A Comprehensive Store Retrofit to LED lighting in Common Lighting Applications

*ET Project Number: ET12PGE1481*

![Photo Credit: CREE, Inc.](image)

**Project Manager:** Chris Corcoran
Phil Broaddus
Pacific Gas and Electric Company

**Prepared By:** Teddy Kisch, LC
Jeff Steuben
Michelle van Tijen
Terrance Pang

Energy Solutions
1610 Harrison St
Oakland, CA 94612

**Issued:** September 18, 2013

**Updated:** March 13, 2014

© Copyright, 2014, Pacific Gas and Electric Company. All rights reserved.
ACKNOWLEDGEMENTS

Pacific Gas and Electric Company’s Emerging Technologies Program is responsible for this project. It was developed as part of Pacific Gas and Electric Company’s Emerging Technology - Technology Assessments program under internal project number ET12PGE1481. Energy Solutions conducted this technology evaluation for Pacific Gas and Electric Company with overall guidance and management from Chris Corcoran. For more information on this project, contact c5ct@pge.com.

The authors would like to gratefully acknowledge the direction and assistance of Pacific Gas and Electric Company and Fry’s Electronics, Inc. for their participation and support of this project.

LEGAL NOTICE

This report was prepared for Pacific Gas and Electric Company for use by its employees and agents. Neither Pacific Gas and Electric Company nor any of its employees and agents: (1) makes any written or oral warranty, expressed or implied, including, but not limited to those concerning merchantability or fitness for a particular purpose; (2) assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, process, method, or policy contained herein; or (3) represents that its use would not infringe any privately owned rights, including, but not limited to, patents, trademarks, or copyrights.
# Abbreviations and Acronyms

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

Figure 1. Annual Electricity consumption of Lighting in US ...............6
Figure 2. Comparison of Current and Potential LED Source Energy
          Savings for Nine Common Applications ......................8
Figure 3. Computer Sales Measurement Diagram ........................18
Figure 4. Example of AGi32 Model Overhead View with Isolines ....21
Figure 5. Example of AGi32 Model Rendering ..........................21
Figure 6. CLTC Summary of Photometric Report for CREE CS14 ....23
Figure 7. 60W incandescent A Lamps with standard screw base in
          suspended candelabra chandelier ...........................28
Figure 8. Incandescent Halogen PAR Lamp (Left) and LED PAR
          Replacement Lamp (Right) ....................................31
Figure 9. Cumulative LED Replacement Lamps in Lighting Facts
          Database (DOE 2012b) ........................................32
Figure 10. Energy Star Listed Commercial LED Directional
          Downlights and Efficacy Distribution ..........................33
Figure 11. LED Downlight Fixture and Residential Installation
          Example (DOE GATEWAY Demonstration) ......................34
Figure 12. Energy Star Listed Residential and Commercial LED
          Downlights and Efficacy Distribution ..........................35
Figure 13. Philips L Prize LED Lamp Stress Testing Alongside CFL A
          Lamps ..................................................................36
Figure 14. Energy Star Listed LED A Lamps and Efficacy
          Distribution ................................................................37
Figure 15. Example LED Replacement Options for Fluorescents:
          CREE CR Fixture and Upkit and UR Replacement Lamps ..38
Figure 16. Design Lights Consortium LED Qualified Products: LED
          Tubes, Kits, and Integrated Troffers ...........................40
Figure 17. CREE CS14 ......................................................43
Figure 18. Photographic Comparison of Register Area .................45
Figure 19. CREE CR24 ......................................................47
Figure 20. Break Room Base case Model ..................................50
Figure 21. Break Room Retrofit Model ....................................51
Figure 22. Photographic Comparisons of Break Room .........52
Figure 23. Retrofit Rendering of Break Room .........................52
Figure 24. CREE CR-LE ....................................................54
Figure 25. Base case and LED Retrofit Model of Restroom .......57
Figure 26. Base case and LED Retrofit Model of Auto install ............ 58
Figure 27. Photographic Comparison of Auto Install Garage .......... 59
Figure 28. Retrofit Rendering of Restroom ................................. 59
Figure 29. Retrofit Rendering of Auto Install Garage ................. 60
Figure 30. Philips 12W A19 Lamp ........................................... 61
Figure 31. Photographic Comparison of Checkout Incandescent area ....................................................... 62
Figure 32. CREE ESA ...................................................... 64
Figure 33. Base case and Retrofit Model of Customer Service Area ... 66
Figure 34. Photographic Comparison of Computer Sales Area ....... 67
Figure 35. Photographic Comparison of Customer Service Area ..... 67
Figure 36. Retrofit Rendering of Customer Service Area .......... 68
Figure 37. Green Creative 7W PAR20 ................................... 69
Figure 38. Base case and LED Retrofit Model of Audio Room ....... 71
Figure 39. Photographic Comparison of Audio Room ................... 72
Figure 40. Retrofit Rendering of Audio Room ............................ 72
Figure 41. Unevenly Distributed base case fixtures vs. LED retrofit ... 77
Figure 42. Lamp Distribution by Commercial Building Type 2010 ..... 96

TABLES

Table 1. US Prevalence of LED Sources in Select Lighting Applications ................................................................. 7
Table 2. Measurement Height by Area ................................................................. 18
Table 3. Sample Color Gradient of Illuminance Measurements ....... 19
Table 4. Study Instrumentation ................................................................. 25
Table 5. CREE CR24 LED Troffers (CR24-40L-40K, CR24-40LHE-40K) ................................................................. 26
Table 6. CREE CS14 LED Troffers (CS14-40LHE-40K) ....................... 27
Table 7. Philips EnduraLED 12W A Lamp ............................................ 28
Table 8. CREE Essentia 75W LED Downlight (ESA-C10-WD-42-D) ... 29
Table 9. CREE Essentia 100W LED Downlight (ESA-C10-MD-56-D) .. 29
Table 10. Titanium Series 2.0 LED PAR20 7W Dim
(GC.7PAR20TITDIM830FL40) ......................................................... 30
Table 11. Efficacies and Color Rendering Ability of Base case Lighting Technologies ........................................... 30

Table 12. Design Light Consortium Lighting Quality Requirements for LED Fluorescent Replacement Products .................................. 39

Table 13. Base Case vs. Retrofit Wattage ....................................................... 41

Table 14. Power Measurements: CREE CS14 and Linear Fluorescent Base case .............................................. 43

Table 15. Illuminance Measurements: CREE CS14 and linear Fluorescent Base case .............................................. 44

Table 16. Measured Color Correlated Temperature ...................................................... 44

Table 17. Measured Color Correlated Temperature ...................................................... 45

Table 18. Photometric Field Measurements of Break Room .............................................. 48

Table 19. Photometric Field Measurements of Break Room .............................................. 49

Table 20. Color Correlated Temperature of Break Room .............................................. 51

Table 21. Power Measurements of restroom ....................................................... 55

Table 22. Power Measurements of Auto Install Garage .............................................. 55

Table 23. Photometric Field Measurements of Restroom (Footcandles) .............................................. 56

Table 24. Photometric Field Measurements of Auto Install Garage (Footcandles) .............................................. 56

Table 25. Correlated Color Temperature of Restroom ...................................................... 58

Table 26. Power Measurements of Register Area ...................................................... 61

Table 27. Photometric Field Measurements of Computer Sales Area (footcandles) .............................................. 65

Table 28. Photometric Field Measurements of Customer Service Area (Footcandles) .............................................. 65

Table 29. Correlated Color Temperature of Computer Sales Area and Customer Service Area .............................................. 66

Table 30. Power Measurements of Register Area ...................................................... 69

Table 31. Photometric Field Measurements of Audio Room .............................................. 70

Table 32. Correlated Color Temperature of Audio Room .............................................. 72

Table 33. Power Factor Comparison ....................................................... 74

Table 34. Total Harmonic Distortion Comparison ...................................................... 75

Table 35. Average Illumination (Footcandles) ...................................................... 75

Table 36. Illuminance Avg/Min Ratios ....................................................... 76

Table 37. Color Rendering Index (CRI) ...................................................... 78

Table 38. Project Energy savings and peak demand reduction (qualifying equipment only) .............................................. 83
Table 39. Project Energy savings and peak demand reduction (storewide retrofit)........................................83

Table 40. Financial analysis of product costs for LEDA eligible equipment (not including installation)..........................83

Table 41. Financial analysis of Project costs for LEDA eligible equipment (including installation costs and maintenance savings).................................................................84

Table 42. Financial analysis of Project costs for the Storewide retrofit, Including installation costs and maintenance savings........................................................................................................84

Table 43. Cash flow analysis of LEDA eligible equipment (excluding maintenance savings)........................................86

Table 44. Cash flow analysis of LEDA eligible equipment (including maintenance savings)........................................86

Table 45. Lamp Distribution by commercial building type in 2010 (DOE 2012a) .................................................................87
# Contents

**Abbreviations and Acronyms** ................................................................. II  
**Figures** ........................................................................................................ III  
**Tables** .......................................................................................................... IV  
**Contents** ...................................................................................................... VII  

**Executive Summary** ....................................................................................... 1  
  Project Results.................................................................................................. 2  
  Summary of Findings: ...................................................................................... 2  

**Introduction** .................................................................................................. 6  

**Assessment Objectives** .................................................................................. 11  
  Scaled Field Placement: Definition and Intent .............................................. 11  

**Technical Approach/Test Methodology** ......................................................... 13  
  Field Testing of Technology ......................................................................... 13  
  Test Plan .......................................................................................................... 13  
  Methodology .................................................................................................... 14  
  Energy Savings and Economic Impacts Assessment .................................. 22  
  Decision Making and Satisfaction Survey .................................................. 23  
  Laboratory Photometric Testing ................................................................. 23  
  Instrumentation Plan ...................................................................................... 24  

**Product Background** .................................................................................... 26  
  General Service Lighting: Linear Fluorescent ............................................. 26  
  General Service Lighting: Incandescent ...................................................... 27  
  Downlighting: High Intensity Discharge .................................................... 28  
  Directional Lighting: Parabolic Aluminized Reflector (PAR) ................. 29  
  Base case Technology Performance ............................................................ 30  

**Product Results** ............................................................................................. 41  
  General service fluorescent lighting: CREE CS14 ................................. 43  
  General Service Fluorescent Lighting: CREE CR24 ............................... 47  
  General Service Fluorescent Lighting: CREE CR-LE-40L Light Engine54  
  General Service Incandescent Lighting: Philips 12W A19 ...................... 61  
  High Intensity Discharge Downlighting: CREE ESA .......................... 64
Parabolic Aluminized Reflector (PAR) Directional Lighting: Green Creative 7W Par20 .............................................................. 69

Data Analysis ................................................................. 74
Analysis of Power Data ...................................................... 74
Analysis of Illuminance Data .............................................. 75

Customer Decision and Satisfaction Survey Results ........................................ 79
Customer Decision Making Process ........................................... 79
Customer Satisfaction Survey Results ....................................... 80

Evaluations ......................................................................... 82
Energy, Peak Demand and Cost Savings ................................ 82
Lighting Performance .......................................................... 82
Satisfaction Survey Results .................................................. 82
Energy Savings, Peak Demand Reduction, and Economic Impact. 82
Financial Analysis ............................................................. 83
The Role of On-Bill Financing to Reduce Initial Project Costs ...... 85

Findings .............................................................................. 88

Appendices .......................................................................... 91
Appendix A. Fry’s LED Retrofit Survey .................................... 91
Appendix B. Scaled Field Placements for PG&E Emerging Technology Program ........................................................................................................................................ 94
Appendix C. Lighting Simulation Design Details ....................... 97
Appendix D. Retrofit Cut sheets ............................................. 99

References ........................................................................... 111
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. 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. 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. 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. 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 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.

**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.

---

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.

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.  

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, 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.\(^\text{10}\) 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

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.\(^1\) 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\(^1\)\(^2\)

<table>
<thead>
<tr>
<th>Application</th>
<th>Estimated LED Penetration of Installed Stock (%)(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>A-Type</td>
<td>-</td>
</tr>
<tr>
<td>Directional</td>
<td>&lt;1</td>
</tr>
<tr>
<td>MR16</td>
<td>3</td>
</tr>
<tr>
<td>Decorative</td>
<td>-</td>
</tr>
<tr>
<td>Downlight</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Troffer</td>
<td>-</td>
</tr>
<tr>
<td>High-Bay</td>
<td>-</td>
</tr>
<tr>
<td>Parking(^a)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Streetlight(^b)</td>
<td>1</td>
</tr>
</tbody>
</table>

### 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.

---

\(^1\) 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).

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). 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. 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), Fry’s Electronics began assessing the potential of a complete store retrofit for all major lighting applications, excluding high bay fixtures. 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. 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. 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

---

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, 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
  o 60W incandescent candelabra lamps with standard screw base fixtures

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

• Directional Lighting: Parabolic Aluminized Reflector (PAR)
  o 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. 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.

---

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.\(^\text{22}\)

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. 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.

**METHODODOLOGY**

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. All electrical work was completed by a certified electrician.

---

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. 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.
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>
<thead>
<tr>
<th>Room</th>
<th>Measurement Height</th>
<th>Reason for Measurement Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Checkout Register Area &amp; Checkout</td>
<td>39 inches</td>
<td>Counter height</td>
</tr>
<tr>
<td>Chandeliers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Break room</td>
<td>30 inches</td>
<td>Table height</td>
</tr>
<tr>
<td>Auto Install Garage</td>
<td>30 inches from floor</td>
<td>IESNA recommendation</td>
</tr>
<tr>
<td>Restroom</td>
<td>36 inches</td>
<td>Counter height</td>
</tr>
<tr>
<td>Audio Room</td>
<td>Varies</td>
<td>Vertical grid against wall</td>
</tr>
<tr>
<td>Customer Service Area</td>
<td>43 inches</td>
<td>Counter height</td>
</tr>
<tr>
<td>Computer Sales Area</td>
<td>30 inches</td>
<td>Counter height</td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Sample color gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
</tr>
</tbody>
</table>

**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.
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.
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. 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%

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.

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

FIGURE 6. CLTC SUMMARY OF PHOTOMETRIC REPORT FOR CREE CS14
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>
<thead>
<tr>
<th>Variable</th>
<th>Illumination</th>
<th>Correlated Color Temperature</th>
<th>Power, Power Quality</th>
<th>Current</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>Konica Minolta CL-200</td>
<td>Konica Minolta CL-200</td>
<td>PowerSight PS-3000; Fluke FLU-434</td>
<td>PowerSight PS-3000; Fluke FLU-434 w/ i400s current clamps</td>
<td>PowerSight PS-3000; Fluke FLU-434</td>
</tr>
<tr>
<td>Units</td>
<td>Foot-candles</td>
<td>Kelvin</td>
<td>Watts, PF, THD</td>
<td>Amps</td>
<td>Volts</td>
</tr>
<tr>
<td>Measurement Range</td>
<td>0.01-9,999 fc</td>
<td>0.5 fc or above</td>
<td>Not given</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>±0.002</td>
<td>±2%±1 digit of displayed value</td>
<td>±1%; ±1%;</td>
<td>±0.5%, ±1%</td>
<td>±0.5%; ±0.5%</td>
</tr>
<tr>
<td>Response time</td>
<td>0.5 seconds</td>
<td>0.5 seconds</td>
<td>16 µsec</td>
<td>16 µsec</td>
<td>16 µsec</td>
</tr>
</tbody>
</table>

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 | 4,000 lm | 36 to 44 W | 90 - 130 lm/W | 4000K | >90 | 50-100,000 HOURS |
| troffers                                |        |         |          |        |        |           |

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. 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.

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
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>
<thead>
<tr>
<th>Table 6. CREE CS14 LED Troffers (CS14-40LHE-40K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
</tr>
<tr>
<td>High-performance integrated 1X4 LED troffers</td>
</tr>
</tbody>
</table>

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). 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.
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 65 lm/W, close to the rated performance of the EnduraLED A lamp used at Fry’s.

### Table 7. Philips EnduraLED 12W A Lamp

<table>
<thead>
<tr>
<th>Description</th>
<th>Output</th>
<th>Wattage</th>
<th>Efficacy</th>
<th>CCT</th>
<th>CRI</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm white LED A lamp, 60W incandescent replacement</td>
<td>800 lm</td>
<td>12.5 W</td>
<td>64 lm/W</td>
<td>2700K</td>
<td>80</td>
<td>25,000</td>
</tr>
</tbody>
</table>

**Downlighting: High Intensity Discharge**

**100W Metal Halide Replacement in a Cylinder Pendant 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)**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>OUTPUT</th>
<th>WATTAGE</th>
<th>Efficacy</th>
<th>CCT</th>
<th>CRI</th>
<th>LIFETIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>10” cylinder downlight with 42 high output LEDs</td>
<td>3829 lm</td>
<td>75 W</td>
<td>50 lm/W</td>
<td>4000K</td>
<td>80</td>
<td>50,000 HOURS</td>
</tr>
</tbody>
</table>

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)**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>OUTPUT</th>
<th>WATTAGE</th>
<th>Efficacy</th>
<th>CCT</th>
<th>CRI</th>
<th>LIFETIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>10” cylinder downlight with 56 high output LEDs</td>
<td>5432 lm</td>
<td>100 W</td>
<td>54 lm/W</td>
<td>4000K</td>
<td>80</td>
<td>50,000 HOURS</td>
</tr>
</tbody>
</table>

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)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Output</th>
<th>Wattage</th>
<th>Efficacy</th>
<th>CCT</th>
<th>CRI</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 W warm white flood angle PAR20</td>
<td>350 lm</td>
<td>7 W</td>
<td>50 lm/W</td>
<td>3000K</td>
<td>85</td>
<td>40,000 HOURS</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Lamp Technology</th>
<th>Efficacy Range (Lumens per Watt)</th>
<th>Color Rendering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Incandescent</td>
<td>7 to 15</td>
<td>Excellent (100)</td>
</tr>
<tr>
<td>Tungsten Halogen</td>
<td>15 to 25</td>
<td>Excellent (100)</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>25 to 75</td>
<td>Good (70+) to Excellent (80+)</td>
</tr>
<tr>
<td>Fluorescent Tubes</td>
<td>65 to 95+</td>
<td>Medium (60+) to Excellent (80+)</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>45 to 95+</td>
<td>Fair (50+) to Good (70+)</td>
</tr>
</tbody>
</table>

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](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 and Incandescent Lamp Comparison](image)

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.
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.”

Energy Star currently lists over 1,500 qualified LED PAR replacement lamps, with average efficacy over 57 lumens per watt, 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 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.
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.
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.\(^3\)

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.\(^4\)

---

38 [ENERGY STAR fixture specifications:](http://www.energystar.gov/ia/partners/product_specs/program_reqs/Final_Luminaires_V1_2.pdf?eb95-8a31)
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 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.\textsuperscript{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.

\textbf{FIGURE 13. PHILIPS L PRIZE LED LAMP STRESS TESTING ALONGSIDE CFL A LAMPS}

![Image](image)

Source: Department of Energy\textsuperscript{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.

\textsuperscript{40} [http://www.lightingprize.org/60watttest.stm](http://www.lightingprize.org/60watttest.stm)

\textsuperscript{41} ibid
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.
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 Lights Consortium Lighting Quality Requirements for LED Fluorescent Replacement Products

<table>
<thead>
<tr>
<th>Application</th>
<th>Minimum Light Output</th>
<th>Minimum Efficacy</th>
<th>CCTs</th>
<th>Minimum CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x2 Luminaires and Retrofit Kits for 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces</td>
<td>2,000 lm</td>
<td>85 lm/W</td>
<td>≤5000K</td>
<td>80</td>
</tr>
<tr>
<td>1x4 Luminaires and Retrofit Kits for 1x4 Luminaires for Ambient Lighting of Interior Commercial Spaces</td>
<td>1,500 lm</td>
<td>85 lm/W</td>
<td>≤5000K</td>
<td>80</td>
</tr>
<tr>
<td>2x4 Luminaires and Retrofit Kits for 2x4 Luminaires for Ambient Lighting of Interior Commercial Spaces</td>
<td>3,000 lm</td>
<td>85 lm/W</td>
<td>≤5000K</td>
<td>80</td>
</tr>
<tr>
<td>Four-foot Linear Replacement Lamps</td>
<td>2 Lamps in Fixture: 3,000 lm</td>
<td>In Fixture: 85 lm/W</td>
<td>≤5000K</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Bare Lamp: 1,600 lm</td>
<td>Bare Lamp: 100 lm/W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

The figure shows data on the number of qualified products over time, with two graphs overlaying each other. The x-axis represents time from January 2011 to February 2013, while the y-axis represents the number of qualified products. The left graph compares fixtures and lamps, and the right graph shows the lumens per watt for kits, lamps, and fixtures.
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>
<thead>
<tr>
<th>TABLE 13. BASE CASE VS. RETROFIT WATTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Case</strong></td>
</tr>
<tr>
<td>GE Ecolux F32 T8 SP41</td>
</tr>
<tr>
<td>GE Ecolux F32 T8 SP41</td>
</tr>
<tr>
<td>GE Ecolux F32 T8 SP41</td>
</tr>
<tr>
<td>60W A-lamp; 19W CFL</td>
</tr>
<tr>
<td>M175/U or M100/U/MED</td>
</tr>
<tr>
<td>EYE Lighting 50PAR20</td>
</tr>
</tbody>
</table>

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.

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>
<thead>
<tr>
<th>Parameter</th>
<th>Base case Fixture</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power/fixture (Watts)</td>
<td>42.7</td>
<td>36.3</td>
</tr>
<tr>
<td>Adjusted Average power/fixture (Watts)</td>
<td>59.0</td>
<td>36.3</td>
</tr>
<tr>
<td>Average current/fixture (Amps)</td>
<td>0.16</td>
<td>0.14</td>
</tr>
<tr>
<td>Weighted Avg. Power Factor</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>Weighted Avg Harmonic Distortion</td>
<td>15%</td>
<td>16%</td>
</tr>
<tr>
<td># of fixtures on circuits</td>
<td>163</td>
<td>163</td>
</tr>
</tbody>
</table>

Photo Credit: CREE, Inc.
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

<table>
<thead>
<tr>
<th>Register Area: Base case</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Register 54-64</td>
<td>Register Area: LED Retrofit</td>
</tr>
<tr>
<td>Base case</td>
<td>LED Retrofit</td>
</tr>
<tr>
<td>Register 54-64</td>
<td>59.0</td>
</tr>
<tr>
<td>23.9</td>
<td>30.2</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Correlated Color Temperature (Kelvin)</th>
<th>Store Area</th>
<th>Base case</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Checkout Register</td>
<td>3660</td>
<td>3742</td>
<td></td>
</tr>
<tr>
<td>Register Area Average</td>
<td>3646</td>
<td>3751</td>
<td></td>
</tr>
</tbody>
</table>
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 $\Delta u'v'$ 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.\footnote{ENERGY STAR Program Requirements for SSLs Version 1.4 \url{http://www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf?2fe9-86db}}

<table>
<thead>
<tr>
<th>Table 17. Measured Color Correlated Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixture 1</td>
</tr>
<tr>
<td>Light Output</td>
</tr>
<tr>
<td>(lumen)</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>2200 Hour Testing</td>
</tr>
<tr>
<td>6000 Hour Testing</td>
</tr>
<tr>
<td>% change</td>
</tr>
</tbody>
</table>

<p>| Fixture 2                                      |
| Light Output       | Color Temperature | CRI | System Power | System Efficacy | Power Factor | Color Shift |</p>
<table>
<thead>
<tr>
<th>(lumen)</th>
<th>(CCT)</th>
<th></th>
<th>(Watts)</th>
<th>(Lumen/Watt)</th>
<th></th>
<th>($\Delta u'v'$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2200 Hour Testing</td>
<td>4172</td>
<td>3915</td>
<td>92.0</td>
<td>35.8</td>
<td>116.5</td>
<td>0.92</td>
</tr>
<tr>
<td>6000 Hour Testing</td>
<td>4021</td>
<td>3911</td>
<td>92.2</td>
<td>35.1</td>
<td>114.6</td>
<td>0.99</td>
</tr>
<tr>
<td>% change</td>
<td>-3.6%</td>
<td>-0.1%</td>
<td>0.2%</td>
<td>-2.0%</td>
<td>-1.6%</td>
<td>7.8%</td>
</tr>
</tbody>
</table>
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.

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

<table>
<thead>
<tr>
<th>Break Room Fluorescents/Linear LED Fixtures</th>
<th>Base case Fixture</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power/fixture (Watts)</td>
<td>96.7</td>
<td>20.7</td>
</tr>
<tr>
<td>Adjusted Average power/fixture (Watts)</td>
<td>108.3</td>
<td>20.7</td>
</tr>
<tr>
<td>Average current/fixture (Amps)</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Weighted Avg. PowerFactor</td>
<td>0.99</td>
<td>0.81</td>
</tr>
<tr>
<td>Weighted Avg Harmonic Distortion</td>
<td>5%</td>
<td>34%</td>
</tr>
</tbody>
</table>

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.
PG&E’s Emerging Technologies Program

TABLE 19. PHOTOMETRIC FIELD MEASUREMENTS OF BREAK ROOM

Break Room: Base case

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

*Bold lines indicate the location of a fixture

Break Room: LED Retrofit

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

*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

Baseline

[Diagram showing a floor plan with various numbers indicating locations or measurements, labeled with 'Baseline']
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

<table>
<thead>
<tr>
<th>Correlated Color Temperature (Kelvin)</th>
<th>Store Area</th>
<th>Base case</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break Room</td>
<td>3730</td>
<td>3846</td>
<td></td>
</tr>
</tbody>
</table>

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

![Base case: Linear Fluorescent](image1)

Retrofit: LED

![Retrofit: LED](image2)

Base case: Linear Fluorescent

![Base case: Linear Fluorescent](image3)

Retrofit: LED

![Retrofit: LED](image4)

**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**

![3D Rendering of Study Area](image5)
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.

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

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

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

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

### 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.
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)

<table>
<thead>
<tr>
<th></th>
<th>Near door under fixture</th>
<th>Between fixtures</th>
<th>Under fixture by wall</th>
<th>2.5 ft. from wall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base case</strong></td>
<td>30.1</td>
<td>33.3</td>
<td>32.2</td>
<td>27.8</td>
</tr>
<tr>
<td><strong>LED Retrofit</strong></td>
<td>31.7</td>
<td>38.5</td>
<td>35.6</td>
<td>29.4</td>
</tr>
</tbody>
</table>

### 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

Baseline

<table>
<thead>
<tr>
<th>24.8</th>
<th>25.7</th>
<th>21.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.1</td>
<td>27.9</td>
<td>30.2</td>
</tr>
<tr>
<td>55.7</td>
<td>54.9</td>
<td>53.0</td>
</tr>
<tr>
<td>67.7</td>
<td>66.2</td>
<td>50.4</td>
</tr>
<tr>
<td>62.5</td>
<td>61.3</td>
<td>47.8</td>
</tr>
<tr>
<td>20.4</td>
<td>21.1</td>
<td>20.6</td>
</tr>
<tr>
<td>18.4</td>
<td>14.8</td>
<td>22.8</td>
</tr>
<tr>
<td>22.3</td>
<td>22.9</td>
<td>18.3</td>
</tr>
<tr>
<td>17.7</td>
<td>24.5</td>
<td>31.4</td>
</tr>
<tr>
<td>24.6</td>
<td>21.9</td>
<td>16.3</td>
</tr>
</tbody>
</table>

LED Retrofit

<table>
<thead>
<tr>
<th>27.9</th>
<th>29.6</th>
<th>23.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.4</td>
<td>42.5</td>
<td>32.6</td>
</tr>
<tr>
<td>43.2</td>
<td>42.6</td>
<td>32.8</td>
</tr>
<tr>
<td>61.6</td>
<td>62.6</td>
<td>47.7</td>
</tr>
<tr>
<td>61.6</td>
<td>62.6</td>
<td>47.7</td>
</tr>
<tr>
<td>71.7</td>
<td>66.1</td>
<td>49.6</td>
</tr>
<tr>
<td>61.2</td>
<td>77.4</td>
<td>55.0</td>
</tr>
<tr>
<td>61.2</td>
<td>77.4</td>
<td>55.0</td>
</tr>
</tbody>
</table>

Baseline vs LED Retrofit comparison showing significant energy savings.
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>
<thead>
<tr>
<th>Correlated Color Temperature (Kelvin)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Store Area</strong></td>
</tr>
<tr>
<td>Restroom</td>
</tr>
<tr>
<td>Auto Install Garage</td>
</tr>
</tbody>
</table>
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](image)

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](image)
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.
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.

<p>| TABLE 26. POWER MEASUREMENTS OF REGISTER AREA |
|------------------|------------------|</p>
<table>
<thead>
<tr>
<th>Register Area Chandelier Lamps</th>
<th>Base case Fixture</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power/fixture (Watts)</td>
<td>17.5</td>
<td>12.4</td>
</tr>
<tr>
<td>Adjusted Average power/fixture (Watts)</td>
<td>22.3</td>
<td>12.4</td>
</tr>
<tr>
<td>Average current/fixture (Amps)</td>
<td>0.20</td>
<td>0.12</td>
</tr>
<tr>
<td>Weighted Avg. Power Factor</td>
<td>0.71</td>
<td>0.81</td>
</tr>
<tr>
<td>Weighted Avg Harmonic Distortion</td>
<td>96%</td>
<td>70%</td>
</tr>
<tr>
<td># of fixtures on circuit</td>
<td>125</td>
<td>125</td>
</tr>
</tbody>
</table>
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

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 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). This product was selected because Fry’s required a very specific, high output LED fixture.

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>
<thead>
<tr>
<th>Computer Sales Area: Base case</th>
<th>Computer Sales Area: LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near wall</td>
<td>Near wall</td>
</tr>
<tr>
<td>Right of room</td>
<td>Right of room</td>
</tr>
<tr>
<td>Center-right</td>
<td>Center-right</td>
</tr>
<tr>
<td>Center-left</td>
<td>Center-left</td>
</tr>
<tr>
<td>Left of room</td>
<td>Left of room</td>
</tr>
<tr>
<td>22.0</td>
<td>93.0</td>
</tr>
<tr>
<td>14.2</td>
<td>66.0</td>
</tr>
<tr>
<td>20.0</td>
<td>86.0</td>
</tr>
<tr>
<td>43.5</td>
<td>106.0</td>
</tr>
<tr>
<td>108</td>
<td>120.0</td>
</tr>
<tr>
<td>24.5</td>
<td>76.0</td>
</tr>
<tr>
<td>24.6</td>
<td>76.0</td>
</tr>
<tr>
<td>30.0</td>
<td>91.0</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Customer Service Area: Base case</th>
<th>Customer Service Area: LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near wall</td>
<td>Near wall</td>
</tr>
<tr>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>Near entrance</td>
<td>Near entrance</td>
</tr>
<tr>
<td>17.5</td>
<td>76.9</td>
</tr>
<tr>
<td>22.8</td>
<td>75.5</td>
</tr>
<tr>
<td>20.0</td>
<td>78.9</td>
</tr>
<tr>
<td>24.4</td>
<td>61.2</td>
</tr>
<tr>
<td>20.3</td>
<td>69.5</td>
</tr>
<tr>
<td>13.5</td>
<td>78.3</td>
</tr>
<tr>
<td>17.6</td>
<td>68.8</td>
</tr>
<tr>
<td>16.1</td>
<td>77.5</td>
</tr>
<tr>
<td>14.3</td>
<td>78.0</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Correlated Color Temperature (Kelvin)</th>
<th>Base case</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer Sales Area</td>
<td>4800</td>
<td>3986</td>
</tr>
<tr>
<td>Customer Service Area</td>
<td>3300</td>
<td>3826</td>
</tr>
</tbody>
</table>
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**

![Image of Green Creative 7W PAR20](image)

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>
<thead>
<tr>
<th>Audio Room</th>
<th>Base case Fixture</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power/fixture (Watts)</td>
<td>28.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Adjusted power/fixture (Watts)</td>
<td>31.2</td>
<td>11.1</td>
</tr>
<tr>
<td>Average current/fixture (Amps)</td>
<td>0.35</td>
<td>0.11</td>
</tr>
<tr>
<td>Weighted Average Power Factor</td>
<td>0.73</td>
<td>0.57</td>
</tr>
<tr>
<td>Weighted Average Harmonic Distortion</td>
<td>60%</td>
<td>58%</td>
</tr>
<tr>
<td># of fixtures on circuit</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>TABLE 31. PHOTOMETRIC FIELD MEASUREMENTS OF AUDIO ROOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio Room: Base case</td>
</tr>
<tr>
<td>h=6'  11.3   10.0   7.7   9.0   12.0</td>
</tr>
<tr>
<td>h=5'  10.6    8.3   5.6   6.0   7.8</td>
</tr>
<tr>
<td>h=4'   8.4    6.5   5.2   4.3   4.7</td>
</tr>
<tr>
<td>h=3'  6.0    5.0   4.2   3.6   3.0</td>
</tr>
<tr>
<td>h=2'   5.6    3.8   3.2   2.6   2.3</td>
</tr>
<tr>
<td>h=0  3.09    2.7   2.2   2.0   1.8</td>
</tr>
</tbody>
</table>

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.
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

<table>
<thead>
<tr>
<th>Store Area</th>
<th>Base case</th>
<th>LED Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio Room</td>
<td>2625</td>
<td>3103</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>LED Retrofit Lamp</th>
<th>Location</th>
<th>Base case (Rated)</th>
<th>Base case (Measured)</th>
<th>Retrofit (Rated)</th>
<th>Retrofit (Measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips A19</td>
<td>Checkout Chandeliers</td>
<td>1.00 (Incandescent)</td>
<td>.71</td>
<td>.95</td>
<td>.81</td>
</tr>
<tr>
<td>CREE CR24</td>
<td>Break Room</td>
<td>.99</td>
<td>1.00</td>
<td>0.9</td>
<td>0.83</td>
</tr>
<tr>
<td>CREE CR-LE-40L</td>
<td>Auto Install Garage</td>
<td>.99</td>
<td>.98</td>
<td>0.9</td>
<td>0.95</td>
</tr>
<tr>
<td>CREE CS14</td>
<td>Checkout Fluorescents</td>
<td>.99</td>
<td>.98</td>
<td>0.9</td>
<td>0.95</td>
</tr>
<tr>
<td>CREE ESA</td>
<td>Customer Service</td>
<td>.90 (est.)</td>
<td>No data</td>
<td>0.9</td>
<td>No data</td>
</tr>
<tr>
<td>Green Creative PAR20</td>
<td>Audio Room</td>
<td>1.00</td>
<td>.73</td>
<td>0.7</td>
<td>0.57</td>
</tr>
</tbody>
</table>

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%.
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

<table>
<thead>
<tr>
<th>LED Retrofit Lamp</th>
<th>Location</th>
<th>Base case (Rated)</th>
<th>Base case (Measured)</th>
<th>Retrofit (Rated)</th>
<th>Retrofit (Measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips A19</td>
<td>Checkout Chandeliers</td>
<td>Nominal THD</td>
<td>96%</td>
<td>No data</td>
<td>70%</td>
</tr>
<tr>
<td>CREE CR24</td>
<td>Break Room</td>
<td>5%</td>
<td>&lt;20%</td>
<td>34%</td>
<td></td>
</tr>
<tr>
<td>CREE CR-LE-40L</td>
<td>Auto Install Garage</td>
<td>7%</td>
<td>&lt;20%</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>CREE CS14</td>
<td>Checkout Fluorescents</td>
<td>15%</td>
<td>&lt;20%</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>CREE ESA</td>
<td>Customer Service</td>
<td>No data</td>
<td>&lt;20%</td>
<td>No data</td>
<td></td>
</tr>
<tr>
<td>Green Creative</td>
<td>Audio Room</td>
<td>60%</td>
<td>No data</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>PAR20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 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)

<table>
<thead>
<tr>
<th>Average Illumination (footcandles)</th>
<th>Audio Room</th>
<th>Auto Install</th>
<th>Restroom</th>
<th>Break Room</th>
<th>Register Area</th>
<th>Computer Sales</th>
<th>Customer Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>5.6</td>
<td>38.3</td>
<td>34.3</td>
<td>77.8</td>
<td>36.2</td>
<td>35.9</td>
<td>18.5</td>
</tr>
<tr>
<td>LED Retrofit</td>
<td>15.6</td>
<td>35.7</td>
<td>44.7</td>
<td>32.7</td>
<td>64.5</td>
<td>83.9</td>
<td>73.8</td>
</tr>
</tbody>
</table>

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'.
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.

| Table 36. Illuminance Avg/Min Ratios |

<table>
<thead>
<tr>
<th></th>
<th>Audio Room</th>
<th>Auto Install</th>
<th>Restroom</th>
<th>Break Room</th>
<th>Register Area</th>
<th>Computer Sales</th>
<th>Customer Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>3.1</td>
<td>1.4</td>
<td>1.7</td>
<td>1.8</td>
<td>1.5</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>LED Retrofit</td>
<td>3.8</td>
<td>1.4</td>
<td>1.4</td>
<td>1.5</td>
<td>1.1</td>
<td>1.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>LED Retrofit Lamp</th>
<th>Base case CRI (Rated)</th>
<th>Retrofit CRI (Rated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips A19</td>
<td>100</td>
<td>81</td>
</tr>
<tr>
<td>CREE CR24</td>
<td>82</td>
<td>90</td>
</tr>
<tr>
<td>CREE CR14</td>
<td>82</td>
<td>90</td>
</tr>
<tr>
<td>CREE CS14</td>
<td>82</td>
<td>90</td>
</tr>
<tr>
<td>CREE ESA</td>
<td>65</td>
<td>80</td>
</tr>
<tr>
<td>Green Creative PAR20</td>
<td>100</td>
<td>85</td>
</tr>
</tbody>
</table>
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. 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. 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. 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.

---

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. 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. 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 on 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. 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.
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.

**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 38. PROJECT ENERGY SAVINGS AND PEAK DEMAND REDUCTION (QUALIFYING EQUIPMENT ONLY)**

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

**TABLE 39. PROJECT ENERGY SAVINGS AND PEAK DEMAND REDUCTION (STOREWIDE RETROFIT)**

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

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

<table>
<thead>
<tr>
<th></th>
<th>SPP (Years)</th>
<th>ROI</th>
<th>MIRR</th>
<th>NPV ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Incentive</td>
<td>5.8</td>
<td>17.3%</td>
<td>10.2%</td>
<td>$63,982</td>
</tr>
<tr>
<td>Customized Retrofit Incentive</td>
<td>5.1</td>
<td>19.5%</td>
<td>11.3%</td>
<td>$76,154</td>
</tr>
<tr>
<td>LEDA Incentive</td>
<td>4.1</td>
<td>24.2%</td>
<td>13.3%</td>
<td>$94,944</td>
</tr>
</tbody>
</table>

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)**

<table>
<thead>
<tr>
<th></th>
<th>SPP (Years)</th>
<th>ROI</th>
<th>MIRR</th>
<th>NPV ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Incentive</td>
<td>4.3</td>
<td>23.2%</td>
<td>12.9%</td>
<td>$146,732</td>
</tr>
<tr>
<td>Customized Retrofit Incentive</td>
<td>3.9</td>
<td>25.6%</td>
<td>13.9%</td>
<td>$158,903</td>
</tr>
<tr>
<td>LEDA Incentive</td>
<td>3.3</td>
<td>30.5%</td>
<td>15.5%</td>
<td>$177,693</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th></th>
<th>SPP (Years)</th>
<th>ROI</th>
<th>MIRR</th>
<th>NPV ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Incentive</td>
<td>5.0</td>
<td>19.8%</td>
<td>11.4%</td>
<td>$194,557</td>
</tr>
<tr>
<td>Customized Retrofit Incentive</td>
<td>4.8</td>
<td>20.9%</td>
<td>11.9%</td>
<td>$206,564</td>
</tr>
<tr>
<td>LEDA Incentive</td>
<td>4.4</td>
<td>22.8%</td>
<td>12.7%</td>
<td>$225,518</td>
</tr>
</tbody>
</table>

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\textsuperscript{55} and a ten-year warranty.\textsuperscript{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.

\textbf{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.\textsuperscript{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.

\textsuperscript{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.


\textsuperscript{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)\(^{58}\)

<table>
<thead>
<tr>
<th>Cash Flow</th>
<th>Initial Cost</th>
<th>Year 0 (today)</th>
<th>End of Year 1</th>
<th>End of Year 2</th>
<th>End of Year 3</th>
<th>End of Year 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outflows</td>
<td>Single Investment</td>
<td>$(71,472)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Financed Investment</td>
<td>$(18,653)</td>
<td>$(19,213)</td>
<td>$(19,789)</td>
<td>$ -</td>
<td></td>
</tr>
<tr>
<td>Inflows</td>
<td>LEDA Incentive</td>
<td>$30,962</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy Savings</td>
<td>$18,858</td>
<td>$19,424</td>
<td>$20,006</td>
<td>$20,607</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance Savings</td>
<td>$11,282</td>
<td>$11,620</td>
<td>$11,969</td>
<td>$12,328</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cash flows</strong></td>
<td></td>
<td>$(40,510)</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$20,607</td>
</tr>
</tbody>
</table>

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)

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

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)

<table>
<thead>
<tr>
<th>Commercial Building Type</th>
<th>Incandescent</th>
<th>Halogen</th>
<th>CFL</th>
<th>Linear Fluorescent</th>
<th>HID</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>1%</td>
<td>2%</td>
<td>10%</td>
<td>85%</td>
<td>1%</td>
<td>2%</td>
<td>100%</td>
</tr>
<tr>
<td>Food Service</td>
<td>20%</td>
<td>1%</td>
<td>8%</td>
<td>67%</td>
<td>1%</td>
<td>3%</td>
<td>100%</td>
</tr>
<tr>
<td>Food Store</td>
<td>1%</td>
<td>1%</td>
<td>3%</td>
<td>94%</td>
<td>1%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Health Care - Inpatient</td>
<td>1%</td>
<td>1%</td>
<td>13%</td>
<td>84%</td>
<td>0%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Health Care - Outpatient</td>
<td>1%</td>
<td>1%</td>
<td>9%</td>
<td>88%</td>
<td>0%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Lodging</td>
<td>1.8%</td>
<td>2%</td>
<td>25%</td>
<td>53%</td>
<td>0%</td>
<td>2%</td>
<td>100%</td>
</tr>
<tr>
<td>Offices (Non-medical)</td>
<td>1%</td>
<td>1%</td>
<td>14%</td>
<td>82%</td>
<td>0%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>8%</td>
<td>1%</td>
<td>21%</td>
<td>58%</td>
<td>3%</td>
<td>9%</td>
<td>100%</td>
</tr>
<tr>
<td>Public Order and Safety</td>
<td>1%</td>
<td>1%</td>
<td>6%</td>
<td>89%</td>
<td>1%</td>
<td>2%</td>
<td>100%</td>
</tr>
<tr>
<td>Religious Worship</td>
<td>4%</td>
<td>1%</td>
<td>8%</td>
<td>84%</td>
<td>1%</td>
<td>2%</td>
<td>100%</td>
</tr>
<tr>
<td>Retail - Mall &amp; Non-Mall</td>
<td>5%</td>
<td>6%</td>
<td>6%</td>
<td>79%</td>
<td>3%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Services</td>
<td>1%</td>
<td>1%</td>
<td>4%</td>
<td>90%</td>
<td>3%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Warehouse and Storage</td>
<td>0%</td>
<td>2%</td>
<td>6%</td>
<td>86%</td>
<td>5%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Other</td>
<td>2%</td>
<td>4%</td>
<td>9%</td>
<td>79%</td>
<td>2%</td>
<td>3%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>4%</strong></td>
<td><strong>2%</strong></td>
<td><strong>10%</strong></td>
<td><strong>80%</strong></td>
<td><strong>2%</strong></td>
<td><strong>2%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

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, 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 upfront 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, 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.

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

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.
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:

\[ .90 \times LLD \times .95 \times LDD \times .87 \times BF = .74 \times LLF \]

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

\[ .90 \times LLD \times .95 \times LDD = .855 \times LLF \]

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 4900 lumens of exceptional 90 CRI light. This breakthrough performance is achieved by combining the high efficiency and high-quality light of CREE® technology and our revolutionary® optics with a unique thermal management approach. The CS14™ is available in neutral or cool color temperatures and has 347V dimming in a standard option. Its compact, lightweight design makes it easy to install, making the CS14 perfect for use in grocery retail, showrooms and light industrial applications in new or retrofit upgrade construction.

Performance Summary
- Utilizes CREE® Revolution™ Technology
- Active Heat Sinks
- Made in the USA of U.S. and imported parts
- Dimming: 1-10V Dimming to 10%
- Mounting: Suspended or Surface with Longhangs (Standard)
- Weight: max 8 lbs.

Accessories
Reference CS Series Accessories document for more details.

Ordering Information
Example: CS14-K6W 30K 347V-10K

<table>
<thead>
<tr>
<th>Product</th>
<th>Lumens/Circuit</th>
<th>Color Temperature</th>
<th>Voltage</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS14 49L</td>
<td>49L M</td>
<td>22W 4000 lumens</td>
<td>380 3500K80110V</td>
<td>Black 10Y Dimming to 8</td>
</tr>
<tr>
<td>CS14 49L</td>
<td>49L M</td>
<td>22W 4000 lumens</td>
<td>380 4000K 5400K 7000K 8000K</td>
<td>10Y Dimming to 8</td>
</tr>
</tbody>
</table>

*See www.cree.com/lighting for recommended dimming control options.
*See www.cree.com/lighting for warranty terms and conditions.
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 talking 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 550mA enables the fixture to consistently run cooler, providing significant boosts to lifetime, efficacy, and color consistency.

LUMEN MAINTENANCE FACTORS
- Designed to a minimum of LLD at 75,000 hours with 1L option and LED at 50,000 hours with base option.

CONSTRUCTION & MATERIALS
- High-strength, lightweight polymer forms the reflector and driver housing.
- Multi-functional heat sink and light bar doubles as the winnery for through wiring harnesses.
- Two plastic long bars provided for surface or suspended installations. One long bar per unit and vice versa, row spacing.
- Hangers are adjustable along fixture to accommodate existing mounting points for upgrade projects. Hanger support required within 18 inches of end-of-travel.
- Individual lenses may be connected end to end for continuous row mounting. Easy removal of individual lenses 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 MicroMolding® Optics which integrates the intense direct light and distributes optimally mixed indirect 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
- 110/120/208/240VAC 50/60Hz or 220-277V 50/60Hz
- UL listed, cULus listed, DLC qualified, and suitable for damp locations.
- For more information, visit www.cree.com/lighting for online building energy codes and other information.
- For more information, visit www.cree.com/lighting for detailed photometric data.

Photometry

C314™

Photometry

C314-40L, HED-40K-10v

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>30</th>
<th>50</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>108</td>
<td>108</td>
<td>99</td>
</tr>
<tr>
<td>15°</td>
<td>119</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>25°</td>
<td>119</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>30°</td>
<td>119</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>45°</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>60°</td>
<td>75</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>75°</td>
<td>60</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>90°</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

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

PG&E’s Emerging Technologies Program

ET12PGE1481

© 2015 Curi, Inc. All rights reserved. For informational purposes only. See www.cree.com/confidential for details on the content of this document. Cree, the Cree logo, TrueWhite®, TrueWhite® and the TrueWhite® Technology logo are registered trademarks, and CSM™ and MicroMolding™ are trademarks of Curi, Inc.

www.cree.com/lighting 1 (800) 235-6800 F (262) 504-5465

Pacific Gas & Electric Company
B. CR24

CR24™
2’x4’ Architectural LED Trolley

Product Description
The CR24 Architectural LED Trolley delivers up to 160 lumens per watt of exceptional performance in a slim, lightweight design. The high efficiency and exceptional performance is achieved by combining the latest LED technology with advanced circuitry. The CR24 is ideal for retrofit applications or for new construction. The CR24-T is available in 3000K, 4000K, and 5000K correlated color temperatures. The CR24 features an easy-to-install flush mount design with a surface mount option. The CR24-T is specifically designed to be installed in areas where space is limited.

Performance Summary
- **Black Crow Technology**: Patented technology for improved performance and energy efficiency.
- **Active Cool Management**: Ensures optimal thermal performance.
- **Slim Line Heat Sink**: Reduces heat dissipation and enhances efficiency.
- **IP20 Protection**: Ensures protection against dust and splashing water.
- **IC Rated**: Meets insulation class IC requirements.
- **10,000 Hours Life**: Extended lifespan for reduced maintenance.
- **5000K 100W**: Provides bright, clear light for everyday use.
- **5000K 200W**: Ideal for large, open spaces or areas requiring high brightness.
- **5000K 300W**: Suitable for industrial applications or areas with high activity.
- **5000K 400W**: Perfect for large commercial or public spaces.
- **5000K 500W**: Ideal for large, high-traffic areas or outdoor installations.
- **5000K 600W**: Suitable for large, high-output applications.

Housings & Accessories
- **CR24-107**
  - 3000K Lumen Kit
  - 4000K Lumen Kit
  - 5000K Lumen Kit

Ordering Information
- **CR24**
  - **Product**: CR24-107
  - **Lumen Output**: 3000K
  - **Color Temp**: 3000K
  - **Voltage**: 120V
  - **Control**: Dimmable
  - **Options**: Standard or Emergency Battery Backup

- **CR24-T**
  - **Product**: CR24-T107
  - **Lumen Output**: 3000K
  - **Color Temp**: 3000K
  - **Voltage**: 120V
  - **Control**: Dimmable
  - **Options**: Standard or Emergency Battery Backup

- **CR24-E**
  - **Product**: CR24-E107
  - **Lumen Output**: 3000K
  - **Color Temp**: 3000K
  - **Voltage**: 120V
  - **Control**: Dimmable
  - **Options**: Standard or Emergency Battery Backup

For more information, please visit www.cree.com/lighting.
**Photometry**

**CR24-4000L**

- **ET**
- **12PGE1481**

**Coefficients of Variation**

<table>
<thead>
<tr>
<th>CoC %</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
</tr>
</tbody>
</table>

**Luminance Table (cd/m²)**

<table>
<thead>
<tr>
<th>0°</th>
<th>2174</th>
<th>2174</th>
<th>2174</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>1976</td>
<td>2116</td>
<td>2152</td>
</tr>
<tr>
<td>55°</td>
<td>1837</td>
<td>2018</td>
<td>2074</td>
</tr>
<tr>
<td>75°</td>
<td>1513</td>
<td>1918</td>
<td>1879</td>
</tr>
<tr>
<td>90°</td>
<td>1149</td>
<td>1501</td>
<td>1419</td>
</tr>
</tbody>
</table>

**Zonal Luminance Summary**

- **0°-90°: 525 27.9% 29.9%**
- **90°-180°: 525 4.9% 40.9%**
- **180°-270°: 3,240 61.1% 811%**
- **270°-360°: 4,000 100% 100%**

Reference: www.cree.com/lighting for detailed photometry data.

**Application Reference**

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Lumens</th>
<th>Voltage</th>
<th>LPW</th>
<th>w/°N</th>
<th>Average ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 8</td>
<td>2300</td>
<td>22W</td>
<td>110</td>
<td>0.51</td>
<td>10</td>
</tr>
<tr>
<td>4000</td>
<td>40W</td>
<td>109</td>
<td>0.61</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>30W</td>
<td>136</td>
<td>0.54</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>50W</td>
<td>136</td>
<td>0.55</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>50W</td>
<td>136</td>
<td>0.55</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>70 x 10</td>
<td>2200</td>
<td>22W</td>
<td>110</td>
<td>0.51</td>
<td>26</td>
</tr>
<tr>
<td>4000</td>
<td>40W</td>
<td>109</td>
<td>0.61</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>30W</td>
<td>136</td>
<td>0.54</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>50W</td>
<td>136</td>
<td>0.55</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>50W</td>
<td>136</td>
<td>0.55</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>10 x 10</td>
<td>2200</td>
<td>22W</td>
<td>110</td>
<td>0.51</td>
<td>17</td>
</tr>
<tr>
<td>4000</td>
<td>40W</td>
<td>109</td>
<td>0.61</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>30W</td>
<td>136</td>
<td>0.54</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>50W</td>
<td>136</td>
<td>0.55</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>50W</td>
<td>136</td>
<td>0.55</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

© 2012 CREE, Inc. and/or one of its subsidiaries. All rights reserved. For internal purposes only. See www.cree.com/lumens for current lumens values. CREE, the CREE logo, CREE TrueWhite, TrueWhite, and the CREE TrueWhite Technology logo are registered trademarks of CREE, Inc. and one of its subsidiaries. Ecosystem and the Ecosystem Enabling logo are registered trademarks of Ecosystem Labs, Inc.
C. CR-LE

1944 or 1675 LED Light Engine

Product Description
The CR-LE LED light engine delivers up to 130 lumens per watt of exceptional 80 CR light at 4000 lumens. The breakthrough performance is achieved by combining the high efficacy and high-quality light of Cree TrueWhite® technology with a unique thermal management design. The CR-LE 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 temperature and is ideal for office or lumen ecosystem enabled dimming spaces.

Performance Summary
- Utilizes Cree TrueWhite® Technology
- Active Color Management
- Room-side heat sink
- Assembled in the US & Mexico
- Efficacy: 50-120 LPH/W
- Delivered Light Output: 2000, 2250, 3500, 4000, 5000 lumens
- Input Power: 22-50 watts
- CCT: 3000K, 4000K, 5000K
- Input Voltage: 120-277 VAC
- Warranty: 10 years
- Lifetime: Designed to last from 50,000 hours up to 100,000 hours with HD option
- Dimming: Step Level to 50%, 0-10V Dimming or Lutron Ecosystem Embedded to 1%
- Mounting: Recessed

Ordering Information

<table>
<thead>
<tr>
<th>CR-LE</th>
<th>Lumen Output</th>
<th>Color Temp.</th>
<th>Voltage</th>
<th>Control</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR-LE</td>
<td>5000 Lumens</td>
<td>3000K, 4000K</td>
<td>120-277 VAC</td>
<td>0-10V Dimming or Lutron Ecosystem Embedded to 1%</td>
<td></td>
</tr>
<tr>
<td>CR-LE</td>
<td>5000 Lumens</td>
<td>3000K, 4000K</td>
<td>120-277 VAC</td>
<td>0-10V Dimming or Lutron Ecosystem Embedded to 1%</td>
<td></td>
</tr>
</tbody>
</table>

Product Specifications

CREE TRUEWATT TECHNOLOGY
A revolutionary way to generate high-quality, white light. CREE TrueWhite® Technology makes the light from the highest performing and cost-effective yellow LEDs. This patented system delivers an exclusive combination of 80-90 CRI, beautiful light characteristics, and lifelong color consistency, all while maintaining high lumen efficacy—true color in a compact solution.

ROOM-SIDE HEAT SINK
An innovative heat management system designed to maximize cost effectiveness by integrating a unique room side heat sink into the dissipation of this. This breakthrough design enables a complete architectural application while conducting heat away from LEDs in a thermally controlled environment. This enables the LEDs to consistently run cooler, providing significant benefits to lifetime, efficacy, and color consistency.

LIFESPAN MAINTENANCE FACTORS

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


OPTICAL SYSTEM
- Unique combination of reflective and refractive optical components achieves a uniform, comfortable appearance while eliminating glare and color-friencing.
- Components work together to optimize distribution, balancing the delivery of high illumination levels on horizontal surfaces with a lower 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 lowering reflected intensity of light with the ceiling to create a longer high angle appearance.

ELECTRICAL SYSTEM
- Input power = 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% or more standard
- Optional continuous dimming to 20% with 0-10V DC control protocol
- Optional lounge control system allows seamless integration with lounge control system.

REGULATORY & VOLUNTARY QUALIFICATIONS
- cULus Listed
- DLC qualified
- Suitable for damp locations
- Designated for indoor use

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

Housings & Accessories

<table>
<thead>
<tr>
<th>Accessories</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMK-1LC-1</td>
<td>Surface mounted (non-rated), light engine 2000K, 2500K, and 3000K as available.</td>
</tr>
<tr>
<td>SMK-1LC-2</td>
<td>Surface mounted (non-rated), light engine 2000K, 2500K, and 3000K as available.</td>
</tr>
<tr>
<td>SMK-1LC-3</td>
<td>Surface mounted (optics for CR rated 1X1 Light engine 2000K, 2500K, and 3000K)</td>
</tr>
<tr>
<td>SMK-1LC-4</td>
<td>Surface mounted (optics for CR rated 1X1 Light engine 2000K, 2500K, and 3000K)</td>
</tr>
<tr>
<td>CR-507V</td>
<td>34V 125W LED</td>
</tr>
<tr>
<td>CR-247V-GD</td>
<td>Step dimming to 20%</td>
</tr>
<tr>
<td>P/N:15-14-06-155-CR1</td>
<td>Power supply</td>
</tr>
<tr>
<td>ACS-7E-FDS-12B-11</td>
<td>Adjustable DUT</td>
</tr>
<tr>
<td>ACS-7E-FDS-15</td>
<td>Adjustable DUT</td>
</tr>
<tr>
<td>ACS-7E-25-P</td>
<td>Adjustable DUT</td>
</tr>
<tr>
<td>ACS-7E-50-P</td>
<td>Adjustable DUT</td>
</tr>
<tr>
<td>ACS-7E-75-P</td>
<td>Adjustable DUT</td>
</tr>
<tr>
<td>ACS-7E-100-P</td>
<td>Adjustable DUT</td>
</tr>
</tbody>
</table>
D. Phillips LED A-Lamp

Attractive, dimmable LED alternative to popular incandescents

Phillips A-shape Dimmable LED Lamps are the smart LED alternative to standard incandescent A-shape lamps. The unique lamp design provides omni-directional light with excellent dimming performance.

- High efficency LED accent light
  - First 60W incandescent equivalent A9 LED bulb to be ENERGY STAR® Qualified
  - Next 9W design is ENERGY STAR® Qualified, and replaces a 40W incandescent equivalent A9 LED bulb
  - 7W A2 ENERGY STAR® Qualified bulb replaces a 75W standard incandescent equivalent A2 bulb
  - 22W A2 bulb replaces a 60W standard incandescent equivalent A2 bulb
  - Smooth dimming to 0% of full light levels
  - 15,000 hour rated average life
  - Emits virtually no UVIR 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
  - 2-year or 3-year limited warranty depending upon operating hours

(<2, *4, *5; See back page for restrictions)
Phillips A-shape Dimmable LED Lamp

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

<table>
<thead>
<tr>
<th>Product Number</th>
<th>Ordering Code</th>
<th>Norm. Watts</th>
<th>Volts</th>
<th>Lumens per SKU</th>
<th>Description</th>
<th>Bulb Type</th>
<th>Base</th>
<th>Rated Avg. Life (hrs.)</th>
<th>Approx. Lumen(^2)</th>
<th>Color Temp (K)</th>
<th>MOL (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 483-9</td>
<td>483-9 7A/12/700-470</td>
<td>8</td>
<td>20</td>
<td>20V Phillips LED Dimmable BW A 9</td>
<td>A 9</td>
<td>Pec</td>
<td>25,000</td>
<td>470</td>
<td>8</td>
<td>2700</td>
<td>4.2</td>
</tr>
<tr>
<td>409954</td>
<td>409954 7A/12/700-880 DIM &amp;</td>
<td>1.5</td>
<td>20</td>
<td>20V Phillips LED Dimmable 2W A 9</td>
<td>A 9</td>
<td>Pec</td>
<td>25,000</td>
<td>880</td>
<td>8</td>
<td>2700</td>
<td>4.2</td>
</tr>
<tr>
<td>859-0</td>
<td>859-0 7A/22/700 DIM</td>
<td>7</td>
<td>20</td>
<td>20V Phillips LED Dimmable 7W A2</td>
<td>A2</td>
<td>Pec</td>
<td>25,000</td>
<td>80</td>
<td>8</td>
<td>2700</td>
<td>4.8</td>
</tr>
<tr>
<td>2325-5</td>
<td>2325-5 3A/22/700 DIM</td>
<td>7</td>
<td>20</td>
<td>20V Phillips LED Dimmable 22W A2</td>
<td>A2</td>
<td>Pec</td>
<td>25,000</td>
<td>780</td>
<td>8</td>
<td>2700</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Shipping Data (Subject to change without notice)

<table>
<thead>
<tr>
<th>Product Number</th>
<th>SKU UPC (6-41677)</th>
<th>Outer Box Code</th>
<th>Case Qc</th>
<th>Case Weight (lbs.)</th>
<th>Case Cube (cu. ft.)</th>
<th>Pallet Qty</th>
<th>SKUs Per Pallet</th>
<th>Layers High</th>
<th>SKU Dimensions (W x D x H) (in.)</th>
<th>Case Dimensions (W x D x H) (in.)</th>
<th>Pallet Dimensions (W x D x H) (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 483-9</td>
<td>4 483-9</td>
<td>4 483-9</td>
<td>6</td>
<td>2.65</td>
<td>0.3</td>
<td>254</td>
<td>6</td>
<td>2.72 x 2.72 x 4.80</td>
<td>8.40 x 8.40 x 4.80</td>
<td>7.20 x 8.80 x 4.80</td>
<td></td>
</tr>
<tr>
<td>409954</td>
<td>409954</td>
<td>409954</td>
<td>6</td>
<td>3.27</td>
<td>0.55</td>
<td>254</td>
<td>6</td>
<td>2.72 x 2.72 x 4.80</td>
<td>8.40 x 8.40 x 4.80</td>
<td>7.20 x 8.80 x 4.80</td>
<td></td>
</tr>
<tr>
<td>859-0</td>
<td>859-0</td>
<td>859-0</td>
<td>4</td>
<td>0.341</td>
<td>0.027</td>
<td>384</td>
<td>4</td>
<td>4.02 x 2.33 x 7.87</td>
<td>9.92 x 9.92 x 20.30</td>
<td>9.54 x 9.54 x 20.30</td>
<td></td>
</tr>
<tr>
<td>2325-5</td>
<td>2325-5</td>
<td>2325-5</td>
<td>4</td>
<td>0.341</td>
<td>0.027</td>
<td>384</td>
<td>4</td>
<td>4.02 x 2.33 x 7.87</td>
<td>9.92 x 9.92 x 20.30</td>
<td>9.54 x 9.54 x 20.30</td>
<td></td>
</tr>
</tbody>
</table>

**Energy Efficiency**

Estimated Lighting Costs Using a Standard 100W Incandescent A2 Lamp

- Present Wattage: 100 W
- Annual Operating Hours: 4000 hrs

**Energy Efficiency**

- Annual energy cost per lamp: $4,400
- Annual energy cost per space: $4,400

Estimated Lighting Costs Using a Phillips 12W Philips A2 LED Lamp

- Present Wattage: 12 W
- Annual Operating Hours: 4000 hrs

**Energy Efficiency**

- Annual energy cost per lamp: $968
- Annual energy cost per space: $968

Total Estimated Annual Savings: $3,432.00

**Energy Efficiency**

- Estimated annual savings on 100 lamps in a space currently using 100 incandescent 100W, 780 lumen A2 lamps, operating 4000 hours per year at a cost of 35c per kWh. Your actual savings may vary depending on the energy costs in your geographic location.

- Replacing 100 standard incandescent 100W, 780 lumen A-lamps with Phillips 12W Philips 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.

**Energy Efficiency**

- Light output of the 12W Philips A2: 780 lumens compared to the 100W standard incandescent A2 at 780 lumens

**Energy Efficiency**

- Estimated annual savings on 100 lamps in a space currently using 100 incandescent 100W, 780 lumen A2 lamps, operating 4000 hours per year at a cost of 35c per kWh. Your actual savings may vary depending on the energy costs in your geographic location.

- Replacing 100 standard incandescent 100W, 780 lumen A-lamps with Phillips 12W Philips 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.

**Energy Efficiency**

- Light output of the 12W Philips A2: 780 lumens compared to the 100W standard incandescent A2 at 780 lumens

**Energy Efficiency**

- Estimated annual savings on 100 lamps in a space currently using 100 incandescent 100W, 780 lumen A2 lamps, operating 4000 hours per year at a cost of 35c per kWh. Your actual savings may vary depending on the energy costs in your geographic location.
E. CREE ESA

ES-A-C 0-MD-56
Essentia® LED Downlight - Cylinder - Medium

**FAMILY** | **PRODUCT** | **OPTIC** | **MOUNTING** | **LED COUNT** | **SERIES** | **VOLTAGE** | **COLOR** | **REFLECTOR COMBINATION** | **LUMEN CURRENT** | **OPTIONS**
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
ESA | C2 | MD | S | Surface | 56 | Universal | BK | Clear | $25, 52, 22 |
C2 | Pendant | | | | | | | | | LM: Lens Media
C2 | SW | Wall Bracket | | | | | | | | 15W/20W
C2 | HP | High Hat Bracket | | | | | | | | 22W/27W
C2 | HC | Pendant | | | | | | | | 22W/27W
C2 | AC | Aircraft Cable | | | | | | | | 24W/30W
C2 | AC2 | Aircraft Cable | | | | | | | | 24W/30W
C2 | AC3 | Aircraft Cable | | | | | | | | 24W/30W

**FOOTNOTES**
1. 24" standard, consult factory for other lengths
2. 24" standard 6" max, may field-cable (consult factory for other lengths)
3. SS = Soft Satin, G = Gloss, C = Clear
4. Color temperature per fixture: 5300K Standard

**LED PERFORMANCE SPECs**

<table>
<thead>
<tr>
<th># OF LEDS</th>
<th>INITIAL DELIVERED LUMENS @1500K/1400K</th>
<th>@3000K/4000K with Lens Media</th>
<th>@3000K</th>
<th>@2700K with Lens Media</th>
<th>@3000K with Lens Media</th>
<th>SYSTEM MATERIALS 10-30V</th>
<th>TOTAL CURRENT @14V</th>
<th>TOTAL CURRENT @30V</th>
<th>@3000K LUMEN MAINTENANCE FACTOR @25°C (77°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>5452</td>
<td>48</td>
<td>40/44</td>
<td>36/4</td>
<td>3/4</td>
<td>0/0</td>
<td>0.44</td>
<td>0.48</td>
<td>0.4</td>
</tr>
</tbody>
</table>

5000K FIKTURE OPERATING AT 25°C (77°F)

<table>
<thead>
<tr>
<th># OF LEDS</th>
<th>INITIAL DELIVERED LUMENS</th>
<th>@3000K LUMEN MAINTENANCE FACTOR @25°C (77°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>6972</td>
<td>5</td>
</tr>
</tbody>
</table>

*For recommended lumen maintenance factor data see PG&E-4.
Essentia® LED Downlight - Cylinder - Medium

### Photometrics

#### Luminance Data

<table>
<thead>
<tr>
<th>Vertical Angle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>347</td>
</tr>
<tr>
<td>55°</td>
<td>291</td>
</tr>
<tr>
<td>65°</td>
<td>0</td>
</tr>
<tr>
<td>75°</td>
<td>0</td>
</tr>
<tr>
<td>85°</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Candela Distribution

<table>
<thead>
<tr>
<th>Degrees</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>992</td>
</tr>
<tr>
<td>5°</td>
<td>735</td>
</tr>
<tr>
<td>10°</td>
<td>828</td>
</tr>
<tr>
<td>25°</td>
<td>199</td>
</tr>
<tr>
<td>35°</td>
<td>274</td>
</tr>
<tr>
<td>45°</td>
<td>34</td>
</tr>
<tr>
<td>55°</td>
<td>9</td>
</tr>
<tr>
<td>65°</td>
<td>8</td>
</tr>
<tr>
<td>75°</td>
<td>8</td>
</tr>
<tr>
<td>85°</td>
<td>0</td>
</tr>
<tr>
<td>90°</td>
<td>0</td>
</tr>
</tbody>
</table>

### Cone of Light

#### Luminance Data

<table>
<thead>
<tr>
<th>Vertical Angle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>066</td>
</tr>
<tr>
<td>55°</td>
<td>454</td>
</tr>
<tr>
<td>65°</td>
<td>236</td>
</tr>
<tr>
<td>75°</td>
<td>499</td>
</tr>
<tr>
<td>85°</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Candela Distribution

<table>
<thead>
<tr>
<th>Degrees</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0835</td>
</tr>
<tr>
<td>5°</td>
<td>96</td>
</tr>
<tr>
<td>10°</td>
<td>34</td>
</tr>
<tr>
<td>25°</td>
<td>132</td>
</tr>
<tr>
<td>35°</td>
<td>553</td>
</tr>
<tr>
<td>45°</td>
<td>333</td>
</tr>
<tr>
<td>55°</td>
<td>14</td>
</tr>
<tr>
<td>65°</td>
<td>50</td>
</tr>
<tr>
<td>75°</td>
<td>5</td>
</tr>
<tr>
<td>85°</td>
<td>8</td>
</tr>
<tr>
<td>90°</td>
<td>0</td>
</tr>
</tbody>
</table>

### Color Quality Commitment

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 luminaires' initial color consistency (t-60) in 2-2 step MacAdam ellipse from the initial specified color point. We are committed to providing luminaires' color point stability over time, within a 2-step MacAdam ellipse to the predicted 1% point (per hour) 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

- Luminaires use 56 high output LEDs, 5500K standard, tolerance to be within a 2-step MacAdam ellipse. See Table for specific color tolerance (below).
- Axial and tilted Axial 1R 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 parasitic spin Alatn aluminum core, 30° elfl with polished radius and continuous soft flange.
- Precision nickel plated core retainers assure that the lower core is held in position.
- Custom extruded aluminum fixture.
- Form, then design to maximize cooling of LEDs.
- Heavy wall aluminum housing.
- Surface, pendant, wall, or ceiling mounting.

### Electrical

- High efficiency constant current driver(s), 120-277VAC input, 500mA, 525mA or 700mA drive current.
- 0-10V dimming, standard 0%-10% full-range continuous dimming.
- LED drivers have power factors >90% and THD <20% at full load.

### Testing & Compliance

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

### Finish

Exclusive Coolonist DeltaSist® finish features an E-coat epoxy primer with an ultra-durable powder topcoat providing excellent resistance to corrosion, ultraviolet degradation and abrasion (Brass: Blue, White and Burnished Silver powder topcoats are available). Finish is covered by our 10 year limited warranty.

### Patents

U.S. and international patents granted and pending. For a listing of patents, visit www.cree.com.
F. Green Creative PAR20

PG&E’s Emerging Technologies Program

ET12PGE1481

PAR20 7W DIM. TITANIUM LED SERIES 2.0

Exceptionally even beam distribution
 Very high efficacy 50 LPW in Warm White
 High Color Rendering Index 85
 Smooth dimming with existing dimmers
 Narrow Flood / Flood beam angle
 Warm White / Natural White color temperature

$154 Savings per lamp

RETURN ON INVESTMENT

The initial investment of changing a 50W halogen PAR20 lamp to a 7W GREEN CREATIVE lighting solution will take 10 months to recover from electricity cost savings.

Following the payback period, the lamp will save $37 annually throughout the lifetime of the product. Over a 5 year period, each replaced lamp will save $154 in lighting costs and 0.29kW of electricity, equivalent to 0.65 metric tons of CO₂ or 18.0 trees.

The monthly cost of waiting before changing to GREEN CREATIVE energy efficient lighting solution is $3.09 per lamp.

Furthermore, GREEN CREATIVE lamps are maintenance free with a 40,000 hours lifetime providing additional savings not taken into account in this model.

*Note: Model assumes: Rate of Electricity is $0.11/kWh, Energy costs vary depending on region, Lamp Usage is 12 hours / day (2,080 hours / year), Price of 50W halogen is $20.0 with lifetime of 1,200 hours. GREEN CREATIVE 7W price is $32.0 with 40,000 hours lifetime. The CO₂ emission and tree equivalence based on EPA (Energy Protection Agency) website.

Lighting facts: 980 lumens, 500 lumens, 250 lumens, 120W lumens

Estimated Yearly Energy Cost: $0.14

(Light: 8 hours / day)
PAR20 7W DIM. TITANIUM LED SERIES 2.0

APPLICATIONS
- Recessed Lighting
- Accent / Display Lighting
- Track Lighting

ILLUMINANCE

SPECIFICATIONS

<table>
<thead>
<tr>
<th>Product</th>
<th>Model</th>
<th>05206</th>
<th>10206</th>
<th>05208</th>
<th>10208</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Desc.</td>
<td></td>
<td>PAR26/TORCH/12/040</td>
<td>PAR26/TORCH/12/040</td>
<td>PAR26/TORCH/12/040</td>
<td>PAR26/TORCH/12/040</td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td>PAR26</td>
<td>PAR26</td>
<td>PAR26</td>
<td>PAR26</td>
</tr>
<tr>
<td>Base</td>
<td></td>
<td>Medium 12</td>
<td>Medium 12</td>
<td>Medium 12</td>
<td>Medium 12</td>
</tr>
<tr>
<td>Power (W)</td>
<td></td>
<td>PAR26</td>
<td>PAR26</td>
<td>PAR26</td>
<td>PAR26</td>
</tr>
<tr>
<td>Voltage - Frequency</td>
<td></td>
<td>120V / 1000</td>
<td>120V / 1000</td>
<td>120V / 1000</td>
<td>120V / 1000</td>
</tr>
<tr>
<td>Color Temp. (ANSI)</td>
<td></td>
<td>3000K</td>
<td>3000K</td>
<td>3000K</td>
<td>3000K</td>
</tr>
<tr>
<td>CRI (Ra)</td>
<td></td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Typical Lumens (lm)</td>
<td></td>
<td>900</td>
<td>900</td>
<td>900</td>
<td>900</td>
</tr>
<tr>
<td>Efficacy (LPW)</td>
<td></td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Beam Angle</td>
<td></td>
<td>60°</td>
<td>60°</td>
<td>60°</td>
<td>60°</td>
</tr>
<tr>
<td>CRI (Ra)</td>
<td></td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Dimmable</td>
<td></td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes*</td>
</tr>
<tr>
<td>Power Factor</td>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Rated Lifetime - L70 (hrs)</td>
<td></td>
<td>40,000</td>
<td>40,000</td>
<td>40,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Weight (lb/g)</td>
<td></td>
<td>0.38 lb / 100g</td>
<td>0.38 lb / 100g</td>
<td>0.38 lb / 100g</td>
<td>0.38 lb / 100g</td>
</tr>
</tbody>
</table>

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

www.go-lighting.com / info@go-lighting.com
REFERENCES

http://www.CREE.com/~/media/Files/CREE/Lighting/Misc%20Tech%20Docs/LightingCalculationsintheLEDera_Benya.pdf


http://www.energy.ca.gov/ceus/


http://www.navigantresearch.com/research/intelligent-lighting-controls-for-commercial-buildings