Information Bulletin
Environmentally Preferable Purchasing

LED REPLACEMENTS FOR LINEAR FLUORESCENT LIGHTING

Tubular LED lamps (top), LED retrofit kit (middle), and LED luminaires (bottom)
Photo: CLTC, UC Davis

Lamps and luminaires that use light emitting diodes (LEDs) can provide efficient, high-quality alternatives to traditional sources in many applications. LED alternatives to the linear fluorescent lamps and luminaires commonly found in offices, classrooms and other commercial spaces are just beginning to emerge. Some high-quality LED replacement products are already available, but many others on the market have yet to match the light output or distribution of today's energy-efficient, long-life fluorescent lamps.

Replacing an expired linear fluorescent lamp with a new linear fluorescent lamp is a fairly simple, straightforward task. Installing LED lamps in place of fluorescent lamps is a more complex process, often requiring an experienced electrician.

In addition to tubular LED lamps, LED retrofit kits and dedicated LED luminaires are also available as replacement options for fluorescent troffers. Simply put, replacement can entail replacing just the lamp, retrofitting a portion of the luminaire while maintaining luminaire components such as the housing, or removing the whole luminaire and exchanging it for a new one.

LED replacement products often use less energy than linear fluorescent lamps and luminaires. They can also produce more light (lumens) per unit of energy (watt) that they consume (lumens/watt), but at this point in the evolution of these products, their overall performance is often not as good as modern linear fluorescent systems.

The light distribution patterns of LED replacements are also noticeably different from that typically provided by linear fluorescent lamps. LED luminaires and retrofit kits that come equipped with complementary optics will generally provide more consistent distribution than tubular LED replacement lamps, which may or may not pair well with the existing fixture optics. Still, LED luminaires vary broadly in terms of their light distribution and other performance characteristics, and the same is true for the other two LED product categories.

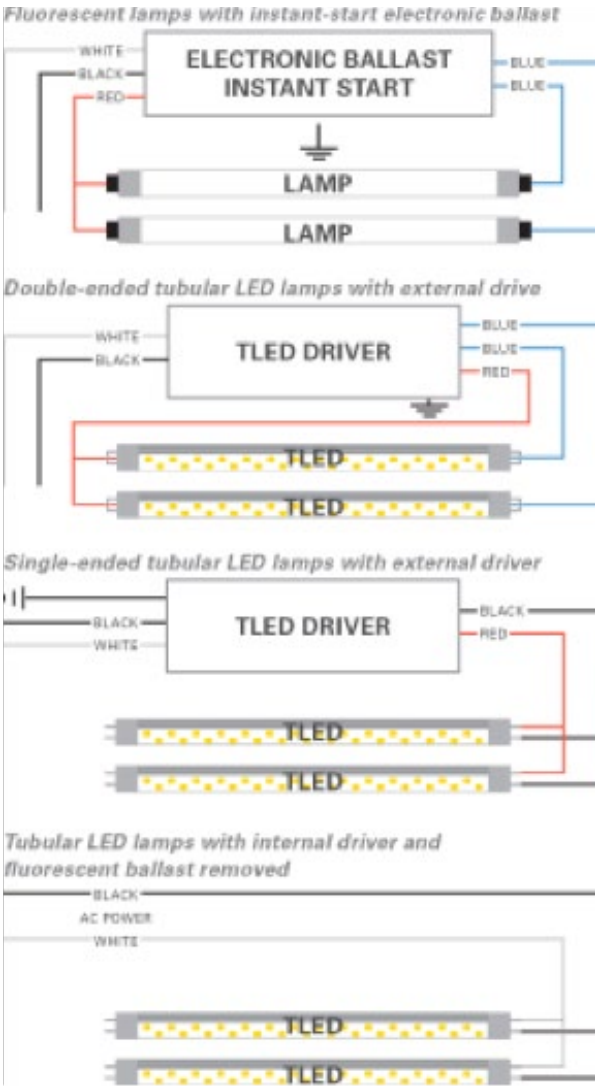
For these reasons and others, the California Department of General Services has not yet included tubular LED replacement products for linear fluorescent lighting systems in its Environmentally Preferable Purchasing program.

Today's linear fluorescent lamps are highly efficient, and some offer lifetimes comparable to LED products. Because the technology is mature and the market for these lamps is well-established, product costs are also much lower than LED alternatives. Standard T8 lamps cost about $2 each (some special linear fluorescent lamps cost $5–$10 each) while an LED replacement lamp costs about $25–$60. Tubular LED lamps cost less than LED retrofit kits or dedicated LED luminaires, but the use of tubular LED lamps will likely incur additional project costs such as labor costs associated with their installation. Other differences between these product categories also merit consideration prior to selection or inclusion of LED solutions in any fluorescent lighting retrofit project.

Tubular LED Lamps

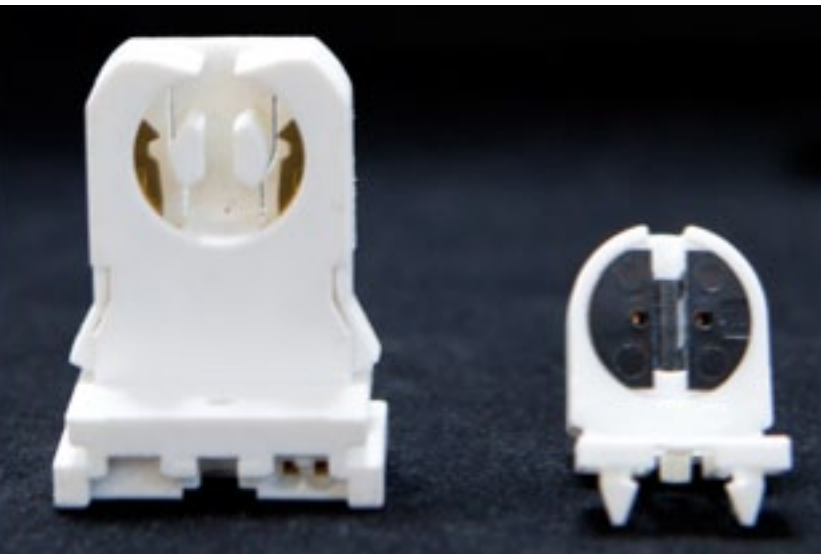
Installing tubular LED lamps in existing linear fluorescent fixtures typically requires replacing the fluorescent ballast with an external LED driver and rewiring the unit. The existing lamp holders may also need to be altered or replaced to accommodate the LED lamp. These alterations require safety labeling and other careful documentation to protect maintenance crews who may do work on the luminaires in the future.

Some "drop-in" tubular LED lamps incorporate a driver into the lamp. These tubular LED lamps with internal, or integrated, drivers can sometimes utilize existing fluorescent ballasts without rewiring, but these products are rare. It should be noted that this can also expose driver components to high temperatures, potentially compromising lamp life. The thermal management characteristics of the particular tubular LED lamp chosen and the specific fixture in which it will be installed both determine how well the lamp will perform.



Examples of some wiring configurations of LED retrofit products as compared to a typical electronic instant start ballasted fluorescent luminaire wiring configuration.

The pins of drop-in LED lamps connect directly to the existing G13 bi-pin sockets (also known as lamp holders or "tombstones"). LED lamps with internal drivers may be single-ended, with power running to one end, or double-ended, with power running to both ends.



Shunted socket (left) and unshunted socket (right)
Photo: CLTC, UC Davis

Tubular LED lamps powered through lamp holders require unshunted sockets to operate as the manufacturer intended, so facility managers will want to identify which type (shunted or unshunted) are installed. Unshunted sockets have four holes and can accept four wires. Shunted sockets can accept only two wires and will have only two holes. Shunted sockets are also often designated as such with an "S" or "shunted" imprinted on the socket case. Fluorescent lamp holders for rapid-start systems are un-shunted while those made for instant-start fluorescent systems are shunted.

LED replacement lamps that have external, or remote, drivers require that the driver be connected to either the existing lamp holders or directly to the lamp. For the latter scenario, which is also more common, the lamp holders only serve to stabilize the lamp in the fixture.

The wiring requirements for most tubular LED lamps raise safety concerns. For instance, future maintenance workers may attempt to replace tubular LED lamps, which are powered directly with line voltage running through the lamp holders, with incompatible linear LED products or traditional fluorescent lamps. Installing a fluorescent lamp into lamp holders energized with unregulated line voltage can cause electrical shock. It can also break the glass lamp tube and damage the fluorescent filament. For this reason, and per manufacturers' instructions, careful documentation and labeling of LED replacement lamps is required for the safety of maintenance staff and end users, both during and after a retrofit.

When installing tubular LED lamps in luminaires designed for fluorescent lamps, it is also often necessary to install new or different diffusers, reflectors or other optical components to achieve proper light distribution. This is due to the fact that fluorescent lamps are an omnidirectional source (light emitted in all directions), while most tubular LED lamps are not. Thus, new optics must often be introduced to compensate for the limited directionality of the LED lamp.

LED Retrofit Kits

LED retrofit kits provide a prepackaged lighting solution that includes all necessary electrical components, optical elements (lensing and baffle), and light sources. Because retrofit kits include optics designed to complement the kit's LED source, these replacement products tend to deliver more even light uniformity and better distribution than tubular LED lamp retrofits. In addition, LED retrofit kits are currently somewhat easier to install than tubular LED replacement lamps.

What's more, manufacturers will often create LED retrofit kits to match the form, optics and appearance of dedicated LED luminaires in their portfolio. In spaces where new luminaires will be installed with existing luminaires, this consistency in appearance and light distribution may be desirable.

While LED retrofit kits are an option for the majority of existing fluorescent troffers, not all kits are universally compatible with all troffers. Special types of troffers, including those equipped with air handling units, may not be compatible with LED retrofit kits. Facilities must ensure the existing troffers will accept the selected retrofit kit(s).

LED retrofit kit
Photo: Philips Day-Brite

Dedicated LED Luminaires

Replacing fluorescent luminaires with dedicated LED luminaires incurs higher initial costs, but this strategy also provides the simplest solution in terms of electrical installation. Dedicated LED luminaires also often provide greater efficacy, producing more light per watt of power consumed, than T8 fluorescent luminaires, LED retrofit kits or tubular LED lamps.

LED luminaires are also comprehensively designed to suit LED sources, addressing issues such as heat management, light distribution and the LEDs' quality characteristics and positioning. For this reason, dedicated LED luminaires have the potential for optimal light distribution and quality.

Dedicated LED luminaire
Photo: Cree, Inc.

Lighting products bear different certification marks to indicate they comply with different levels and standards of testing and certification by Nationally Recognized Testing Laboratories (NRTLs). When selecting an LED replacement product, it is important to note whether the product has been certified as Listed, Classified or Recognized.

UL Listed, ETL Listed

Both Underwriters Laboratories (UL) and Intertek Testing Services North America (ITSNA, or Intertek) issue Listed marks certifying that the laboratory found product samples meet a published set of minimum safety standards. ("US" indicates U.S. product safety standards have been met, a "C" indicates Canadian product safety standards have been met, and marks bearing both indicate the product meets both nations' safety standards.)

Those LED luminaires, retrofit kits and lamps marked as Listed are typically meant to be "plug-and-play" or "drop-in" systems, meaning they only require a power connection, via wiring or plugging in to a power source. Tubular LED lamps fall into this category if they are designed as a fluorescent lamp replacement with no associated ballast change or wiring modifications required. Listed LED replacement lamps are rare, and product specifiers should verify that products described as Listed in marketing materials actually bear a Listed certification mark.

Safety Standard mark on lamps
Photo: CLTC, UC Davis

UL Classified

A UL Classified mark might be found on tubular LED lamps and LED retrofit kits. It indicates the product has met a more limited set of safety criteria as compared to Listed products and is safe for use only under certain conditions. LED retrofit kits and LED replacement lamps that require disconnection of the original ballast and re-wiring fall into the "Classified" category. UL-1598C is the specific UL standard followed when retrofitting luminaires with an LED source. LED replacement lamps or retrofit kits marked as Classified under UL-1598C and are properly installed in a previously UL-certified luminaire retain the UL Classified certification after installation.

Recognized

The Recognized mark applies to component parts manufactured for factory installation in a larger system. For example, an LED driver made for installation in a luminaire may be tested and certified as Recognized. Listed or Classified luminaires or retrofit kits may use a variety of Recognized components, so that a product that one UL Recognized power supply can replace another UL Recognized power supply without the luminaire requiring another UL classification.

LED replacement lamps and retrofit kits with external drivers must comply with UL-1598C requirements for "LED Retrofit Luminaire Conversion Kits." Tubular LED replacement lamps with internal drivers that also require wiring modifications should comply with both the ***UL-1598C*** and ***UL-1993*** standards for "Self-Ballasted Lamps and Lamp Adapters." Tubular LED replacement lamps with internal drivers that do not require any wiring modifications or other component replacements for operation should comply with UL-1993 only.

More information on the NRTL program and safety standards is available at ***www.OSHA.gov***.

PERFORMANCE CHARACTERISTICS

Recent studies of tubular LED lamps show products vary widely in quality and performance. Likewise, some LED retrofit kits outperform others by a considerable margin in terms of color consistency, light distribution, and flicker upon dimming. Dedicated LED luminaires, used as a complete replacement for fluorescent luminaires, come closest to performing like fluorescent luminaires. They also provide improved efficacy and distribute light more evenly than tubular LED lamps or LED retrofit kits.

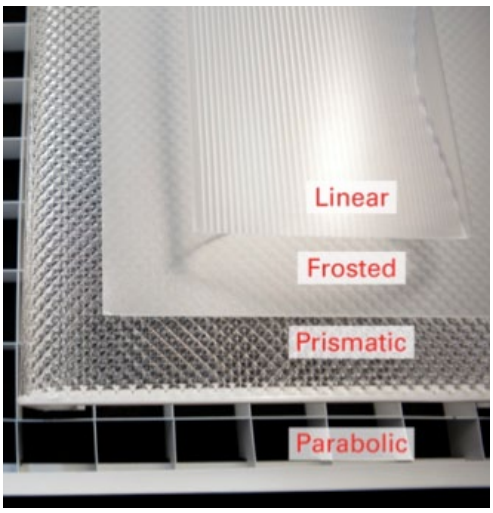
Efficacy

A 2013 study conducted by the Department of Energy's Commercially Available LED Product Evaluation and Reporting program (CALiPER) determined minimum, mean and maximum luminaire efficacy values (lm/W) for a representative sample of T8 fluorescent luminaires, tubular LED lamps installed in luminaires originally designed for fluorescent lamps, LED retrofit kits installed in luminaires originally designed for fluorescent lamps, and dedicated LED luminaires. The study found that the luminaires with linear LED lamps and LED retrofit kits had luminaire efficacies in the same range as luminaires with fluorescent T8 products. Dedicated LED luminaires demonstrated the highest

efficacy levels of all LED replacement solutions. Other factors also play roles in determining the actual effectiveness and energy efficiency of any lighting technology. These include input power, lumen output, light distribution, and features associated with the space where the luminaires are installed, such as ceiling height, windows and partitions.

Brightness

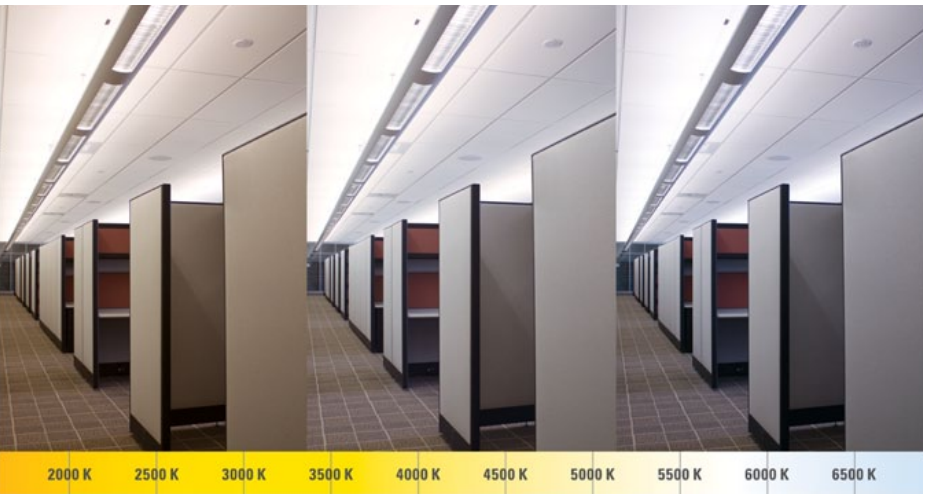
While some LED replacement products can provide greater efficacy and draw less power than the fluorescent products they are intended to replace, they also typically emit less light. This means one-to-one replacement of fluorescent lamps or luminaire with LED lamps, retrofit kits or dedicated luminaires may result in insufficient light levels. For example, the 2013 CaliPer study utilized three tubular LED lamps as an equivalent to two linear fluorescent T8 lamps in order to achieve comparable performance.



Luminaire lenses
Photo: CLTC, UC Davis

Distribution and Optics

LED luminaires and retrofit kits typically demonstrate better light distribution than tubular LED replacement lamps because they are able to better integrate LED light sources with the fixture housing and lens. Most LED luminaires currently on the market have frosted or linear lenses designed to diffuse light. The prismatic lens materials and parabolic designs typical of older fluorescent luminaires do not pair well with tubular LED lamps, sometimes producing distracting patterns of light and shadow. This is partly due to the fact that fluorescent luminaires are designed to reflect and redirect light from fluorescent sources. Fluorescent lamps are omnidirectional, meaning they emit light in all directions, while LEDs are directional light sources. Dedicated LED luminaires and most LED retrofit kits include customized optics designed to increase the uniformity of light distribution from LEDs. This is yet another reason why these two LED replacement solutions typically distribute light better than tubular LED lamps installed in fluorescent luminaires.



This simulation provides a sense of how the same office space might appear under lighting with three different correlated color temperatures. (Note: The technology shown in the picture is a linear pendant, not a troffer) *Photo: CLTC, UC Davis*

Color Quality

Most linear fluorescent lamps range from warm white (3000K) to cool white (4100K) in their correlated color temperature (CCT). They typically measure above 80 on the color rendering index (CRI), the industry standard for measuring how accurately a light source renders colors. LED replacement lamps have a similar range of color temperature options available, and products are available with an average CRI of 85 – 90. It should be noted that LED solutions with lower CCT tend to be less efficacious than high CCT solutions.

Lifetime

Fluorescent T8 lamps rate high in lumen maintenance, continuing to produce about 90% of initial light output at the end of product life. Typical T8 lifetimes range from 24,000 to more than 45,000 hours, depending on switching frequency and ballast type. Some long-life T8 fluorescent lamps now have rated lifetimes of 80,000 hours or more, although this is often coupled with a limited set of operating conditions for which they can be expected to last for this duration.

The useful life of LED products is currently quoted the number of operating hours they can maintain at least 70% of their initial lumen output ("L70"). The DLC requirement for tubular LEDs is set at an L70 of 50,000 hours, or a practical lifespan of roughly 16 years (based on 12 hours of operation per day, 255 days per year).

Cost

Fluorescent T8 replacement lamps cost $2– $10 per lamp. Prices for tubular LED replacements vary considerably. At the time this document was prepared, tubular LED lamps averaged around $30–$60 per lamp, with some lamps costing over $100 each. Prices for LED lighting, in general, continue to decrease, and bulk purchases can result in significant per-unit savings. To offset their higher initial cost, LED replacement lamps must last longer than their fluorescent counterparts and have higher efficacy.

A fair cost comparison of tubular LED and fluorescent lamps should factor in light output, energy savings, relamping and maintenance costs, as well as disposal or recycling costs. Over 50,000 hours (the lifetime of a tubular LED lamp), a linear fluorescent lamp might require one replacement. Even after consideration for this replacement cost, fluorescent lamps are over 80% less expensive.

Thermal Management

Like all light sources, LEDs convert most of the energy they use (75–85%) into heat. Unlike some other light sources, however, LEDs are extremely sensitive to heat. The LED luminaire's ability to manage heat directly affects the luminaire's safety, performance and useful life. The tubular form factor of LED T8 replacement lamps pose challenges for thermal management. Operating in recessed troffers and enclosed ceiling spaces, poses similar challenges. Manufacturers of tubular LED products have devised solutions for these challenges, including use of cooling materials, forced convection methods, and advanced heat sink components that dissipate heat from around the LED source.

These methods continue to advance and improve performance, but to select suitable tubular LED replacement lamps, careful attention must be paid to how the lamp is built to manage heat and how it will perform in the specific luminaire in which it will be installed. Good design may not be readily apparent, even to the experienced facility manager. Buyers must often trust sellers' claims regarding the thermal management properties of its materials or design configurations, or buyers must undertake extensive testing to verify performance. Dedicated LED luminaires are equipped with thermal management elements designed to conduct heat away from the LEDs. Similarly, LED retrofit kits often include better heat dissipation elements and are better equipped to manage heat than tubular LED lamps.

DESIGN LIGHTS CONSORTIUM QUALIFIED PRODUCT LIST

The Design Lights Consortium (DLC) maintains a Qualified Product List of LED lamps that meet stringent performance standards. Tubular LED lamps included on the Qualified Product List, or QPL, come with a minimum five-year warranty and have met safety certification standards. They are also tested by qualified laboratories to ensure they meet the following criteria: System efficacy above 100 lumens per watt (lm/W); correlated color temperature (CCT) below 5000K; color rendering index (CRI) above 80; and lumen maintenance (L70) of 50,000 hours. Criteria for total harmonic distortion (THD) and power factor are also applied to qualifying products.

USING T8 LED REPLACEMENT PRODUCTS IN DGS FACILITIES

DGS has not yet approved tubular LED replacement lighting products for inclusion in its Environmentally Preferable Purchasing program. LED technology continues to advance, and prices continue to decrease, but at this time, many types of linear fluorescent lamps offer a more consistent and cost-effective means of maintaining or reducing lighting energy use, particularly when paired with dimmable ballasts and lighting controls. As the technology matures, these lamps will likely be reconsidered for inclusion. Facilities interested in retrofitting existing fluorescent fixtures with LED alternatives should consider LED retrofit kits and luminaires before tubular LED replacement lamps. Installing a demonstration in a small space allows for evaluation of particular products' performance before larger purchasing decisions are made.

TITLE 24 AND T8 LED REPLACEMENTS

California's 2013 Building Energy Efficiency Standards for lighting (Title 24, Part 6) take effect July, 1 2014. Under the new standards, altering just 10% of the light fixtures in a building space may make the project subject to Title 24 regulation.

Replacing linear fluorescent lamps with tubular LED lamps typically requires modifying the existing luminaire housing, wiring or other components; these qualify as luminaire alterations under Title 24. LED replacement products that require the fluorescent ballast to be disconnected and replaced with an LED driver qualify as alterations, as do LED retrofits that involve disconnecting the fluorescent ballast and wiring the lamp holders directly to line voltage. Under the new standards, replacing or relocating luminaires may trigger compliance requirements for additional lighting system upgrades to make the system compliant with Title 24, Part 6.

The new standards reduce lighting power allowances in some commercial spaces. Replacing a linear fluorescent lamp with a lower-wattage tubular LED lamp will lower actual energy consumption, but it will not lower lighting power in the space for compliance purposes. With tubular LED lamps and LED retrofit kits, the original rated (fluorescent) wattage of the modified luminaire is still used for lighting power calculations. The luminaires are also still classified as fluorescent, and, as such, they must be equipped with multi-level, stepped dimming or continuous dimming controls, per Title 24 requirements for fluorescent lighting. The most recent studies show that tubular LED replacement lamps vary greatly in their ability to dim reliably and without noticeable flicker.

Dedicated LED luminaires certified to the California Energy Commission meet California's appliance efficiency requirements and are able to deliver the continuous dimming (10–100%) and controls compatibility required of LED luminaires under Title 24.

ABOUT DGS ENVIRONMENTALLY PREFERABLE PURCHASING PROGRAM

Environmentally Preferable Purchasing (EPP) is the procurement of goods and services that have a reduced impact on human health and the environment, as compared to other goods and services serving the same purpose (Public Contract Code §12400-12404). In simple terms, EPP means "buying green." The law also states that the Department of General Services (DGS) is to provide state agencies with information and assistance regarding EPP. In response, DGS developed a best practices manual—the Buying Green Guide. This guide provides information, tools and tips for buyers, and it provides insights for suppliers on how the State views "green" products and businesses. View the Guide and learn more at ***www.dgs.ca.gov/buyinggreen/Home.aspx***.

ABOUT CLTC

This fact sheet was prepared by the California Lighting Technology Center (CLTC) for the California Department of General Services. CLTC is a not-for-profit RD&D facility dedicated to advancing energy-efficient lighting and daylighting technologies. Part of the Department of Design at the University of California, Davis, CLTC's facility includes full-scale laboratories for research and development. The center also provides instruction to both undergraduate and graduate students of lighting design. Working in partnership with designers, manufacturers, end users, utilities, government agencies, and others, CLTC conducts prototype and product testing, technology demonstrations, and case studies. CLTC also provides resources for applying best practices to lighting design and installation. Learn more at ***cltc.ucdavis.edu***.

RESOURCES

"LED Replacements for Four-Foot Linear Fluorescent Lamps"—U.S. Department of Energy: Energy Efficiency & Renewable Energy
http://cool.conservation-us.org/byorg/us-doe/led-t8-fluorescent-replacement.pdf

"CALiPER Benchmark Report, January 2009: Performance of T12 and T8 Fluorescent Lamps and Troffers and LED Linear Replacement Lamps"—Pacific Northwest National Laboratory for the U.S. Department of Energy
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/troffer_benchmark_01-09.pdf

"CALiPER Exploratory Study: Recessed Troffer Lighting"—U.S. Department of Energy: Energy Efficiency & Renewable Energy
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_recessed-troffer_2013.pdf