUMEN MAINTENANCE FACTOR @ 25°C (77°F)
	@ 3500K/ 4000K	@ 3500K/ 4000K with Lens Media	@ 3000K	@ 3000K with Lens Media	@ 2700K	@ 2700K with Lens Media		@ 20V	@208V	@240V	@277V		
525mA FIXTURE OPERATING AT 25°C (77°F) - *0-10V Dimming Standard*													
56	5432	48 8	4074	36 4	3748	3324	00	0.84	0.48	0.4	0.36	38,000	90%
700mA FIXTURE OPERATING AT 25°C (77°F) - *0-10V Dimming Standard*													
56	6868	6092	5 5	4569	4739	4203	34	. 4	0.66	0.58	0.52	5,000	88%

* For recommended lumen maintenance factor data see: TD- 4

Rev. Date: 0 / / /

ESA-C 0-MD- -56 Essentia® LED Downlight - Cylinder - Medium

PHOTOMETRICS



ESAC 0MDS56DUWH700SSGC35K

LED Count	56
Efficacy	52 Lm/W
S/M	0.70
Color Temperature	3500K
Drive Current	700mA
Delivered Lumens	6945

Test Number:
ESAC 0MDS56DUWH700SSGC35K

LUMINANCE DATA

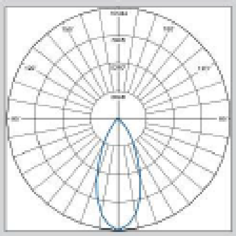
Vertical Angle	Average
45°	3473
55°	293
65°	0
75°	0
85°	0

CONE OF LIGHT

Distance from Workplane	Footcandles	Beam Diameter
6'	333	2. '
8'	87	2.8'
0'	20	3.5'
2'	83	4.2'
4'	6	4.9'

CANDELA DISTRIBUTION

Degrees	CD
0°	992
5°	735
5°	8828
25°	4799
35°	574
45°	24
55°	9
65°	0
75°	0
85°	0
90°	0



ESAC 0MDS56DUWH700SSGC35KLM

LED Count	56
Efficacy	47 Lm/W
S/M	0.70
Color Temperature	3500K
Drive Current	700mA
Delivered Lumens	6300

Test Number:
ESAC 0MDS56DUWH700SSGC35KLM

LUMINANCE DATA

Vertical Angle	Average
45°	0686
55°	4594
65°	23 6
75°	493
85°	0

CONE OF LIGHT

Distance from Workplane	Footcandles	Beam Diameter
6'	279	2. '
8'	57	2.8'
0'	00	3.5'
2'	70	4. '
4'	5	4.9'

CANDELA DISTRIBUTION

Degrees	CD
0°	0035
5°	96 9
5°	7353
25°	4022
35°	553
45°	383
55°	34
65°	50
75°	6
85°	0
90°	0

COLOR QUALITY COMMITMENT

COLOR TOLERANCE

Nominal CCT	CCT	CRI	R9
2700K	2755 +/- 42K	90 min	50
3000K	2993 +/- 50K	90 min	50
3500K	3388 +/- 63K	80 min	40
4000K	3899 +/- 75K	80 min	40

The needs and concerns regarding color quality, consistency and stability as they relate to interior spaces are paramount to a successful interior lighting design. Cree is committed to delivering the color-quality performance that meets or exceeds the expectations of best-in-class traditional light source technologies.

Cree Essentia luminaire's initial color consistency to be within a 2-step MacAdam Ellipse from the initial specified color point.

We are committed to providing luminaire color point stability over time, within a 2-step MacAdam Ellipse to the predicted L_{70} point (in hours) for all products. BetaLED® NanoOptic® Technology enables color spatial uniformity that meets requirements demanded by the most discerning lighting designers.

GENERAL DESCRIPTION

Ten-inch cylinder downlight designed for 56 high output LEDs. Two piece optical assembly provides a broad, even light distribution, combining low brightness with maximum visual cutoff and efficiency. Five light distributions available – narrow pin, narrow spot, narrow, medium, and wide.

FEATURES

- Luminaire uses 56 high output LEDs, 3500K standard, tolerance to be within a 2-step McAdam Ellipse. See table for specific color tolerance (below).
- Axial and Tilted Axial TIR NanoOptic on each individual LED to maximize light delivered through aperture.
- Provides 45° visual cutoff to source.
- Light distribution available in narrow pin, narrow spot, narrow, medium, or wide.
- Low brightness parabolic spun Alzak aluminum cone, 0.06" thick with polished radius and continuous self-flange.
- Precision nickel plated cone retainers assure that the lower cone is held in position.
- Custom extruded aluminum heatsink.
- Flow-Thru design to maximize cooling of LEDs.
- Heavy-wall aluminum housing.
- Surface, pendant, wall, or cable mounting.

ELECTRICAL

- High Efficiency constant current driver(s), 20-277VAC input, 50/60Hz, 525mA or 700mA drive current.
- 0- 0V dimming standard. 00%- 0% full-range continuous dimming.
- LED drivers have power factor>90% and THD <20% at full load.

TESTING & COMPLIANCE

UL listed in the U.S. and Canada for damp locations. RoHS compliant.

FINISH

Exclusive Colorfast DeltaGuard® finish features an E-Coat epoxy primer with an ultra-durable powder topcoat, providing excellent resistance to corrosion, ultraviolet degradation and abrasion. Bronze, black, white and camaro silver* powder topcoats are available. The finish is covered by our 0 year limited warranty.

* One year warranty

PATENTS

U.S. and international patents granted and pending. For a listing of patents, visit www.uspto.gov.

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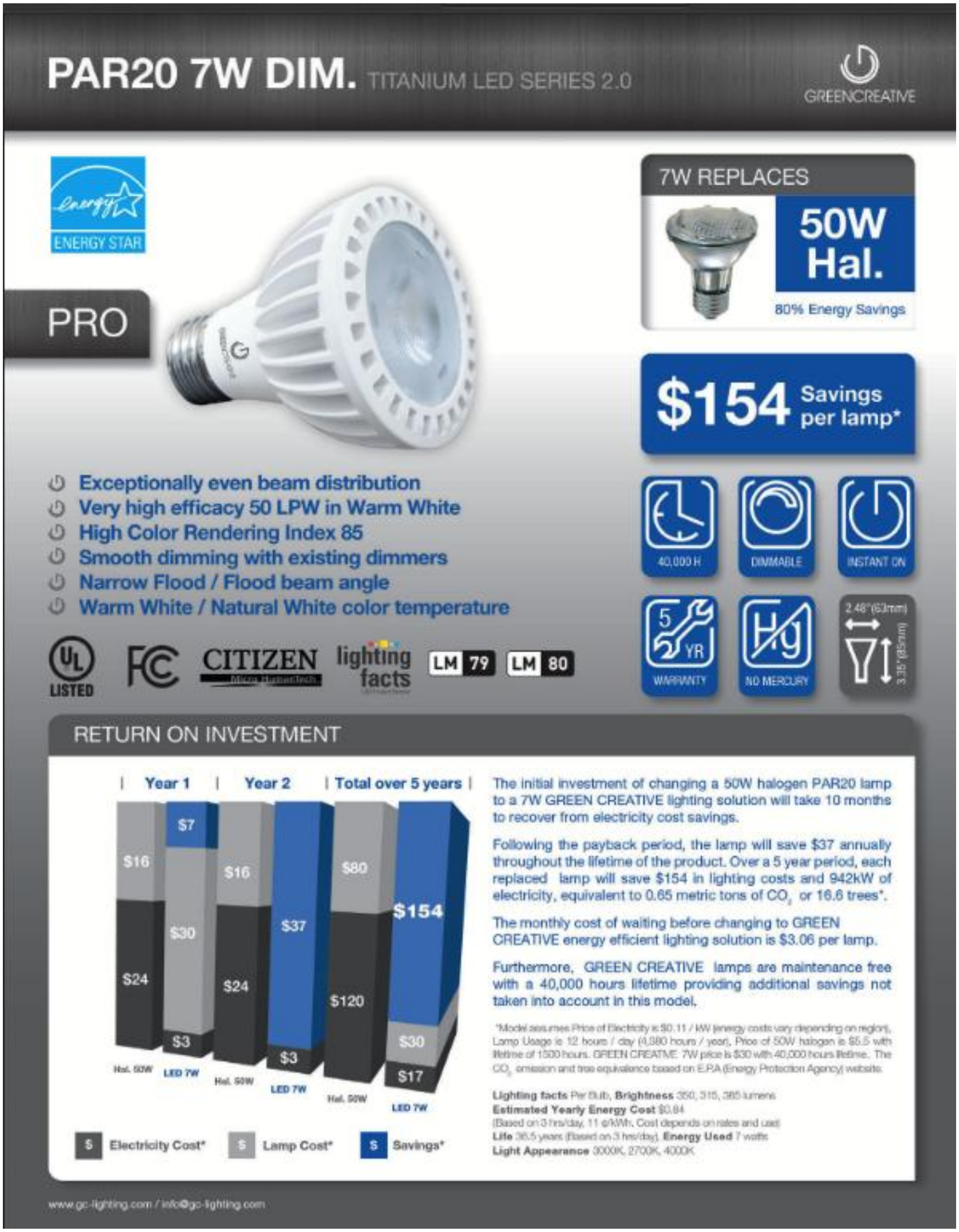
Made in the U.S.A. of U.S. and imported parts. Meets Buy American requirements within the ARRA.

BetaLED® TECHNOLOGY

F. Green Creative PAR20



PAR20 7W DIM. TITANIUM LED SERIES 2.0

GREENCREATIVE

APPLICATIONS

ILLUMINANCE

SPECIFICATIONS

Product Model	95286 01-704-D/830-25D	95286 01-704-D/830-40D	95288 01-704-D/827-40D	95290 01-704-D/840-40D
Nominal Desc.	7PAR20/TIT/DIM/830/NF25	7PAR20/TIT/DIM/830/FL40	7PAR20/TIT/DIM/827/FL40	PAR20/TIT/DIM/840/FL40
Type	PAR20	PAR20	PAR20	PAR20
Base	Medium E26	Medium E26	Medium E26	Medium E26
Power (W)	7	7	7	7
Voltage - Frequency	120V 60Hz	120V 60Hz	120V 60Hz	120V 60Hz
Color Temp. (ANSI)	Warm White 3000K	Warm White 3000K	Warm White 2700K	Natural White 4000K
CRI (Ra)	85	85	85	85
Typical lumens (lm)	350	350	310	385
Efficacy (LPW)	50	50	45	55
Beam Angle	NF 25°	FL 40°	FL 40°	FL 40°
CBCP (cd)	1180	595	540	660
Dimmable	Yes*	Yes*	Yes*	Yes*
Power Factor	0.7	0.7	0.7	0.7
Rated Lifetime - L70 (hrs.)	40,000	40,000	40,000	40,000
Weight (lb./g)	0.29 lb. / 132g	0.29 lb. / 132g	0.29 lb. / 132g	0.29 lb. / 132g

* Dimmable with most dimmer switch. List of tested dimmer switch available on our website

www.gc-lighting.com / info@gc-lighting.com

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